International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 5, Number 6 (2012), pp. 723-730

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Dynamic Surface Control of Power System Stability using Adaptive Neuro Fuzzy Logic

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Abstract

In this paper, the power system with an excitation controller is represented as a class of large-scale, uncertain, interconnected nonlinear continuous-time system in a strict-feedback form. Power System Stabilizer (PSS) controller design is one of the methods of combining the PSS with the excitation controller for the investigation of many different input signals. Subsequently, Dynamic Surface Control (DSC) based Adaptive Neuro- Fuzzy (ANF) controller is designed to overcome the repeated differentiation of the control input that is observed in the conventional backstepping approach.

The ANF is utilized to approximate the unknown subsystem and the interconnection dynamics. By using novel online ANF weight update laws with quadratic error terms, the closed-loop signals are shown to be locally asymptotically stable via Lyapunov stability analysis, even in the presence of Neuro- Fuzzy (NF) approximation errors in contrast with other NF techniques where a bounded stability is normally assured.

Simulation results on the IEEE 9-bus power system with generator excitation control are provided to show the effectiveness of the approach in damping oscillations that occur after the removal of the disturbances. By using a new variant of the projection scheme and dynamic surface control with ANF, the need for the repeated differentiation in the backstepping design procedure is overcome. The end result is a nonlinear decentralized adaptive state-feedback excitation controller for damping power systems oscillations in the presence of uncertain interconnection terms.

Keywords: ANFC, ANN, DSC, FLC, PSS and AVR

Introduction

In the recent years, the competitive market for power generation and energy services demands a more reliable power network. Due to offshore wind generation plants and solar cells, a noticeable uncertainty in the load flows will occur in a power system, thus impacting the dynamic behaviour and stability. Therefore, excitation controller, PSS, static VAR compensators, and other power system controllers play an even more important role in maintaining dynamic performance and power system stability, thus increasing reliability. Centralized control strategies for ensuring performance and stability are not viable due to the sheer size of the power network which causes time delays in acquiring power system bus voltages and currents. Decentralized Control (DC) techniques, on the other hand, have been evolving for power systems so that they can achieve transient stability as well as steady-state behaviour in terms of damping oscillations caused by faults/disturbances. Linear power system model is used to design turbine and exciter voltage controllers, and the method tacitly assumes that the network variables remain in the neighbourhood of the desired operating point. A Linear Matrix Inequality (LMI) approach is chosen and sequential linear matrix inequality programming is utilized to design a PSS. By considering the nonlinear power system representation, a suboptimal performance for all admissible variations of generator parameters is achieved using an LMI-based control approach which depends on the existence of LMI solutions.

By contrast, in an ANF control of a general class of nonlinear systems in the strict-feedback form has been proposed for power systems, by using backstepping technique while relaxing the matching condition where the interconnected terms appear in the input domain only. The method is applied to design excitation and steam turbine controls rendering state boundedness, due to NF reconstruction errors while encountering repeated differentiation of the control signal resulting from the standard backstepping design. In a Linear Parameter Varying (LPV) representation of the nonlinear power system is chosen at each operating point obtained via linearization and subsequently, a decentralized PSS is designed. In this approach a linear time-varying model of the power system is used instead of the nonlinear model.

In this paper, the large-scale power system with generator excitation control is represented as a nonlinear uncertain, interconnected system, in a strict-feedback form. Subsequently, the DSC design framework is proposed while relaxing the matching condition (i.e., the interconnected terms appear in several dynamic equations as opposed to the one where the actual control input appears). Next, NF are introduced to approximate both subsystem and the interconnection dynamics. Novel NF weight update laws are derived which render asymptotic stability even in the presence of NF approximation errors and interconnection terms. Finally, simulation results on a 9-bus two-generator power system with generator excitation control confirm the satisfactory performance of this controller in damping the oscillations after a disturbance has occurred.

Literature Survey

Two NNs based decentralized controller designs for the excitation and steam valve control of multimachine power systems was proposed. The controller designs are based on the bound analysis of the interconnection terms and rigorous Lyapunov stability analysis. NNs eliminates the need for precise parameters of the system model. Though the control inputs are calculated using local signals, the transient and overall system stability can be guaranteed. W. Liu, et al (2007).

The DSC technique has eliminated the problem of "explosion of complexity" caused by the traditional backstepping approach. All signals in the closed-loop system are guaranteed to be uniformly, ultimately bounded and the tracking error may be made arbitrarily small by adjusting the parameters in the control law. The implementation of the controller is much simpler than that of the controllers designed by the traditional backstepping approach. D. Wang and J. Huang (2005).

A new method to generate a nonlinear dynamic representation of the power network is introduced to enable more sophisticated control design. Once the new representation is obtained, a back stepping methodology for the UPFC is utilized to mitigate the generator oscillations. Finally, the neural network approximation property is utilized to relax the need for the knowledge of the power system topology and to approximate the nonlinear uncertainties. The net result is a power system representation that can be used for the design of an enhanced FACTS control scheme. S. Mehraeen et al (2010).

Adaptive function approximation approach consists of formulating a limit-integral representation of the function to be approximated and subsequently evaluating that integral with the Monte-Carlo method. The main results is the Random Vector Functional Link (RVFL) which is a universal approximator for continuous functions on hounded finite dimensional sets and the RVFL is an eminent universal approximator with the rate of approximation error convergence to zero of order. B. Igelnik and Y. H. Pao (1995).

Robust decentralized PSS design approaches for power system that can be expressed as minimizing a linear objective function under LMI in tandem with Bilinear Matrix Inequality (BMI) constraints. Approaches are based on the concept of interconnection method for designing robust decentralized dynamic output feedback controllers and also on parameter continuation method involving matrix inequalities for designing reduced-order decentralized dynamic output feedback controllers. G.K. Befekadu and I. Erlich (2006).

DSC design is intuitively appealing, and it has "r-1" lowpass filters, where r is the relative degree of the output to be controlled. These low pass filters allow a design where the model is not differentiated, at the same time, avoid the complexity that arises due to the explosion of term. The key feature of the backstepping algorithm removes the need for differentiations in the controller design and reduces the explosion of terms that is due to the presence of the auxiliary first-order filters. D. Swaroop et al (2000).

Dynamic Surface Control

DSC has been receiving attention in this decade. In the DSC scheme, the well-known problem of repeated differentiation of the control signal in the backstepping design is replaced by a series of algebraic terms which simplifies the implementation of nonlinear systems in the strict-feedback form. Consequently, the DSC scheme results in the asymptotic stability in a semi-global manner, provided the system dynamics accurately known. Further, attempts to provide asymptotic stabilization for a class of uncertain nonlinear systems using adaptive DSC, provided the control gain coefficient matrix being unity and the system uncertainties are assumed to be linear in the unknown parameters. Hence, neuro fuzzy universal approximation property is asserted to relax this LIP assumption for subsystem uncertainties in order to ensure state boundedness.

The block diagram of proposed controller is shown in Fig1.1. The DSC controller is combined with PSS and Automatic Voltage Regulator (AVR) to provide supplementary signals for the excitation system in order to make the system stable. The DSC controller is responsible for attenuating the disturbance in the system and also to attenuate the low frequency damping oscillations present in the system.

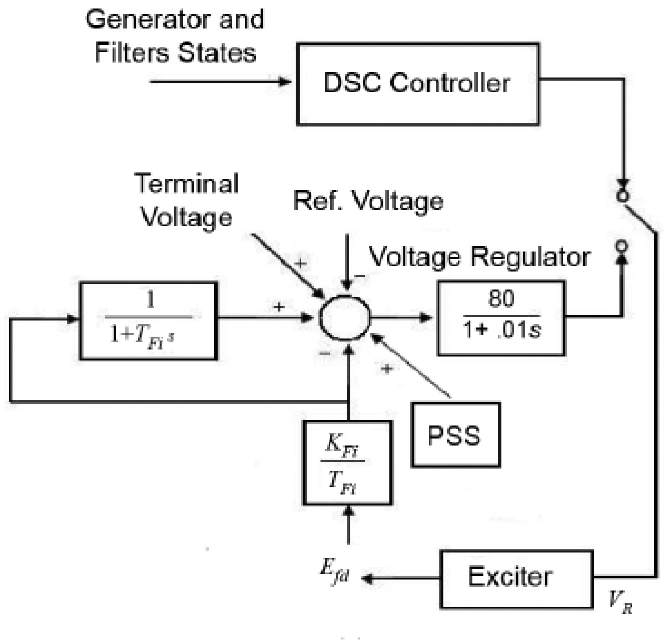

Figure 1.1: Block diagram of proposed controller

Artificial Neural Networks

Artificial Neural Networks (ANNS) are systems that are deliberately constructed to make use of some organizational principles resembling those of human brain. The key factors that distinguish Artificial Neural Networks from other computational techniques are

- **ANNS are nonlinear:** Able to classify patterns and capture complex interactions among the input variables in the system.
- **ANNS are adaptive:** They can take data and learn from it. (i.e.) online training.

- **ANNS can generalize:** They can correctly process data which broadly resembles the originally trained data.
- ANN is a parallel distributed information processing structure.

Fuzzy Logic Controller

Fuzzy Logic Control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic (FL), unlike Boolean or crisp logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. Fuzzy Logic tends to mimic human thinking that is often fuzzy in nature.

In fuzzy logic a particular object has a degree of membership in a given set, which is in the range of 0 to 1. The essence of fuzzy control algorithms is a conditional statement between a fuzzy input variable A and a fuzzy output variable B. This is expressed by a linguistic implication statement such as

IF A THEN B

In general, a fuzzy variable is expressed through a fuzzy set, which in turn is defined by a membership function μ.

Adaptive Neuro-Fuzzy Controller

The fusion of ideas from fuzzy control and neural networks had acknowledged a significant role in improving controller performances. FL has proven effective for complex, non-linear and imprecisely defined systems. The common bottleneck in FL is the derivation of fuzzy rules and the parameter tuning for the controller. The neural networks have powerful learning abilities, optimization abilities and adaptation. The fuzzy logic and neural networks can be integrated to form a connectionist Adaptive network based Fuzzy logic controller. This integrated adaptive system modifies the characteristics of the rules, topology of fuzzy sets and/or the structure of control system.

Simulation Result and Analysis

The MATLAB high-performance language for technical computing integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Simulink is a software package that enables you to model, simulate, and analyze systems whose output change over time. Such systems are often referred to as dynamic systems. The simulink software can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems. Simulating a dynamic system is a two-step process. First, a user creates a block diagram, using the simulink model editor that graphically depicts time-dependent mathematical relationships among the system's inputs, states, and outputs. Simulation results show the variation of speed deviation and power angle using ANF controller and without controller. Simulation results show the effectiveness of the approach in damping oscillations that occurs due to single line to ground fault in power systems.

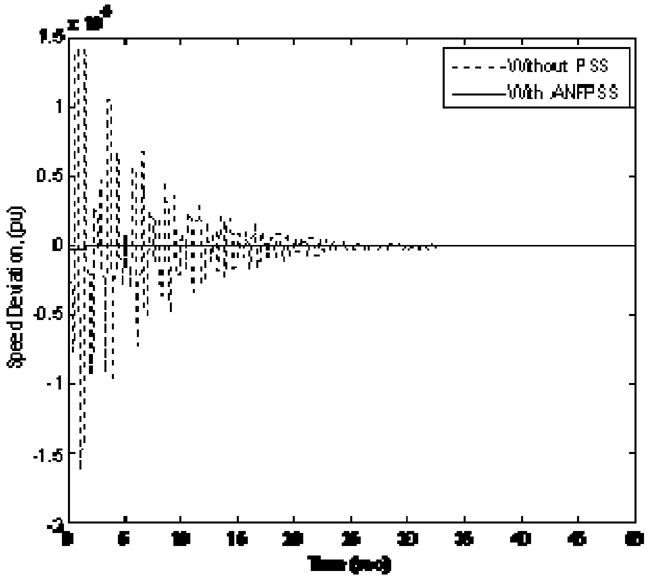

Figure 2: Speed deviation curve for generator 1

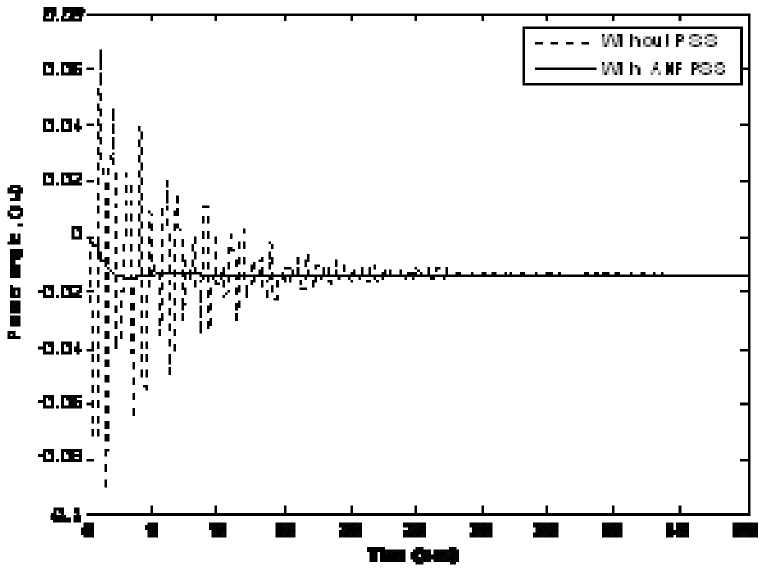

Figure 3: Power angle curve for generator 1

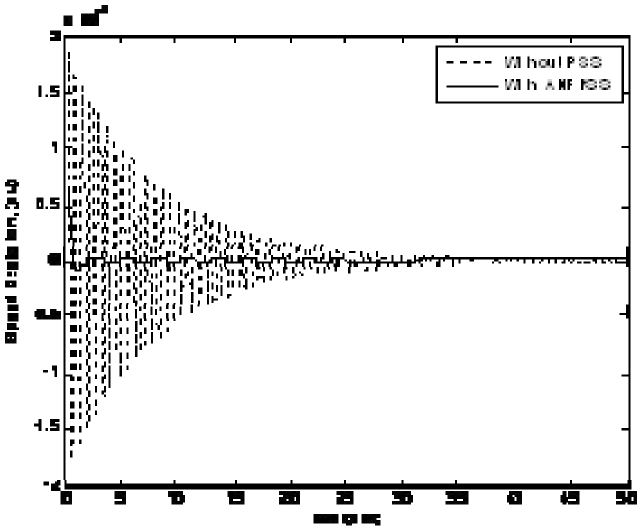

Figure 4: Speed deviation curve for generator 2

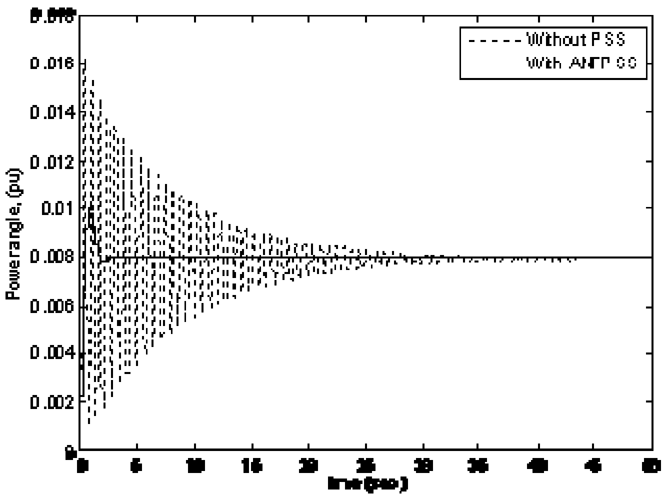

Figure 5: Power angle curve for generator 2

The proposed controller deduces the low frequency damping oscillation in a rapid way when compared to the conventional approach. The settling time and the maximum peak overshoot also drastically reduced. So,the proposed controller provides stable system with low settling time. Also, the proposed controller is shown to be robust when dealing with different fault locations and generation/load levels.

Conclusion

In this paper, the power system is represented as a large-scale interconnected nonlinear system with uncertainties in both subsystem and the interconnection terms where the system does not satisfy the matching condition. By using a new variant of the projection scheme and dynamic surface control with adaptive neuro fuzzy, the need for the repeated differentiation in the backstepping design procedure has been overcome. The neuro fuzzy approximation property is used to approximate the nonlinearities of the subsystems and interconnection terms in the power system. It is shown that the closed-loop system is asymptotically regulated to zero with state feedback control, even in the presence of neuro fuzzy function reconstruction errors. Simulation results on power system with generator excitation control shows the effectiveness of the approach in damping oscillations that occurs after faults in power systems. Also, the proposed controller shown in fig 2 to 5 is to be robust when dealing with different fault locations and generation/ load levels.

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