NEURAL NETWORK BASED SELF-TUNING PID CONTROLLER FOR AUTOMATIC VOLTAGE REGULATOR OF HYDROPOWER PLANT

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DEDICATION

This work is dedicated to father's soul, who has always motivated us to seek knowledge. Also, to my dear mother who sacrificed so much to continue our study journey. Moreover, to my dear wife, who shared with me the difficulties of this task and endured a lot throughout my study. Furthermore, to my daughters and son, it may be an incentive for them. Finally, to my brothers, sisters and friends who have supported and encouraged me to complete my study mission successfully.

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ABSTRACT

Hydropower plant is a renewable resource with low operating, maintenance expenses and low environmental effects. Due to the constant load change as a result of changing consumers demand, terminal voltage from the generator is fluctuating for certain period before it settle to the desired level. The amount of fluctuation is negatively influencing the power quality and performance of power system. Automatic voltage regulator (AVR) is playing vital role for maintaining the terminal voltage within desired level. The proportional-integral-derivative (PID) controller's is popularly deployed in AVR system due to its ease structure and straightforward design with almost no computational cost. However, traditional methods of PID tuning in some industrial applications does not meet the required response due to severe load fluctuations. In this work, in order to meet the optimum PID-AVR performance; a three types of neural networks namely: feed forward neural network (FFNN), cascade back propagation neural network (CBPNN), and convolutional neural network (CNN) were used to design three self-tuning PID controllers (NNs-PIDF) for AVR system. These artificial intelligence based controller are proven stunning performance over traditional PID controllers also over those controller made using particle swarm optimization (PSO) and fuzzy logic. The outcomes of this work revealed that FFNN-PIDF based AVR system was able to produce best results e.g. settling time, overshoot, and rise time. The proposed controllers has provided consistence performance in controller stability and robustness tests.

Kaywords: AVR system, Zeigler-Nichols, neural network, self-tuning PID, robustness analysis

ABSTRAK

Loji hidrokuasa adalah satu sumber yang boleh diperbaharui, dengan perbelanjaan operasi penyelenggaraan, dan kesan alam sekitar. yang rendah. Disebabkan oleh perubahan beban yang berterusan akibat perubahan permintaan pengguna, voltan terminal dari penjana turun dan naik dalam tempoh masa tertentu sebelum ia sampai ke aras yang dikehendaki. Kadar turun-naik mempengaruhi secara negatif kualiti kuasa dan prestasi sistem kuasa. Pengawal voltan automatik memainkan peranan yang penting dalam mengekalkan voltan terminal pada aras yang dikehendaki. Kawalan berkadar kamiran terbitan (PID) banyak digunakan dalam sistem AVR disebabkan strukturnya yang mudah dengan tiada kos pengiraan. Namun begitu, metod-metod penalaan tradisional PID dalam beberapa aplikasi industri tidak memberi makluman yang diperlukan disebabkan beban turun-naik pelayan. Dalam kajian ini, untuk memenuhi prestasi PID-AVR yang optima; tiga jenis rangkaian neural iaitu: *feed forward neural network* (FFNN), *cascade back propagation neural network* (CBPNN), dan *convolutional neural network* (CNN) telah digunakan untuk mereka cipta tiga kawalan PID penalaan kendiri (NNs-PIDF) untuk sistem AVR. Kawalan berasaskan kecerdasan buatan ini terbukti mempamerkan prestasi yang sangat hebat menandingi kawalan PID tradisional, serta kawalan yang digunakan dengan menggunakan *particle swarm optimization* (PSO) dan *fuzzy logic*. Hasil kajian ini menunjukkan bahawa sistem AVR berasaskan FFNN-PIDF mampu menghasilkan keputusan terbaik, contohnya masa tetapan, *overshoot*, dan masa menaik. Kawalan-kawalan yang disarankan telah menyediakan prestasi yang konsisten dalam kestabilan kawalan dan ujian-ujian keteguhan.

Kata kunci: Sistem AVR, Zeigler-Nichols, rangkaian neural, PID penalaan kendiri, analisis keteguhan

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LIST OF ABBREVIATIONS

AVR	-	Automatic voltage regulator
PID	-	Proportional integral derivative
ADP	-	Adaptive dynamic programming
RHC	-	Routh-Hurwitz criterion
FOPID	-	Fractional order proportional derivative integral
ITAE	-	Integral Time Absolute Error
IAE	-	Integral Absolute Error
ITSE	-	Integral Time Square Error
ISE	-	Integral Square Error
GA	-	Genetic algorithm
PSO	-	Practical swarm Optimization
STC	-	Self-tuning control
IE	-	Integral error
Ms	-	Modulus of sensitivity function
Mn	-	Measurement noise
FPC	-	Frequency linked pricing control
ALFC	-	Automatic load frequency control
DFIG	-	Doubly fed induction generators
ABT	-	Availability based tariff
ChBWO	-	Chaotic Black Widow Optimization
ZLG	-	Zwe-Lee Gaing's
PSS	-	Power System Stabilizer

SMIB	-	Single-Machine Infinite-Bus
YSGA	-	Yellow saddle goatfish algorithm
FVOPID	-	Fractional-variable-order proportional integral derivative
LFC	-	Load frequency control
COA	-	Coyote optimization algorithm
PIDA	-	Proportional integral derivative accelerator
WOA	-	Whale optimization algorithm
CS	-	Cuckoo Search
VURPSO	-	Velocity update relaxation particle swarm optimization
CRPSO	-	Crazy particle swarm optimization
ABC	-	Artificial Bee Colony
DE	-	Differential Evolution
ROC	-	Receiver Operating Characteristic
ALO	-	Ant Lion Optimizer algorithm
CAs	-	Cultural algorithms
MOEO	-	Multi-objective evolutionary optimizers
CNC-ABC	-	Cyclic exchange neighborhood with chaos- Artificial Bee Colony
CAS	-	Chaotic Ant Swarm
ACO-NM	-	Ant Colony Optimization algorithm with the Nelder–Mead approach
2DOF-PID	-	Two-degree-of-freedom PID controller
ANNs	-	Artificial neural networks
STNPID	-	Self-tuning neural network PID controller
SVC	-	Static VAR Compensator
TLBO	-	Teaching-learning based optimization
FPID	-	Fuzzy PID

FPIDF	-	Fuzzy PID with filter
FLC	-	Fuzzy Logic Controller
PLCs	-	Programmable logic controllers
RBF-NN	-	Radial-basis function network
GNFPID	-	Genetic neural Fuzzy PID
AGC	-	Automatic generating control
TSFL	-	Takagi Sugeno Fuzzy Logic
MSE	-	Mean square error
CD	-	Correct decision
TD	-	Total decision
Pu	-	Per unit
Vref	-	Reference voltage

LIST OF SYMBOL

k_p	-	Proportional gain
k_i	-	Integral gain
k_d	-	Derivative gain
K_a	-	Amplifier gain
τ_a	-	Amplifier time constant
K_e	-	Exciter gain
τ_e	-	Exciter time constant
K_g	-	Generator gain
τ_g	-	Generator time constant
K_r	-	Sensor gain
τ_r	-	Sensor time constant
K_u	-	Ultimate gain
T_u	-	Ultimate period
T_i	-	Integral time constant
T_d	-	Derivative time constant
T_r	-	Rise time
T_o	-	Overshoot time
T_s	-	Settling time
O_p	-	Overshoot period
$in_i^{(i)}$	-	Input of hidden layer
w_{ij}	-	Weight of hidden layer that connected with input layer

$O_j^{(j)}$	-	Output of input layer
f	-	Activation function
y	-	Actual output vector of neural network
w_{li}	-	Weight of hidden layer that connected with output layer
$O_i^{(i)}$	-	Output of hidden layer
T	-	Target vector of neural network
e	-	Error vector of neural network
X_{Nj}	-	Input vector of neural network

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CHAPTER 1

INTRODUCTION

1.1 Preface

Power generation by means of coal and other traditional fuels are amongst main pollution causes due to its harsh litters. Alternatively, many other sources of energy are invented so far with no negative impact on the environments (Beires et al., 2018). Those means have come with good economic advantages since conventional fuel usage is dispensed. Power is producible after power turbines (generators) which in turn required the exciters, which make turbines coils to run and produce the required energy. In hydro power plants, water dynamic energy is used to run the turbines, has such power plants are established within water falling areas such as dams and natural waterfalls (Weldcherkos et al., 2021). Power with big amounts can be generated from the hydropower plants makes it outperform over other renewable energy resources such as wind and solar power plants. Electrical loads in the transmission and distribution networks are usually variable as a result of changing consumer usage, which in turn causes the voltage of generator terminals to fluctuate in generating stations. Automatic voltage regulator (AVR) is proven noteworthy performance in controlling the generator's output to a constant level. AVR works to determine the error in produced voltage with respect to a reference voltage (to be set within AVR configurations). This error is represented by the difference between generator output voltage and AVR reference voltage. The quality of power generated in hydro power plant is limited to AVR configuration accuracy. Controllers such as Proportional integral derivative (PID) are used to tune up AVR so that constant voltage is ensured at generator terminals. However, traditional methods of tuning PID controller in AVR system does not meet the required response. In this project, neural network is being used for implementing of self-tuning AVR system.

1.2 Problem statement

Providing a constant voltage to the consumer is one of the important priorities in the field of electrical energy production, in order to ensure the work of consumer's appliances within the rated voltages. AVR takes responsibility to maintain the generator terminal voltage within requires levels according to regulator reference voltage. Therefore, AVR preforms voltage mismatch calculation by subtracting terminal voltage from existing regulator reference voltage. Considering that generator terminal voltage is fluctuating so frequently as a result of continuous load change, AVR responses to such fluctuations might be differ in time which trigger another drawback in system stability. Settling time uncertainty forces to use external controllers such as PID in order to stabilize the system. PID processes is taking place in two stages, firstly, time- integration which stabilize the voltages by integrating the voltage signal over the time. The gain added on the voltage signal during this stage is influencing the system response time for voltage fluctuation. Consequently, the resultant of the integration is further optimized by applying derivation in which scales up/down the final value in order to reach the maximum approximation, which in turn enhance the system's response. Inaccurate tuning of PID parameters in AVR system may lead to drawback such as high delay system response, which make the system to fall in confronting generator voltage fluctuation. PID controller integral process involves three gains balancing which impact the performance of PID. In spite of good voltage regulation, AVR system may suffer from delay in responding time for voltage fluctuation.

1.3 Research gap

In spite of well designing of PID controller (Herbst, 2021), PID performance remains unstable while other interferences such as power surge, temperature hike and weather fluctuation are occurring (Kezunovic et al., 2008). Hence, research activities are more concentrating to optimize the performance of AVR-PID system by optimizing the gains of PID controller. Cuckoo Search algorithm is used at (Sikander & Thakur, 2020) for this purpose, this algorithm is suffering from shortcoming such as slower convergence. From the other hand, analytical approach such as adaptive dynamic programming (ADP) method is used at (Batmani & Golpîra, 2019), which involves high computational budget. Routh-Hurwitz criterion (RHC) is analytical method used to evaluate the gains of PID controller at (Soliman & Ali, 2021), this method cannot be deployed for non-linear systems.

1.4 Objectives

This research focuses on controller part in AVR system with intension to enhance the AVR response to terminal voltage fluctuation. For this purpose, the following objectives are set. Figure 1.1 is demonstrating the objectives:

i. Design PID control of AVR system using Ziegler-Nichols method.

ii. Design Self-Tuning PID control of AVR system based on neural network that ensure the robustness of the controller to deal with uncertainty for AVR system.

iii. Compare the results of traditional PID controller and the proposed Self-Tuning PID controller of AVR system in terms of rise time, settling time and overshoot.

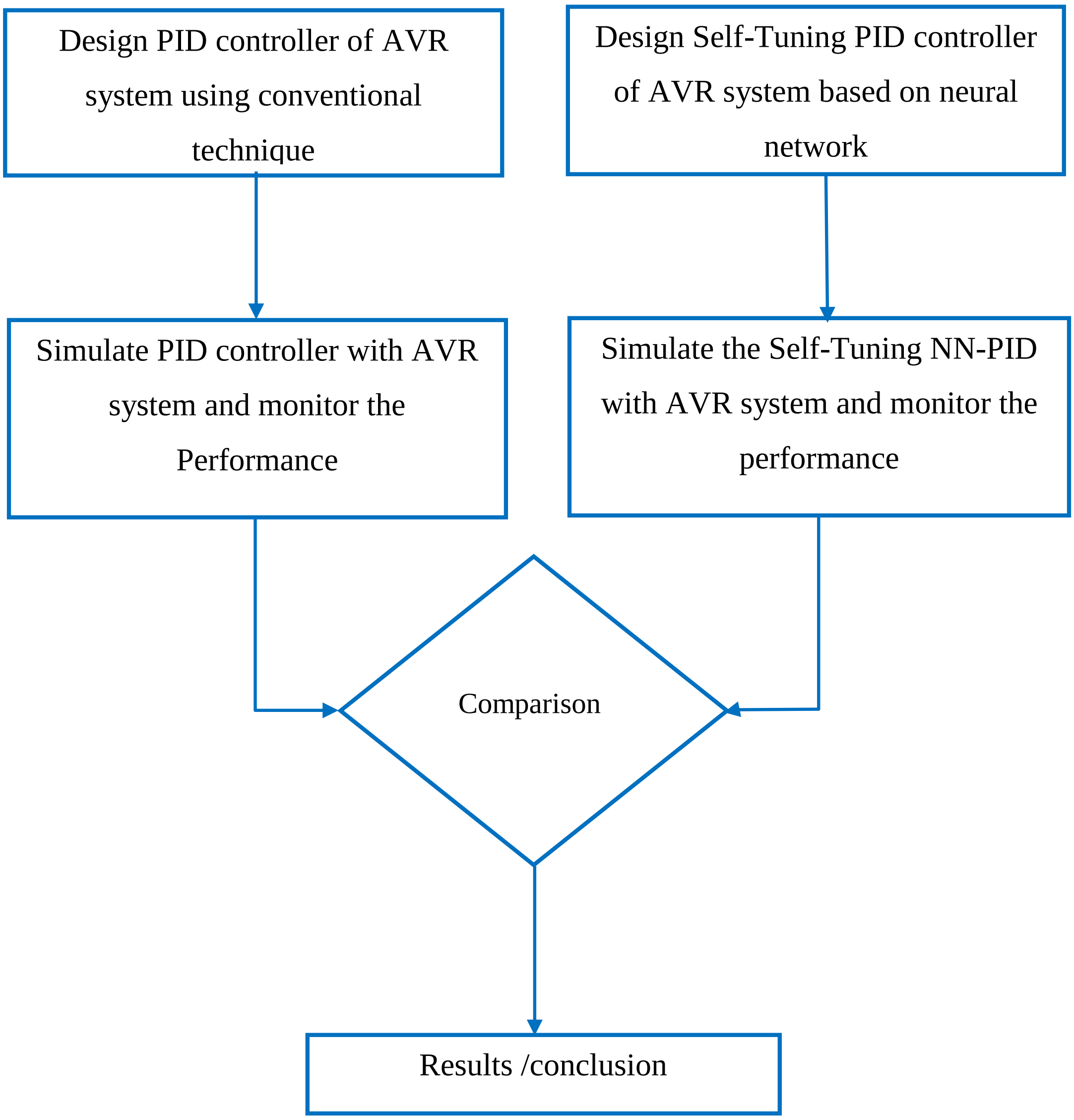

Figure 1.1 Research objectives overview

1.5 Research question

The purpose of the study is to answer the following questions:

i- Will a self-tuning PID controller based on a neural network for AVR outperform a traditional PID controller for automatic voltage regulation?

ii- Can a neural network based self-tuning PID controller for AVR system yield better performance in terms of rise time, settling time, overshoot and robustness?

1.6 Scope of the project

i. The current scope of research includes the development of a PID controller which to compare the performance of the traditional PID with the developed PID based on neural network.

ii. The traditional PID tuning method is limited to Ziegler Nichols (ZN) method.

iii. The project is implemented using MATLAB\SIMULINK.

iv. The proposed controller is applied only to linear AVR system on MATLAB\SIMULINK.

1.7 Organization of the project

This project report is consisting of five chapters that prescribing the proposed methodology and techniques of AVR controlling. From the other hand, the impact of various traditional and automatic controllers of AVR are discussed. Therefore, the structure of this project report can be as in herein Table 1.1.

Table 1. 1 Thesis structure and contains summary

Chapter Number	Chapter Title	Brief Introduction
1	Introduction	Includes a summarized introduction of the automatic voltage regulator (AVR) and illustrating the problem statement and the objectives of the project.
2	Literature Review	Demonstrates the previous attempts made in the previous studies on interest of automatic voltage regulator (AVR) and its control methods.
3	Research methodology	Illustrates the infrastructure of the Automatic voltage regulator (AVR) as well as the traditional controller and automatic/smart controllers also the mathematical modelling of the research problem.
4	Results and Discussions	Reviews with the required discussions the results obtained after involving the proposed techniques.
5	Conclusion	Includes the conclusions of the project
6	References	Enlists the references and books used while constructing of this project report.

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