

WIDE AREA DAMPING CONTROLLER DESIGN FOR POWER SYSTEM INTER- AREA OSCILLATIONS THROUGH NPC AND ANFIS

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Abstract: This paper presents damping controller for power system inter area oscillations through Network Predictive Control(NPC) and Adaptive Neuro Fuzzy Inference System(ANFIS).Wide area damping controller(WADC) uses communication networks to transmit remote signals. Communication delays are inherent component in transmission data of communication channels. These time delays would degrade the damping performance of WADC or it leads to the system instability. Network predictive control design comprises of Generalized predictive control(GPC),Network delay compensator and online model identification. The ANFIS controller is designed with Sugeno model of suitable rules. Model identification is used an equivalent reduced order model of large scale power system. The case study of New England 10-machine 39 bus system with NPC and ANFIS is presented. The simulation results shows that both NPC and ANFIS are provide better damping performance than GPC and NO-WADC. The satisfactory damping is obtained with proposed NPC and ANFIS.

Index Terms: Delay compensation, inter area oscillations, Model identification, NPC and ANFIS

1. Introduction

In a modern deregulated power system main concern is signal stability, inter area oscillations which are greatly influence the reliable and economic operation of large scale inter connected power systems as they will increase the possibility of inter area oscillations between different control areas and even breakup of whole system[2].Therefore they should be effectively damped. Conventially, inter area mode oscillations are damped together with local mode oscillations through installation of power system stabilizers(PSSs). Although thee same effectiveness of PSSs in damping inter area mode is bounded as the inter area modes are not always controllable and observable from local signals[3].

In recent past, with rapid development of phasor measurement units(PMUs) and communication network technology ,the remote signals from wide area measurement system(WAMS) become available for exercising a wide area damping controller(WADC) to boost the damping of inter area oscillations in inter connected power systems. To employing a WADC, it requires communication channels to transmit remote signals which bring out time delays into control loop of WADC[10],[13]. Generally these time delays are ranges from tens to several hundred milliseconds which depends upon the type of communication channels, routines of signal transmission, transmission protocols and communication loads[10]-[12],[14].These time delays are cut down the damping performance or even cause system instability so they must be consider in the design of WADC[14]. An other challenge for outlining of WADC is availability of correct model of large scale power system because of components and variation of operating conditions.

The actual research results can be correlating into following two groups. The first one is bring into application of robust control methods to deal with model uncertainties. Some of these did not consider rap of time delays at the design stage[16]-[20] and whereas most of them treated as part of system uncertainties[21]-[22].The second one chooses the compensation of communication delays at design stage such as Smith predictor based H_∞ controller[22],[23], recurrent neural network based adaptive WADC[26],stochastic subspace identification based adaptive WADC[27] and fuzzy logic control based WADC[22].

The WACS based on WAMS is a typical network control systems which are spatially distributed systems in which the communication between sensors, actuators and controllers occur through a shared band limited digital communication network[14]. A network predictive control(NPC) which can handle communication delays and data dropout caused by communication is proposed in [15]-[18].The NPC incorporates the Generalized Predictive Control(GPC) and takes benefits of

communication networks that a group of data not a single data is transmitted in a packet at one communication. The root idea of NPC is that GPC is employed to produce set of future control signals and then pickup corresponding control prediction based on identical communication delays and data dropout[14]. The case study of New England 10 machine 39 bus system with NPC-WADC is presented and simulation results are used for comparative study of adaptive neuro-fuzzy inference system(ANFIS) with the same bus system.

The rest of this paper is organized as follows. Section II briefly recalls the NPC and ANFIS with design procedure for ANFIS and NPC. In Section III, a case study based on New England 10 machine 39 bus system is carried out to demonstrate the effectiveness of NPC-WADC and ANFIS. The Section IV presents the conclusions. Lastly section V presents references used in this paper.

2. Control Methodologies

2.1 Network Predictive Controller (NPC):

This section will briefly present the NPC scheme and a model identification algorithm based on recursive least squares (RLS) with a variable forgetting factor. The configuration diagram of an NPC combined with model identification is shown in Fig.1 , which includes three main components: 1) GPC; 2) network delay compensator (NDC); and 3) online model identifier. The details about configuration of NPC and design procedure is taken from the NPC scheme[1].

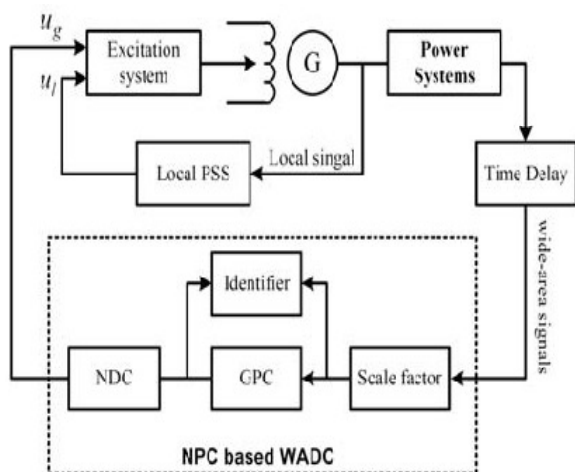


Figure 1. Configuration of the generator equipped with a local PSS and NPC-WADC.

2.2 Adaptive Neuro-Fuzzy Inference System

2.2.1 What Is ANFIS?

Jang et al proposed ANFIS architecture in 1993 [29]. The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Using a given input/output data set, ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method. This adjustment allows your fuzzy systems to learn from the data they are modeling. [30] ANFIS is an adaptive network which allows the implementation of neural network topology, together with fuzzy logic [31, 32]. An ANFIS study compiles these two methods and utilizes the characteristics of both methods. Also, ANFIS gathers both the neural network and fuzzy logic, and is able to treat nonlinear and complex problems [33]. ANFIS is a class of adaptive multilayer feeding forward networks, which is functionally equivalent to a fuzzy inference system

2.2.2 ANFIS architecture

According to Jang and al [29, 34] the global structure of adaptive neuro-fuzzy systems is shown in Fig.2

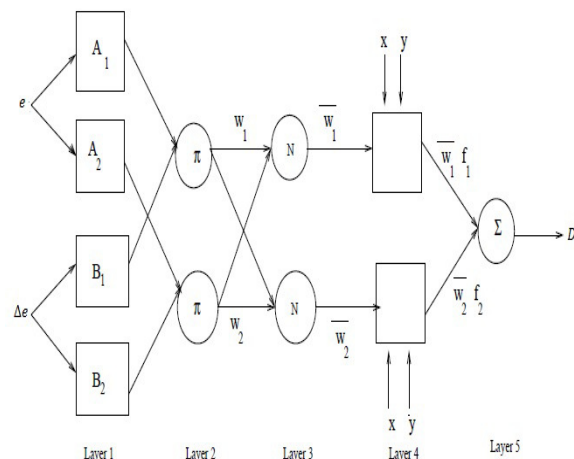


Figure 2. ANFIS system structure

Layer 1: Every node i in this layer is adaptive with a node function

$$O_i^1 = \mu_{A_i}(e)$$

where, e is the input to node i , A_i is the linguistic variable associated with this node function and μ_{A_i} is the membership function of A_i . Usually $\mu_{A_i}(e)$ is chosen as

$$\mu_{A_i}(e) = \frac{1}{1 + \left[\left(\frac{e - c_i}{a_i} \right)^2 \right]^{b_i}}$$

where e is the input and $\{a_i, b_i, c_i\}$ is the premise parameter set.

Layer 2: Each node in this layer is a fixed node which calculates the firing strength w_i of a rule. The output of each node is the product of all the incoming signals to it and is given by,

$$O_2^1 = w_i = \mu_{A_i}(e) \times \mu_{B_i}(\Delta e), \quad i = 1, 2, 3..$$

Layer 3: Every node in this layer is a fixed node. Each i^{th} node calculates the ratio of the i^{th} rule's firing strength to the sum of firing strengths of all the rules. The output from the i^{th} node is then normalized firing strength given by,

$$O_3^1 = \bar{w}_i = \frac{w_i}{w_1 + w_2}, \quad i = 1, 2, 3..$$

Layer 4: Every node in this layer is an adaptive node with a node function given by

$$O_4^1 = \bar{w}_i f_i = \bar{w}_i (p_i e + q_i \Delta e + r_i), \quad i = 1, 2, 3..$$

Where $\bar{w}_i$ is the output of Layer 3 and $\{p_i, q_i, r_i\}$ is the consequent parameter set.

Layer 5: This layer comprises of only one fixed node that calculates the overall output as the summation of all incoming signals, i.e.

$$O_5^1 = \text{overall output} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

Learning Algorithm of ANFS controller:

In the ANFIS structure, it is observed that given the values of premise parameters, the final output can be expressed as a linear combination of the consequent parameters. The output f in Fig. 2 can be written as

$$\begin{aligned} D &= \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2 \\ &= \bar{w}_1 f_1 + \bar{w}_2 f_2 \\ &= (\bar{w}_1 e) p_1 + (\bar{w}_1 \Delta e) q_1 + (\bar{w}_1) r_1 + (\bar{w}_2 e) p_2 \\ &\quad + (\bar{w}_2 \Delta e) q_2 + (\bar{w}_2) r_2 \end{aligned}$$

where D is linear in the consequent parameters $(p_1, q_1, r_1, p_2, q_2, r_2)$.

In the forward pass of the learning algorithm, consequent parameters are identified by the least squares

estimate. In the backward pass, the error signals, which are the derivatives of the squared error with respect to each node output, propagate backward from the output layer to the input layer. In this backward pass, the premise parameters are updated by the gradient descent algorithm.

3. Case Study

A case study of NPC based on the New England 10-machine 39-bus system, as shown in Fig. 3. This test system consists of 10 machines, 39 buses, and 46 lines, and its detailed parameters are given in [39]. It has been widely used as a test benchmark for studying the low-frequency oscillations as it performs several interarea modes under disturbances or faults. Each of the generators is represented by a fourth-order model and equipped with an IEEE ST1A excitation system. The transmission system is modeled as a passive circuit, whereas the loads are considered as constant impedances. The output of the mechanical power of each generator is treated as a constant value for simplicity. The nonlinear model of the New England 39-bus power system is linearized at a nominal operating condition [39]. The GPC-WADC and NPC-WADC use same parameters for the GPC part. The main difference between them is the NPC-WADC uses the N -step forward control prediction to compensate the communication delay existing in the control-loop, whereas the GPC-WADC only uses the first step control prediction. In addition, the transfer function of the CWADC is given as follows:

$$H_{wadc}(s) = 0.01 \left(\left(\frac{10s}{1+10s} \right) \right) \left(\frac{1+0.6280s}{1+0.125s} \right)^3$$

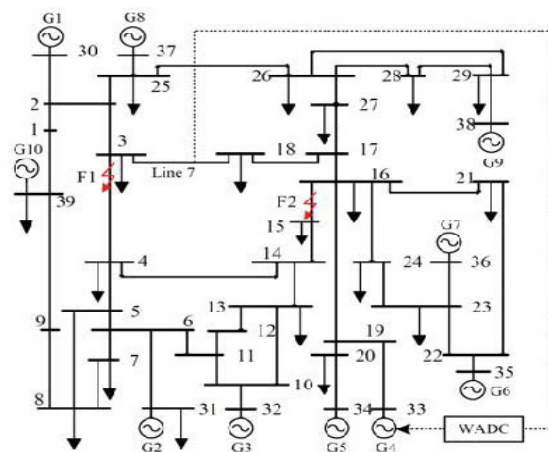


Figure 3. New England 39 bus system

Simulation studies are carried out based on the detailed nonlinear model to verify the effectiveness of the proposed NPC-WADC and ANFIS under a wide range of operating conditions and different constant and random communication delays.

The following scenarios is considered.

Scenario I: A three-phase-to-ground fault (fault F1 shown in Fig. 3) occurs at the end terminal of line between bus 3 and 4 near bus 3 at $t = 0.5$ s, followed by switching off the faulty transmission line at $t = 0.6$ s.

Test System with NPC

The fig.4 shows that response to fault scenario I of transmission line P_{17-18} . It reveals that proposed WADC can still provide a good damping performance in case of measurement noise. For constant delay of 100ms, the response to fault scenario I shown in fig.5 which represents the response of active power of transmission line P_{3-18} and P_{17-18} . It can be observed from fig.5 CWADC cannot maintain the stability of whole test system whereas GPC-WADC cannot provide satisfactory damping performance. However at both cases the NPC-WADC can maintain the stability of whole test system which demonstrates its ability of compensation of the time delays.

For random communication delays between 200ms to 600ms the system response shown in fig.8. It displays that the NPC-WADC can damp the interarea oscillations effectively whereas the GPC-WADC can't maintain the stability of whole system. The response of test system installed with NPC-WADC in presence of longer time delays are shown in fig.9. The control horizon with $N_u=12$ which provide better damping performance for longer communication delays.

Test System with ANFIS:

ANFIS controller is designed for test system with sugeno model of one input and three membership functions. The fig.10 predicts for response to scenario I for longer communication delays of 1200 and 1500ms. The responses shown are active powers of transmission lines of P_{3-18} and P_{17-18} . It concludes that ANFIS provides better damping performance than NO-WADC.

Simulation results show that the NPC-WADC and ANFIS controller provide better damping performance than the CWADC. However, it is worth pointing out that the NPC-WADC has a more complex structure and thus requires more computation time than the CWADC. Moreover, the NPC-WADC requires more control effort to achieve better performance than the CWADC even without the time delays.

Simulation Results:

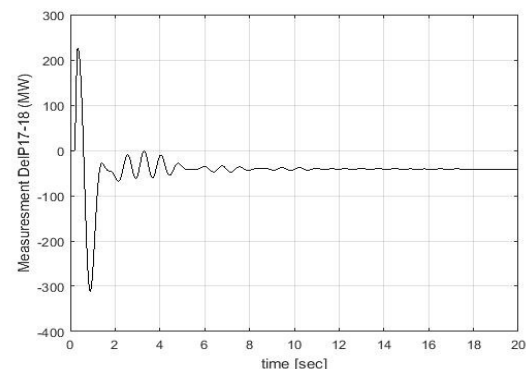


Figure 4. Responses to measurement noise under fault Scenario I

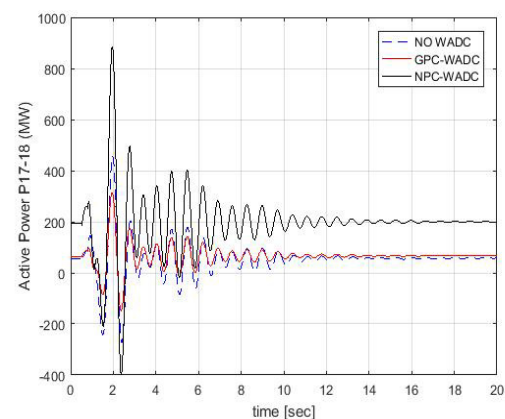
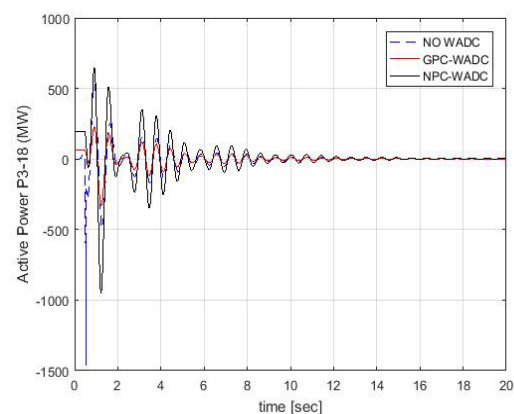


Figure 5. Responses to fault Scenario I, with 100ms constant delay

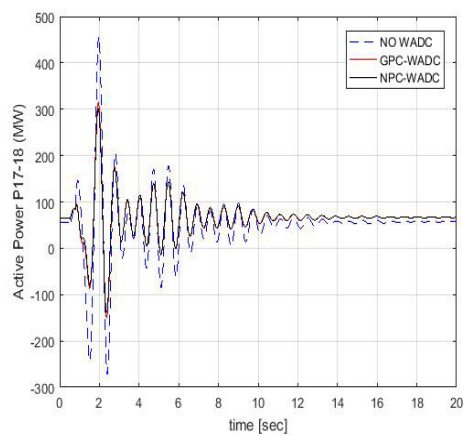
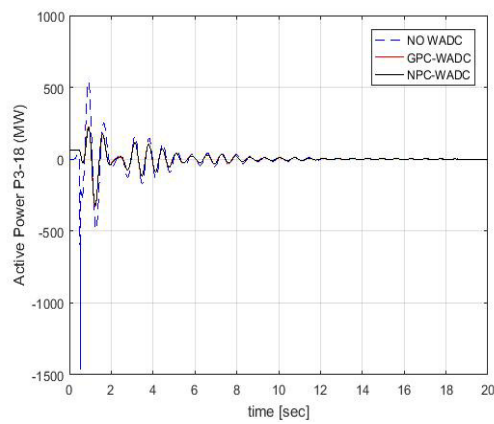


Figure 6. Responses to fault Scenario I, with 200ms constant delay

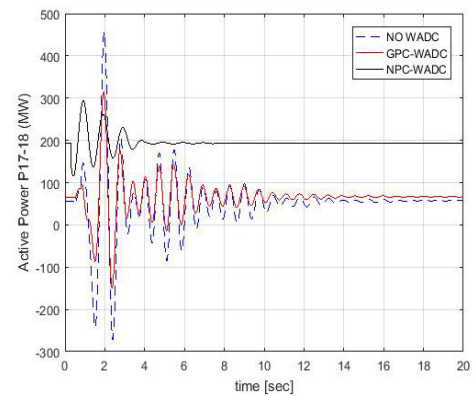
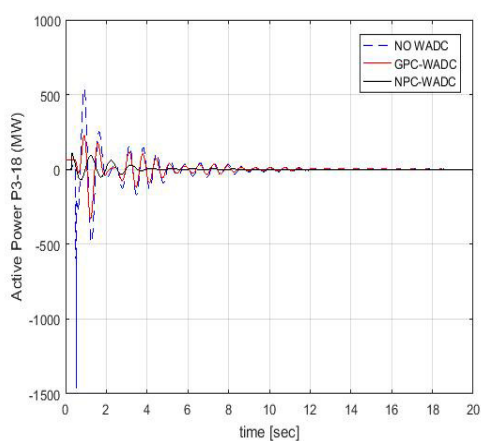


Figure 7. Responses to fault Scenario I, with 200 to 600ms random delays

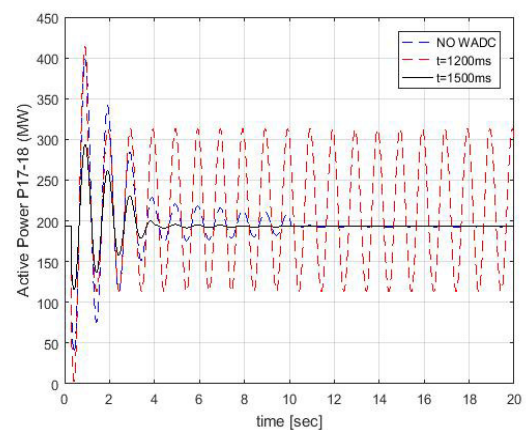
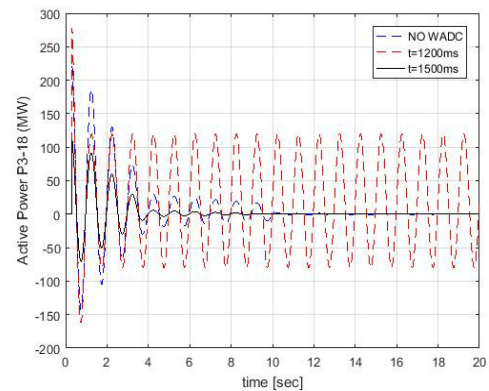


Figure 8. Delay margin of NPC-WADC with $Nu = 12$, under fault Scenario I.

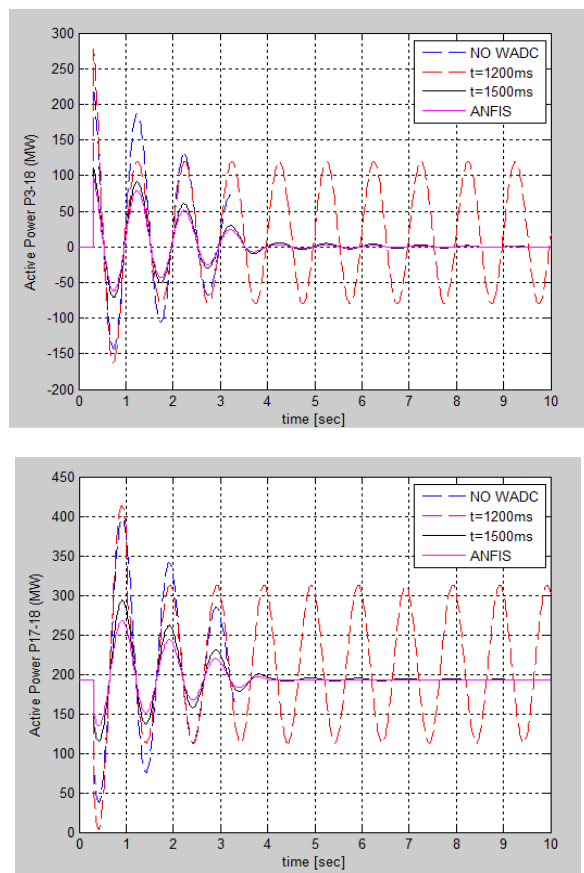


Figure 9. Delay margin of ANFIS under fault scenario I

4. Conclusion

A WADC has been proposed based on NPC and model identification technique for enhancing the damping of power system interarea oscillations and improving power system stability. The proposed NPC-WADC and ANFIS can effectively damp interarea oscillations and actively compensate time delays in the wide-area feedback signals. Moreover, model identification has been applied to deal with model uncertainties of the large-scale power systems and obtain a reduced-order equivalent prediction model for the NPC-WADC. The simulation results demonstrate that the NPC-WADC and ANFIS can damp out the concerned critical interarea oscillations and compensate constant and random delays effectively under wide range of operating conditions. Future work will focus on design of multiple input multiple output(MIMO) to damping multiple interarea oscillations in large scale interconnected power system.

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