UNIVERSITI PUTRA MALAYSIA

NEURO-FUZZY LOGIC-BASED POWER SYSTEM STABILIZERS FOR ANGLE STABILITY ENHANCEMENT IN MULTI-MACHINE POWER SYSTEMS

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FK 2022 71

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By

SABO ALIYU

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2022

DEDICATION

This thesis is gratefully dedicated to:

My number one woman in my life, my beloved mother, Late Hajiya Fatima for her love and prayers, Allaummagfirlaha Ummi warahamha, wa'afiha wa'afuanha, Amin ya Allah, also to my beloved wife for her patience and understanding

&

My beloved brother and sisters.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Noor Izzri bin Abdul Wahab, PhD
Faculty : Engineering

Improvements in angle stability are commonly a significant emphasis in power system stability management. Although low frequency oscillations (LFOs) may not appear to be too alarming at first appearance, but failure to mitigate the oscillatory signals might cause the system to lose synchronization. To avoid power system disruption, adequate damping force is required for these oscillations. A power system stabilizer (PSS) well-known option for mitigating the effects of these oscillations have good performance for damping local oscillatory modes in general but they cannot sufficiently damp inter-area modes. Also, tuning PSSs control parameters is a difficult task which possess heavy optimization process and sometimes the PSSs design solution does not always provide a satisfactory solution. As a result, traditional PSSs performance fails to provide superior damping under other operating circumstances. Many adaptive control approaches have been proposed to solve this problem, but they are both difficult and expensive. FACTS (Flexible AC Transmission Systems) devices are efficient at suppressing oscillations and increasing power transmission rates. When a power oscillation damping (POD) controller is coupled to the control loop of the FACTS devices, recent research reveal that the FACTS-POD unit can function to introduce additional damping to the inter-area modes sufficiently. POD was connected to an Interline Power Flow Controller (IPFC) in this studies with the purpose of adding further damping to the inter-area oscillation modes found in power systems and simulation results shows a more viable option than PSSs. However, studies have shown that when controller parameters are set incorrectly, different types of controllers may weaken system damping or even worsen system oscillation, thus, the PSS-IPFC-POD controller needs to be designed correctly. Because of this, IPFC-POD coordinated PSSs optimization burden increases the systems computational and simulation cost. To address these shortcomings a Neuro-Fuzzy Controller (NFC) was proposed as a damping controller that is capable of adequately dampening both local and inter-area modes and is independent of coordination of PSSs to avoid optimization burden. The dynamic model of WSCC three-machine system and ten-machine test systems under multiple operating conditions and on SMIB test system was developed with the presence of NFC in SIMULINK. By linearization of the system model around the point of work, the eigenvalues of the system were obtained. Quantitative analysis results from the SMIB test system simulation shows that the proposed NFC model has the requirement to increase the rotor speed and rotor angle stability based on the time to settle by 64% and 28% respectively when compared to the FFA-PSS. In the same way, the proposed NFC SMIB model was observed to maximize the minimum damping ratio by 75% when compare to the PSSs-IPFC-POD model. Under the WSCC system simulation, the proposed NFC model recorded a 32% rotor speed and 66% rotor angle respective angle stability improvement in G2 based on the time to settle when compared to the FFA-PSS model. In the case of comparing the angle stability of the proposed NFC WSCC model to that of the PSS-IPFC-POD WSCC model, the proposed NFC model conceivably maximize the minimum damping ratio for the weakest modes by 38% when compare to the PSSs-IPFC-POD model. After carrying out the time-domain simulation on the New England IEEE test system, the proposed NFC model produced a 13% rotor speed and 43% rotor angle respective angle stability enhancement in G5 based on the time to settle when compared to the FFA-PSS model. Our work has led us to conclude that the simulation results with the proposed NFC model shows a great improvement in angular stability displaying a noticeable increase in the damping of the system oscillations. We have also found a way to achieve an efficient NFC damping controller performance that is capable of dampening both local and inter-area modes which avoid optimization burden experienced by the simulation on the PSSs and PSSs-IPFC-POD respectively. To sum up our work, considerable improvement have been made by the NFC controller to withstand long-term oscillations without the use of a supplementary controller which reduces the computational and simulation cost.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENSTABIL SISTEM KUASA BERASASKAN LOGIK NEURO-FUZZY UNTUK PENINGKATAN KESTABILAN SUDUT DALAM SISTEM KUASA PELBAGAI MESIN

Oleh

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Penambahbaikan dalam kestabilan sudut lazimnya merupakan penekanan penting dalam pengurusan kestabilan sistem kuasa. Walaupun ayunan frekuensi rendah (LFO) mungkin kelihatan tidak terlalu membimbangkan pada penampilan pertama, tetapi kegagalan untuk mengurangkan isyarat berayun mungkin menyebabkan sistem kehilangan penyegerakan. Untuk mengelakkan gangguan sistem kuasa, daya redaman yang mencukupi diperlukan untuk ayunan ini. Pilihan penstabil sistem kuasa (PSS) yang terkenal untuk mengurangkan kesan ayunan ini mempunyai prestasi yang baik untuk meredam mod ayunan tempatan secara umum tetapi ia tidak boleh melembapkan mod antara kawasan dengan secukupnya. Selain itu, menala parameter kawalan PSS adalah tugas yang sukar yang mempunyai proses pengoptimuman yang berat dan kadangkala penyelesaian reka bentuk PSS tidak selalu memberikan penyelesaian yang memuaskan. Akibatnya, prestasi PSS tradisional gagal memberikan redaman yang lebih baik di bawah keadaan operasi yang lain. Banyak pendekatan kawalan penyesuaian telah dicadangkan untuk menyelesaikan masalah ini, tetapi kedua-duanya sukar dan mahal. Peranti FAKTA (Sistem Transmisi AC Fleksibel) cekap dalam menyekat ayunan dan meningkatkan kadar penghantaran kuasa. Apabila pengawal redaman ayunan kuasa (POD) digandingkan dengan gelung kawalan peranti FACTS, penyelidikan terkini mendedahkan bahawa unit FACTS-POD boleh berfungsi untuk memperkenalkan redaman tambahan kepada mod antara kawasan dengan secukupnya. POD telah disambungkan kepada Pengawal Aliran Kuasa Antara Talian (IPFC) dalam kajian ini dengan tujuan menambahkan lagi redaman kepada mod ayunan antara kawasan yang terdapat dalam sistem kuasa dan hasil simulasi menunjukkan pilihan yang lebih berdaya maju daripada PSS. Walau bagaimanapun, kajian telah menunjukkan bahawa apabila parameter pengawal ditetapkan dengan tidak betul, jenis pengawal yang berbeza mungkin melemahkan redaman sistem atau malah memburukkan ayunan sistem, oleh itu, pengawal PSS-IPFC-POD perlu direka bentuk dengan betul. Oleh sebab itu, beban pengoptimuman PSS yang diselaraskan IPFC-POD meningkatkan kos pengiraan dan simulasi sistem. Untuk menangani kelemahan ini, Neuro-Fuzzy Controller (NFC) telah dicadangkan sebagai pengawal redaman yang mampu melembapkan kedua-dua mod tempatan dan antara kawasan dengan secukupnya dan bebas daripada penyelarasan PSS untuk mengelakkan beban pengoptimuman. Model dinamik sistem tiga mesin WSCC dan sistem ujian sepuluh mesin di bawah pelbagai keadaan operasi dan pada sistem ujian SMIB telah dibangunkan dengan kehadiran NFC dalam SIMULINK. Dengan linearisasi model sistem di sekitar titik kerja, nilai eigen sistem diperolehi. Hasil analisis kuantitatif daripada simulasi sistem ujian SMIB menunjukkan model NFC yang dicadangkan mempunyai keperluan untuk meningkatkan kelajuan pemutar dan kestabilan sudut pemutar berdasarkan masa untuk mendap masing-masing sebanyak 64% dan 28% jika dibandingkan dengan FFA-PSS. Dengan cara yang sama, model NFC SMIB yang dicadangkan telah diperhatikan untuk memaksimumkan nisbah redaman minimum sebanyak 75% jika dibandingkan dengan model PSSs-IPFC-POD. Di bawah simulasi sistem WSCC, model NFC yang dicadangkan merekodkan 32% kelajuan rotor dan 66% sudut rotor peningkatan kestabilan sudut masing-masing dalam G2 berdasarkan masa untuk menyelesaikan jika dibandingkan dengan model FFA-PSS. Dalam kes membandingkan kestabilan sudut model NFC WSCC yang dicadangkan dengan model WSCC PSS-IPFC-POD, model NFC yang dicadangkan boleh memaksimumkan nisbah redaman minimum untuk mod paling lemah sebanyak 38% jika dibandingkan dengan PSSs-IPFC. -Model POD. Selepas menjalankan simulasi domain masa pada sistem ujian IEEE New England, model NFC yang dicadangkan menghasilkan 13% kelajuan rotor dan 43% sudut rotor peningkatan kestabilan sudut masing-masing dalam G5 berdasarkan masa untuk menyelesaikan jika dibandingkan dengan FFA-PSS. model. Kerja kami telah membawa kami membuat kesimpulan bahawa hasil simulasi dengan model NFC yang dicadangkan menunjukkan peningkatan yang hebat dalam kestabilan sudut yang memaparkan peningkatan ketara dalam redaman ayunan sistem. Kami juga telah menemui cara untuk mencapai prestasi pengawal redaman NFC yang cekap yang mampu melembapkan kedua-dua mod tempatan dan antara kawasan yang mengelakkan beban pengoptimuman yang dialami oleh simulasi pada PSSs dan PSSs-IPFC-POD masing-masing. Untuk meringkaskan kerja kami, banyak peningkatan telah dibuat oleh pengawal NFC untuk menahan ayunan jangka panjang tanpa menggunakan pengawal tambahan yang mengurangkan kos pengiraan dan simulasi.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my thesis advisor Assoc. Prof. Ir. Dr. Noor Izzri b. Abdul Wahab, for his immense support and supervision throughout my PhD program and I would like to express my deepest gratitude to my beloved wife Khadija Muhammad Tuggar, for her patience, support and prayers in each and every stage of my PhD.

Besides, I would like to express my appreciation for the guidance and coaching of co-supervisors, Associate Professor Ir. Ts. Dr. Mohammad Lutfi Othman, and Dr. Mai Zurwatul Ahlam Mohd Jaffar for their profound and carefully aimed comments and suggestions of this study.

I am very grateful to all staff members of Department of Electrical and Electronics Engineering and Faculty of Engineering (Electrical), especially many thanks also extended to my colleagues in the Advanced Lightning Power and Energy Research (ALPER) group for their companionship, helpful insights and friendly working environment.

Last but not the least, I would like to thank my family and friends for supporting me spiritually throughout writing this thesis.

This thesis was submitted to the Senate of Universiti Putra Malaysia and accepted as a fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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ABC	Artificial Bee Colony
AEs	Algebraic Equations
AI	Artificial Intelligence
ANFIS	Adaptive Neuro Fuzzy Inference System
ANFleg	Adaptive Neuro-Fuzzy Legendre Wavelet
ADC	Adaptive Delay Compensator
ACO	Ant Colony Optimization
ANN	Artificial Neural Network
AVR	Automatic Voltage Regulator
BP	Back-Propagation Algorithm
BSA	Backtracking Search Algorithm
BA	Bat Algorithm
BFO	Bacteria Foraging Optimization
BMI	Bilinear Matrix Inequalities
HBB-BC	Hybrid Big Bang-Big Crunch
BBO	Biogeography Based Optimization
CSA	Cuckoo Search Algorithm
CSC	Convertible Static Compensator
DC	Direct Current
DE	Differential Evolution
DEs	Differential Equations
DAE	Differential Algebraic Equations
DG	Distributed Generation

DTA	Damping Torque Analysis
DG	Distributed Generation
DSA	Differential Search Algorithm
DFIGs	Doubly Fed Induction Generators
MatEMTP	Electromagnetic Transients Program in MATLAB
EMs	Electromechanical Oscillation Modes
ED	Eigenvalue Drifting
EGWO-SCA-CS	Enhanced Grey Wolf Optimization-Sine Cosine Algorithm-Cuckoo Search
EST	Educational Simulation Tool
EA	Evolutionary Algorithm
ES	Excitation System
FACTS	Flexible Alternating Current Transmission System
FFA	Farmland Fertility Algorithm
FIS	Fuzzy Inference System
FLS	Fuzzy Logic System
GA	Genetic Algorithm
GRSA	General Relativity Search Algorithm
GS	Gauss-Seidal
GOA	grasshopper optimization algorithm
GSA	Gravitational Search Algorithm
GWO	Grey Wolf Optimization
HHO	Harris Hawks Optimization
HBA	Honey-Bee optimization method
HPS	Hybrid Power System

HVDC	High Voltage Direct Current
I	Integral
IWOA	improved whale optimization algorithm
IAOMs	Inter -area Oscillation Modes
IAE	Integral Absolute Error
IGWO	Improved Grey Wolf Optimization
ISE	Integral Square Error
IPFC	Interline Power Flow Controller
ITAE	Integral Time Absolute Error
ITSE	Integral Time Square Error
KA	kidney-inspired algorithm
LOMs	Local Oscillation Modes
LFOs	Load Frequency Oscillations
LG	Line to Ground Fault
LMI	Linear Matrix Inequalities
LL	Double Line Fault
LLG	Double Line to Ground Fault
LLLG	Three Phase Fault
MatPower	Matlab Power Simulation System Package
MATLAB	Matrix Laboratory
Matsim	Matpower and Simulink
MAE	Mean Absolute Error
MF	Membership Function
MG	Microgrid

MLP	Multi Layer Perceptron
MMs	Multi Modes
MM	Multi-Machine
MV	Medium Voltage
NN	Neural Network
NEs	Network Equations
NR	Newton Raphson
NRJM	Newton Raphson-Jacobian Marquardt
PD	Proportional Derivative
PST	Power System Toolbox (PST)
PSS/E	Power System Simulator for Engineering
Simpow	Power System Simulator
PF	Power Flow
PFA	Power Flow Analysis
PFEs	Power Flow Equations
PST	Power System Toolbox
PAT	Power Analysis Toolbox
PSAT	Power System Analysis Toolbox
PI	Proportional Integral
PID	Proportional Integral Derivative
PSS	Power System Stabilizer
POD	Power Oscillation Dampers
PID	Proportional Integral Derivative
PIs	Performance Indices

PMU	Phasor Measurement Unit
PV	Photovoltaic
PSO	Particle Swarm Optimization
PSO-GSA	Particle Swarm Optimization-Gravitational Search Algorithm
PVDG	Photovoltaic Distributed Generation
PWM	Pulse Width Modulation
RBF	Radial Basis Function
RE	Renewable Energy
RES	Renewable Energy Sources
RFB	Redox Flow Battery
RK4	4th order Runge Kutta
RMSE	Root Mean Square Error
RNN	Recurrent Neural Network
SE	Steady state Error
SI	Stability Index
SMC	Sliding Mode Control
ST	Settling Time
SPS	SimPowerSystems
SMIB	Single Machine Infinite Bus
SOF	Static Output Feedback
STATCOM	Static Compensatory
SSSC	Static Synchronous Series Compensator
SVD	Singular Value Decomposition
SVC	Static Var Compensator

SOS	Symbiotic Organisms Search
TLBO	Teaching Learning Based Optimization
TCSC	Thyristor Controlled Series Capacitors
UPFC	Unified Power Flow Controller
VSC	Voltage Source Converters
WSCC	Western System Coordinated Council

CHAPTER 1

INTRODUCTION

1.1 Background

In the past, electrical power systems were relatively local and simple. Today's power systems are complex for example, as large-scale wind and photovoltaic (PV) energy become more integrated into traditional power systems, the interaction mechanism between the thermal, wind, and PV energy and its impact on the power transmission system becomes more complicated. At the same time, the increased uncertainty of these renewable energy sources (RES) will affect power flow and even negatively affect damping characteristics (He et al., 2022), (Nguyen, Bera, & Mitra, 2018). Due to the lower damping, the power system will be especially be vulnerable to low frequency oscillation (LFO). LFOs with frequencies in the range of 0.2 to 3 Hz are one of the consequences of weak interconnected network. These oscillations are the result of fluctuations between generators in one area versus generators in the adjacent area. They are also consequences of the expansion of large-scale power systems. When they occur, the oscillation continues for a while and then goes away, or it increases steadily, causing the system to collapse.

The power system oscillation can be inspired by a severe fault in the system performance such as a three-phase short circuit to the ground or tripe of a transmission line. Therefore, if power fluctuations cause the collapse of a power system, it can be due to the problem of the stabilization of the angle of the large or small perturbation rotor of the power system (Zhao et al., 2019). This particular kind of stability is called the oscillation of the power system. The oscillations of power system was first observed in The North American Power Grid in October 1964 during the north's network of power testing connections to the Southern Power Grid (Schleif & White, 1966). After the connecting line, power oscillation with frequency of 0.1 Hz was observed and after a while the connecting line was tripped.

Moreover, some cases of power system fluctuation in transmission network of many countries have been observed and reported. Examples include: In the late 1970s and early 1980s, power fluctuations on the route from Scotland to England were observed in the great British power grid. Practical experience showed that these oscillations are very high when power transmission is transmitted. The results of a series of studies conducted in 1980 and 1985 showed that these fluctuations occur when the power transfer level is significantly adjusted and the oscillation frequency of these power fluctuations was 0.5 Hz. This problem was successfully addressed by the installation of PSSs in several power plants in Scotland (C. M. Gibson, 1998).

Continuous power fluctuations in Taiwan's power grid were reported in 1984, the damping of power fluctuations was found effectively improved by successfully installing power system stabilizers (PSSs) in selected locations. Further investigations shows that other factors such as the amount of automatic voltage regulator (AVR) and load characteristics also affect the damping of power fluctuations (Hsu, Shyue, & Su, 1987). The departure of the North American WSCC network on August 10, 1996 was directly due to power oscillations (with frequencies between 0.2 and 0.3 Hz). Lines and generators were expanded with tripping, eventually leading to the WSCC network becoming four islands. These effect left over 5.7 million consumers in total blackout for nine hours, resulting in significant economic losses (Taylor & Erickson, 1996).

Since 1970's, traditional solution for controlling these oscillations is the use of damping controller device called of PSSs that provide a supplementary control in the generators excitation control system (Peres, 2019). The PSSs creates a positive component of phase torque with vetting changes in speed on the rotor, thus removing the negative damping torque effect by providing additional damping (P. S. Kundur, 2004a) (Anderson & Fouad, 2003). When the system damping is quickly improved with a damping ratio greater than 0.1, then the system is said to be stable and the power system has a good oscillation damping, and if there is a LFOs for a certain period (several seconds to ten seconds) and finally disappears, then the power system has oscillation power, but the damping of volatility is weak (Du, Wang, & Dunn, 2009).

Nowadays, the volatility factor of the weak damping of power system known as electromechanical oscillating modes (EMs). Oscillating modes are divided into two types: Local swing modes (or local modes) and Inter-regional oscillation modes (or inter-area modes). Power system oscillations related to local oscillating modes is a power fluctuation of a group of local generators against the power system (Peres, 2019). The frequency of these fluctuations is often between about (1 to-2Hz). An inter-area oscillation is the power oscillation of the connecting line between the two regions with a weak connection in the power system having frequency between (0.1 to-1Hz) (Peres, 2019). The fluctuation of the power system can only be due to a mode (local or inter-regional modes), called single mode oscillation. Oscillation can be related to many other swing modes, such as local or inter-region mode, which is called multi-mode oscillation (P. S. Kundur, 2004a).

1.2 Problem statement

To ensure the stability of electrical power systems, they must be free of improperly damped oscillations. This condition is critical in modern power grids, especially as power systems become more interconnected. Although LFOs may not appear to be too disturbing at first appearance, failure to mitigate the oscillatory signals might cause the system to lose synchronization (Tawfik Guesmi, Alshammari, Almalaq, Alateeq, & Alqunun, 2021). To avoid power system disruption, adequate damping force is required for these oscillations. In addition to the economic loss caused by the interruption, these oscillations will harm the lifetime of synchronous machines. PSSs well-known option for mitigating the effects of these oscillations have good performance for damping local oscillatory modes in general (L. F. B. Martins, de Araujo, de Vargas Fortes, & Macedo, 2017), however they cannot sufficiently damp inter-area modes. On the other hand, depending on the settings provided to the PSSs control parameters, previously stable modes, particularly inter-area modes, can become unstable (De Vargas Fortes, De

Araujo, MacEdo, Gamino, & Martins, 2016). Also, tuning PSSs control parameters is a difficult task which possess heavy optimization process and sometimes the PSSs design solution does not always provide a satisfactory solution (Abido & Abdel-Magid, 2000).

FACTS (Flexible AC Transmission Systems) devices are efficient at suppressing oscillations and increasing power transmission rates (Du et al., 2009). When a power oscillation damping (POD) controller is coupled to the control loop of FACTS devices, recent research reveal that the FACTS-POD set can function to introduce additional damping to the inter-area modes, as shown in the works of (Miotto et al., 2018), (E. de V. Fortes, Macedo, Araujo, & Romero, 2018) and (L. F. B. Martins et al., 2017). The Interline Power Flow Controller (IPFC) is one of the most advanced and effective power flow controllers available among the FACTS various devices (E. V. Fortes et al., 2022) (Tawfik Guesmi et al., 2021). POD was connected to an Interline Power Flow Controller (IPFC) in this studies with the purpose of adding further damping to the inter-area oscillation modes found in power systems and is a more viable option than PSSs. However, studies have shown that when controller parameters are set incorrectly, different types of controllers may weaken system damping or even worsen system oscillation, as such the PSS-IPFC-POD controller needs to be designed correctly (He, Shen, Wen, & Pan, 2021), (Bhukya & Mahajan, 2019). As such, the major drawback of this procedure involves IPFC-POD coordinated PSSs optimization burden and is difficulty in developing the dynamic IPFC-POD model in the test systems.

Artificial intelligent (AI) – based PSSs controllers is the research focus of importance in recent years (Paital, Ray, Mohanty, & Mohanty, 2021). In the same way as the FACTS stabilizers, AI stabilizers techniques are also designed with the coordination of PSSs on the test systems. Therefore, it is necessary to develop a stabilizer that will replace the conventional optimized PSSs and FACTS thereby bypassing the system PSSs design modelling and complications.

The above problem statements can be summarized as follows:

1. Improvements in angle stability are commonly a significant emphasis in power system stability management. Proliferation of LFOs may cause the interconnected power systems lose its synchronism. PSSs however cannot sufficiently damp inter-area modes.

2. The system equipped with IPFC-POD provides adequate damping to the inter-area oscillatory modes present in power systems. However, the PSS-IPFC-POD controller needs to be optimised correctly and because of this, IPFC-POD coordinated PSSs optimization burden increases the systems computational and simulation cost.

3. An efficient and robust damping controller that is capable of dampening both local and inter-area modes is required which can withstand long-term oscillations without the use of a supplementary controller thus reducing the computational and simulation cost.

1.3 Objectives

The main focus of this research is to develop a stabilizer using Neuro-Fuzzy Controller (NFC) that can replace the work of PSSs and provide superior properties than the conventional PSSs and FACTS stabilizers in controlling low frequency oscillations in power system. In order to achieve this, three specific objectives of the study are:

1. To build a multi-machine power systems model for optimizing PSSs and PSSs-IPFC-POD damping controllers using Farmland Fertility Algorithm.

2. To propose a Neuro-Fuzzy Controller to act as a damping controller for multi-machine power systems without the use of a supplementary control.

3. To validate the proposed NFC with the FFA-PSSs and FFA-PSSs-IPFC-POD damping controllers for multi-machine power systems.

1.4 Scope of the study

The scope and limitation of this research work are as follows:

1. Three standard IEEE bus test systems of Single-machine infinite bus (SMIB), 9-bus and 39-bus of the New England test systems respectively were model for numerical simulation and damping controllers design.

2. A Neuro-Fuzzy Controller (NFC) was proposed as a damping controller that can replace the work of the PSSs and PSSs-IPFC-POD on the three test systems.

3. The design of the control parameters settings between the PSSs, the PSS-IPFC-POD and the NFC controllers were efficiently obtained using the FFA optimization technique on the three test systems.

1.5 Thesis outline

This thesis is organized into 5 chapters according to thesis format of Universiti Putra Malaysia (UPM), in which each chapter comprises of introduction, methodology, results and discussion, and conclusions. Brief explanation of each chapter has been discussed in the following section.

Chapter 1 presents overview of the thesis by describing the summary of the background and its problem statements. Furthermore, the research objectives and its scope of works are presented followed by the organization of the thesis. After that, Chapter 2 provides the detailed and comprehensive literature review of power system angular stability, power system dynamic modelling, small signal stability analysis, power system stabilizers and FACTS stabilizers.

Next, Chapter 3 portrays the detail explanation on methodology and simulation works, simulation works on PSSs design, simulation works on Interline Power Flow Controller (IPFC) modelling in load flow. Moreover, it explains the dynamic IPFC modelling and optimal mode feedback design with additional IPFC control for damping LFOs in multi-machine power system. Lastly, the chapter ends with explaining the propose Neuro-Fuzzy Controller (NFC) modelling for LFOs control in power system.

Next is Chapter 4 which describes the detail non-linear time-domain simulations and quantitative analysis results based on the simulation methodology of Chapter 3. First is the simulation and quantitative analysis results obtained for PSSs design for all the three standard test systems, then the simulation and quantitative analysis results obtained for IPFC system design with coordinated PSSs and lastly is the simulation and quantitative analysis results obtained for the proposed NFC design.

Chapter 5 is the last chapter and it presents the conclusion, contribution and recommendation for further studies.

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