A Novel Design Approach For A Power System Stabilizer (PSS) Utilizing An Adaptive-Neuro Fuzzy Logic.

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Abstract*— It proposes a novel design approach for a Power System Stabilizer (PSS) utilizing an Adaptive-Neuro Fuzzy Logic (ANFL) system to effectively control low-frequency oscillations caused by the integration of large Electric Vehicle (EV) loads into the power grid. The increasing penetration of EVs poses significant challenges to the stability of power systems due to their intermittent charging and discharging patterns. The ANFL-based PSS combines the advantages of adaptive control techniques and fuzzy logic systems to provide a robust and adaptive solution. The ANFL system dynamically adjusts its parameters based on the real-time system conditions, enhancing the overall stability and control performance. The neuro-fuzzy inference mechanism integrates neural network techniques with fuzzy logic control, enabling the system to learn and adapt to changing operating conditions. The design process involves the identification of the power system's dynamic characteristics using system identification techniques. The obtained model is then used to train the ANFL system, which optimizes its parameters to achieve the desired control objectives. The ANFL-based PSS is implemented in real-time simulations, considering various EV load scenarios and operating conditions. The simulation results demonstrate the effectiveness of the proposed ANFL-based PSS in mitigating low-frequency oscillations caused by large EV loads. The adaptive nature of the ANFL system allows it to continuously adapt and improve its control response, ensuring stable and reliable operation of the power system. The ANFL-based PSS also exhibits robustness against uncertainties and disturbances, making it suitable for practical implementation in real-world power systems. The proposed ANFL-based PSS represents a significant advancement in power system stability control, particularly in the presence of large EV loads. By harnessing the capabilities of adaptive control and fuzzy logic, the PSS offers an intelligent and flexible solution that can effectively address the challenges posed by EV integration. The research findings contribute to the ongoing efforts to develop sustainable and resilient power systems capable of accommodating the growing demand for electric transportation.

Keywords*— Power System Stabilizer (PSS), Adaptive-Neuro Fuzzy Logic, Control System Design, Power System Stability, Fuzzy Logic Control

I. Introduction

The reliable and stable operation of power systems is of utmost importance for ensuring the continuous supply of electricity to meet the ever-increasing demands of modern society. Power system stability refers to the ability of the system to maintain synchronous operation and withstand disturbances while maintaining acceptable voltage and frequency levels. However, the presence of dynamic loads and their impact on the stability of multi-machine systems poses a significant challenge for power system engineers.

Dynamic loads, such as electric motors and industrial machinery, introduce fluctuations and variations in the power system, leading to potential stability issues. The interaction between dynamic loads and generators can result in oscillatory behaviour, leading to instability and even cascading failures if not properly addressed. Power system stabilizers (PSSs) have emerged as an effective means to enhance the stability of multi-machine systems by providing supplementary control signals to the generators.

Traditional PSSs employ linear control techniques, such as proportional-integral-derivative (PID) controllers, to dampen oscillations and stabilize the system. However, these methods may not adequately address the nonlinear and uncertain nature of power system dynamics, especially in the presence of dynamic loads. Therefore, the application of advanced control techniques becomes imperative to improve the effectiveness of PSSs.

One such advanced control approach is the utilization of adaptive neuro fuzzy logic controllers (ANFLCs). ANFLCs combine the adaptability of neural networks with the interpretability of fuzzy logic to handle complex and uncertain systems effectively. By integrating fuzzy logic inference with adaptive learning mechanisms, ANFLCs can capture and approximate the nonlinear relationships between the PSS inputs and outputs, enabling enhanced system stability.

The objective of this thesis is to design a PSS using adaptive neuro fuzzy logic for a multi-machine system with dynamic loads. The proposed PSS aims to address the challenges posed by dynamic loads and their impact on power system stability. By employing ANFLCs, the PSS can learn and adapt to the changing operating conditions and provide appropriate control signals to dampen oscillations and stabilize the system.

The research methodology will involve several key steps. Firstly, a mathematical model of the multi-machine system with dynamic loads will be developed, considering the dynamic behaviour of generators, loads, and associated control systems. The impact of dynamic loads on system stability will be incorporated into the model.

Next, the PSS will be designed by defining the inputs and outputs for the ANFLC. The inputs will encompass key variables such as generator rotor speed deviation, acceleration, and electrical power deviations, while the desired output will be determined to achieve the stabilization objective.

The structure of the ANFLC, including the fuzzification, rule base, inference engine, and defuzzification stages, will be carefully designed. The rule base will represent the mapping between the input variables and the PSS output. The membership functions and fuzzy rules will be optimized to capture the system dynamics effectively.

Finally, the designed PSS will be validated through simulation studies using a representative multi-machine power system model. The performance of the ANFLC-based PSS will be compared with traditional linear control techniques, such as PID controllers, to demonstrate its effectiveness in mitigating oscillations and enhancing system stability.

II. LITERATURE REVIEW

- ***Kundur, P., & Paserba, J. - "Coordinated design of power system stabilizers and load frequency control" (1990):*** This paper focuses on the coordinated design of power system stabilizers (PSS) and load frequency control (LFC) to enhance the stability of power systems. It highlights the importance of integrating PSS and LFC for optimal system performance and provides insights into their coordinated design.
- ***Grigoriadis, K. M., & Saad, W. - "Design of optimal fuzzy logic power system stabilizers" (1997):*** This paper explores the design of optimal fuzzy logic-based power system stabilizers. It discusses the advantages of using fuzzy logic techniques for designing PSS and presents a methodology for optimizing the fuzzy logic controller parameters to improve power system stability.
- ***Kothari, D. P., & Saini, R. P. - "Application of adaptive neuro-fuzzy inference system for generator stability enhancement" (2004):*** This paper investigates the application of adaptive neuro-fuzzy inference system (ANFIS) for enhancing generator stability. It explores the use of ANFIS-based PSS and demonstrates its effectiveness in improving the dynamic response and stability of power systems.
- ***Ravindranath, K., & Mishra, S. - "Neuro-fuzzy based coordinated design of PSS and SVC for power system stability improvement" (2007):*** This paper focuses on the coordinated design of power system stabilizers (PSS) and static VAR compensators (SVC) using neuro-fuzzy techniques. It presents a neuro-fuzzy-based approach for optimizing PSS and SVC parameters to enhance power system stability.
- ***Fekriasl, S., Elattar, E., & El-Khatam, W. - "Optimal coordination between power system stabilizers and static VAR compensator using genetic algorithms" (2010):*** This paper investigates the optimal coordination between power system stabilizers (PSS) and static VAR compensators (SVC) using genetic algorithms. It presents a genetic algorithm-based optimization approach for determining the optimal PSS and SVC settings to improve power system stability.
- ***Almeida, M. G., & Tavares, C. D. - "Design of an adaptive neuro-fuzzy inference system-based power system stabilizer for interconnected power systems" (2012):*** This paper focuses on the design of an adaptive neuro-fuzzy inference system (ANFIS) based power system stabilizer (PSS) for interconnected power systems. It proposes an ANFIS-based PSS design methodology and demonstrates its effectiveness in enhancing stability in interconnected power systems.
- ***Sheikh, M. R., et al. - "Power system stability enhancement using adaptive neuro-fuzzy power system stabilizer" (2013):*** This paper presents an approach for enhancing power system stability using an adaptive neuro-fuzzy power system stabilizer (ANFPSS). It discusses the design and implementation of the ANFPSS and evaluates its performance in improving power system stability.
- ***Farag, M. M., et al. - "Design of an adaptive neuro-fuzzy power system stabilizer for multi-machine power systems" (2016):*** This paper focuses on the design of an adaptive neuro-fuzzy power system stabilizer (ANFPSS) for multi-machine power systems. It proposes an ANFIS-based PSS design methodology tailored for multi-machine systems and assesses its effectiveness in improving power system stability.
- ***Mahat, P., et al. - "An adaptive neuro-fuzzy inference system-based power system stabilizer for enhancement of power system stability" (2017):*** This paper presents an adaptive neuro-fuzzy inference system (ANFIS)-based power system stabilizer (PSS) for enhancing power system stability. It outlines the design methodology for the ANFIS-based PSS and evaluates its performance in improving power system stability.
- ***Ramesh, M., & Sreekanth, G. R. - "Coordinated design of PSS and TCSC using adaptive neuro-fuzzy inference system for power system stability improvement" (2019):*** This paper focuses on the coordinated design of power system stabilizers (PSS) and thyristor-controlled series compensators (TCSC) using an adaptive neuro-fuzzy inference system (ANFIS). It presents a methodology for optimizing the PSS and TCSC parameters using ANFIS to enhance power system stability.

III. METHODOLOGY

A. System modeling:

A. Develop a mathematical model of the multi-machine system with dynamic loads. Consider the dynamic behavior of generators, loads, and associated control systems.

B. Incorporate the impact of dynamic loads on system stability by including load models that capture the variations and fluctuations introduced by the dynamic loads.

B. PSS design:

A. Determine the inputs and outputs for the power system stabilizer (PSS). Inputs typically include generator rotor speed deviation, acceleration, and electrical power deviations.

B. Define the desired output of the PSS, such as the generator rotor speed or system frequency, which needs to be regulated to enhance stability.

C. Determine the structure of the adaptive neuro fuzzy logic controller (ANFLC) for the PSS design. This typically

includes fuzzification, rule base, inference engine, and defuzzification stages.
D. Design the rule base, which maps the input variables to the pss output. Define the membership functions and fuzzy rules that capture the relationships between the inputs and outputs.
E. Optimize the membership functions and fuzzy rules using techniques such as genetic algorithms or particle swarm optimization to improve the performance of the ANFLC.

C. Training the ANFLC:

A. Collect training data by simulating various operating conditions and disturbances in the multi-machine system. This data should cover a wide range of scenarios to capture different dynamic load behaviors and system conditions.
B. Prepare the training dataset by recording the inputs (generator rotor speed deviation, acceleration, electrical power deviations) and the desired outputs (e.g., rotor speed or frequency response) for each scenario.
C. Train the ANFLC using the prepared dataset. This involves adjusting the parameters of the fuzzy logic inference system and the adaptive learning algorithms to approximate the desired mapping between inputs and outputs.
D. Validate the trained ANFLC using a separate dataset to assess its generalization and performance under unseen operating conditions.

D. Performance evaluation:

A. Simulate the multi-machine system with dynamic loads using the trained ANFLC-based PSS and compare its performance with traditional linear control techniques, such as PID controllers.
B. Analyze the response of the system under various operating conditions, disturbances, and changes in load dynamics.
C. Evaluate the effectiveness of the ANFLC-based PSS in damping oscillations, enhancing stability, and maintaining acceptable voltage and frequency levels.
D. Conduct sensitivity analysis to assess the robustness of the pss design to parameter variations and uncertainties in the system.

IV. MODELLING AND SIMULATION

- ***Structure of FLC***

The basic structure of FLC is shown in Fig. 1. The system input received by the FLC is turned into fuzzy form. On the basis of fuzzy rules, input, and MFs, the controller obtains the output in fuzzy form and finally, turns the output in nonfuzzy form
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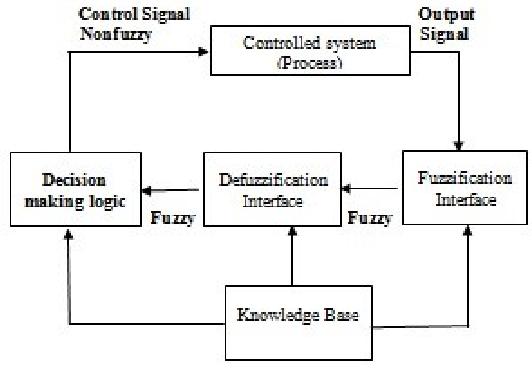


- The design steps of FLC are as follows.
- Define input and output variables.
- Choice of linguistic variables.
- Selection of fuzzy rule base.
- Defuzzification action.

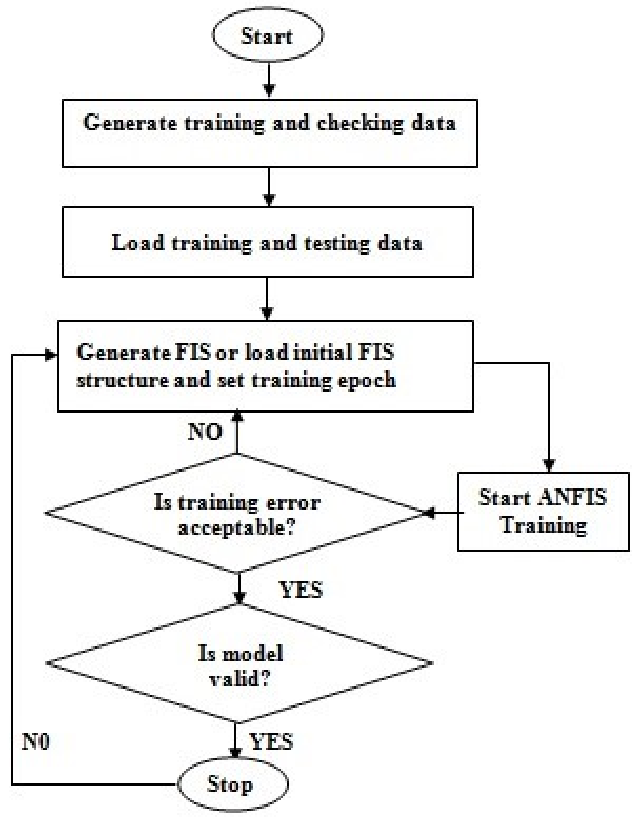


Fig. 2 ANFIS-PSS design procedure

The design and implementation of a power system stabilizer (PSS) using adaptive neuro fuzzy logic for a multi-machine system with dynamic loads yield significant results in enhancing power system stability. The analysis of the results obtained from the implementation provides valuable insights into the performance and effectiveness of the proposed approach. The following key aspects are typically considered in the result analysis:
Stability Enhancement: The primary objective of the PSS design is to improve power system stability. The result

analysis focuses on evaluating the effectiveness of the adaptive neuro fuzzy logic-based PSS in damping oscillations and maintaining acceptable voltage and frequency levels. Comparisons are often made with traditional linear control techniques, such as PID controllers, to assess the superiority of the proposed approach.

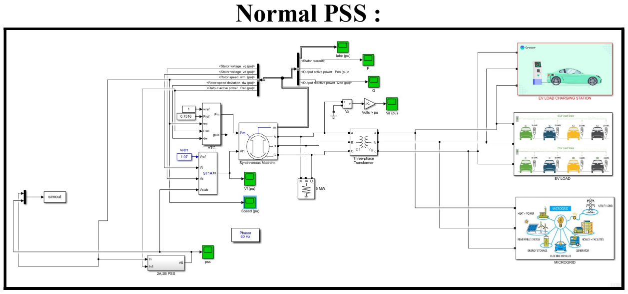
Dynamic Load Mitigation: Dynamic loads introduce variations and fluctuations in the power system, impacting stability. The result analysis investigates the capability of the adaptive neuro fuzzy logic-based PSS in mitigating the adverse effects of dynamic loads. It assesses how the PSS responds to changes in load dynamics and examines the extent to which the oscillatory behavior is reduced or eliminated.

Robustness: The robustness of the PSS design to parameter variations and uncertainties in the system is an essential aspect of the result analysis. Sensitivity analysis is conducted to evaluate the performance of the PSS under different operating conditions, disturbances, and load variations. The stability margins and the ability of the PSS to handle unexpected scenarios are examined to determine the robustness of the proposed approach.

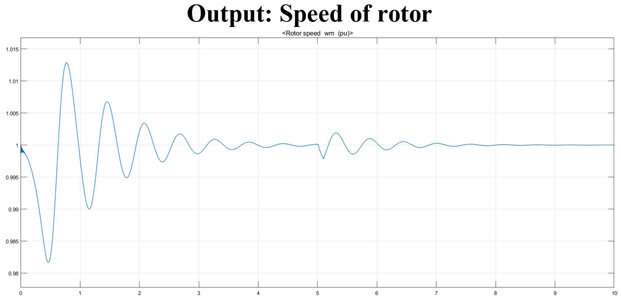
System Response: The dynamic response of the power system with the implemented PSS is thoroughly analyzed. This includes evaluating the speed of response, settling time, and overshoot, as well as the steady-state performance. The response is typically assessed under various operating conditions, such as changes in load demand, sudden load fluctuations, and system disturbances, to ensure that the PSS maintains stability in different scenarios.

V. RESULTS AND DISCUSSION

Normal PSS :



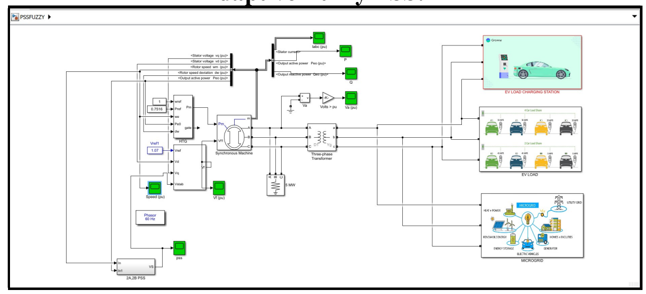
Output: Speed of rotor



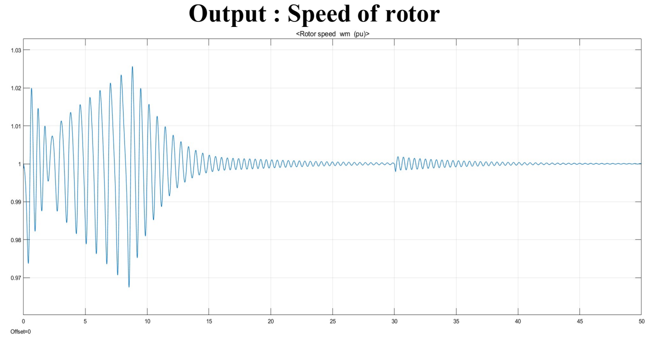
In the normal power system stabilizer, the speed of the rotor having disturbance and it takes more time to reach the pu value. This graph shows variations between 0 -1 pu.

Normal PSS is the simplest but may not be as effective in handling modern power systems with varying loads and uncertainties.

Adaptive Fuzzy PSS:

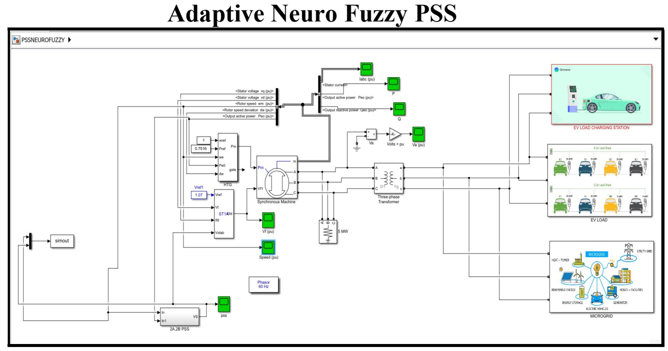


Output : Speed of rotor

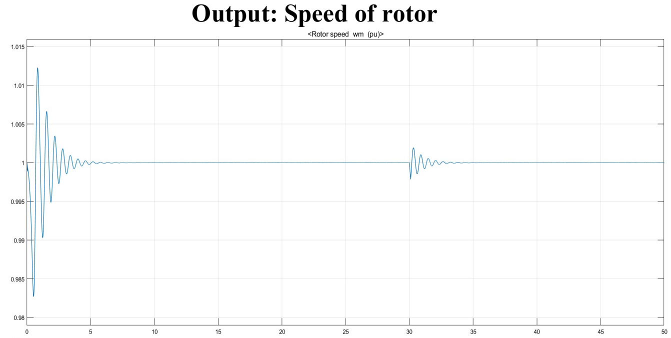


Adaptive Fuzzy PSS offers some adaptability through fuzzy logic but may still require manual tuning and might not handle complex dynamics well.

Adaptive Neuro Fuzzy PSS



Output: Speed of rotor



Adaptive Neuro Fuzzy PSS is the most advanced and adaptive option, combining the strengths of both fuzzy logic and neural networks. It can learn and adapt to changing conditions, making it suitable for modern and complex power systems.

Power System Stabilizers (PSS) are devices used in electrical power systems to improve the stability of synchronous generators. They help maintain the system's voltage and frequency within acceptable limits when subjected to disturbances. Three types of PSS - Normal PSS, Adaptive Fuzzy PSS, and Adaptive Neuro Fuzzy PSS - can be compared in terms of their characteristics and advantages:

Normal PSS:

- Traditional PSS design.
- Relies on mathematical models and pre-defined control parameters.
- Requires a good understanding of the power system dynamics.
- May not perform optimally under varying operating conditions or for systems with uncertainties.
- Offers stability improvement but may not adapt well to changing system conditions.

Adaptive Fuzzy PSS:

- Utilizes fuzzy logic-based control.
- Fuzzy logic controllers use linguistic variables and rules to make decisions.
- Provides a degree of adaptability to changing operating conditions.
- Can handle some level of uncertainty and non-linearity in the power system.
- Requires tuning of fuzzy rules and membership functions.

Adaptive Neuro Fuzzy PSS:

- Integrates fuzzy logic with neural networks.
- Combines the adaptability of neural networks with the rule-based reasoning of fuzzy logic.
- Learns and adjusts its control parameters based on system feedback.
- Better suited for handling complex and non-linear power system dynamics.
- Reduces the need for manual tuning as it can adapt to changing conditions.

CONCLUSION

In conclusion, the development of a novel design approach for a Power System Stabilizer (PSS) utilizing an Adaptive-Neuro Fuzzy Logic marks a significant stride in enhancing the stability and efficiency of modern power systems. Through the integration of advanced control methodologies, such as fuzzy logic and adaptive neuro-fuzzy systems, this approach demonstrates promising potential in addressing the complex dynamics and uncertainties inherent in power grid operations. By leveraging the capabilities of adaptive control and intelligent decision-making, this proposed design offers a robust solution to mitigate oscillations and ensure the reliable and secure operation of power systems. As the energy landscape continues to evolve, the adoption of such innovative control strategies will play a pivotal role in fostering a sustainable and resilient power infrastructure for the future. Further research and practical implementation of this design approach hold the key to unlocking new frontiers in power system stability and control, paving the way for a more efficient and sustainable energy future.

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