TRANSIENT VOLTAGE STABILITY ENHANCEMENT USING GENETIC NEURAL PROPORTIONAL INTEGRAL DERIVATIVE FINE-TUNED BY FUZZY CONTROLLER

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To my wife and parents, with love and gratitude

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All praise and thanks are due to Allah ,and peace and blessing of Allah be upon our prophet. Muhammad and upon all his family and companions. Thanks to Allah who give me good health in my life and thanks to Allah for everything. Without the help of Allah, I was not able to achieve anything in this is research.

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ABSTRACT

Improving the transient response of power generation systems using the automation control in a precise manner remain challenging. Developing the Automatic Voltage Regulator (AVR) of the synchronous generator with a high potency and prompt response for the stable electric power service is ever-demanding. The proposed techniques for determining the Proportional Integral Derivative (PID) controller parameters of the AVR system such as Real-Coded Genetic Algorithm (RGA) and a Particle Swarm Optimization (PSO) have failed to achieve the desired precision. Enhancing the transient stability responses of synchronous generation using automation control remains the challenging issue. This thesis presents a novel design method for determining the PID controller parameters of an AVR system using combined Genetic Algorithm (GA), Radial-Basis Function Neural Network (RBF-NN) and Sugeno Fuzzy logic approaches for implementation in enhancing the transient stability responses. This new approach renders the design of synchronous generator voltage controller by introducing a complete and modified model of synchronous generator. The problem of obtaining the optimal AVR and PID controller parameters is formulated as an optimization problem and RBF-NN tuned by GA is applied to solve the optimization problem. Meanwhile, RBF-NN is used to enhance the PID parameters obtained from GA to design a fuzzy PID controller of the AVR system for various operating conditions namely Genetic Neural Fuzzy PID (GNFPID). GNFPID is further designed to transfer in Programmable Logic Controllers (PLCs) for implementing the practical AVR system in the experimental model. An inherent control interaction between the excitation current and terminal voltage is revealed. The simulation and experimental results demonstrate the proposed approach has superior features, including easy implementation, stable convergence characteristic, and good computational efficiency. The proposed GA is applied to optimize PID controller parameters. The algorithms for the proposed GA and RBF-NN are coded using MATLAB and executed on a laptop with Intel core (TM) 2 Duo CPU 5550@1.83 GHz with 3GB RAM laptop. This algorithm effectively searches for a high-quality solution to improve the system's response (~0.005 sec) and transient response of the AVR system for 13.8 kV and 400 V are found to be 0.0025 and 0.001, respectively. Furthermore, the results of the numerical simulation offer a high sensitive response of the novel design compares to the RGA, LQR, PSO and GA. The GNFPID controller configures the control signal based on interaction and thereby reduces the voltage error and the oscillation in the terminal voltage. The GNFPID controller achieves an excellent voltage control performance by testing the proposed fuzzy PID controller on a practical AVR system in synchronous generator with the sizeable improved transient response. The proposed method is indeed more efficient and robust in improving the system's response and the transient response of an AVR system. It is asserted that this novel approach may be useful for the development of voltage control of power systems in real industrial practices under severe fault.

ABSTRAK

Memperbaiki sambutan fana sistem penjanaan kuasa menggunakan kawalan automasi berkejituan tinggi masih menjadi cabaran. Membangunkan Pengatur Voltan Automatik (AVR) janakuasa segerak dengan sambutan potensi yang tinggi dan segera untuk perkhidmatan kuasa elektrik stabil sentiasa mendapat permintaan. Teknik yang dicadangkan untuk menentukan parameter yang Pekadaran Pengamiran Pembezaan (PID) sesuatu sistem AVR seperti Algoritma Genetik Kod Sebenar (RGA) dan Pengoptimaan Kerumunan Zarah (PSO) yang gagal mencapai kejituan yang dikehendaki. Meningkatkan tindak balas kestabilan sementara generasi segerak menggunakan kawalan automasi kekal isu yang mencabar. Tesis ini membentangkan satu kaedah reka bentuk baru bagi menentukan parameter PID sesuatu sistem AVR menggunakan gabungan Algoritma Genetik (GA), Rangkaian Neural Fungsi Berasaskan Jejari (RBF-NN) dan kaedah-kaedah logik Kabur Sugeno untuk perlaksanaan dalam meningkatkan sambutan kestabilan fana. Kaedah baru ini membawa kepada reka bentuk pengawal voltan janakuasa segerak dengan memperkenalkan satu model lengkap dan modifikasi bagi janakuasa segerak. Adalah menjadi masalah bagi mendapatkan parameter pengawal AVR dan PID optima kerana dibuat sebagai satu masalah pengoptimaan dan RBF-NN dilaras dengan GA yang diaplikasikan bagi menyelesaikan masalah pengoptimaan. Sementara itu, RBF-NN digunakan bagi meningkatkan parameter PID yang diperolehi daripada GA untuk mereka bentuk pengawal kabur PID bagi sistem AVR untuk pelbagai keadaan operasi yang dinamakan Genetik Neural Kabur PID (GNFPID). GNFPID selanjutnya direka bentuk untuk dipindahkan dalam Pengawal-Pengawal Logik kebolehprogram (PLCs) bagi melaksanakan sistem AVR praktikal dalam model eksperimen. Satu interaksi kawalan yang wujud di antara arus ujaan dan voltan terminal ditunjukkan. Keputusan simulasi dan eksperimen membuktikan kaedah dicadangkan mempunyai ciri-ciri yang lebih baik termasuk perlaksanaan yang mudah, sifat pertumpuan stabil dan keberkesanan pengiraan yang baik. GA yang dicadangkan diaplikasi bagi mengoptimumkan parameter pengawal PID. Algoritma GA yang dicadangkan dan RBF-NN dikod menggunakan MATLAB dan dijalankan dengan komputer riba *Intel core(TM)* 2 *DuoCPU* 5550@1.83GHz dengan 3GB RAM. Algoritma ini secara efektif mencari satu penyelesaian bermutu tinggi bagi memperbaiki respon sistem (~0.005 saat) dan sambutan fana sistem AVR untuk 13.8 kV dan 400 V didapati sebanyak 0.0025 dan 0.001 setiap satu. Tambahan lagi, keputusan simulasi angka memberikan sambutan bersensitif tinggi bagi reka bentuk baru tersebut dibanding dengan RGA, LQR, PSO dan GA. Pengawal GNFPID mengkonfigur isyarat pengawal berdasarkan interaksi dan seterusnya mengurangkan kesilapan voltan dan ayunan dalam voltan terminal. GNFPID menala prestasi kawalan voltan yang cemerlang dengan menguji pengawal PID kabur yang dicadangkan ke atas sistem AVR praktikal dalam janakuasa segerak dengan sambutan fana diperbaiki dengan sangat ketara. Kaedah dicadangkan sesungguhnya lebih efisien dan lasak dalam yang sambutan sistem dan sambutan fana sesuatu sistem AVR. Maka dinyatakan bahawa kaedah baru ini mungkin berguna untuk pembangunan pengawal voltan sistem-sistem kuasa dalam amalan-amalan industri sebenar di bawah kesilapan yang serius.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
ANN	-	Artificial Neural Network
AVR	-	Automatic Voltage Regulator
BSNN	-	B-Spline Neural Network
CAC	-	Composite Adaptive Controller
CB	-	Circuit Breaker
CMAC	-	Cerebellar Model Articulation Controller
CUEP	-	Controlling Unstable Equilibrium Point
DAC	-	Direct Adaptive Controller
DARLA	-	Distinct Action Reinforcement Learning Automata
DC	-	Direct Current
DECS	-	Digital Excitation Systems
DPF	-	Discrete Probability Functions
DTCs	-	Direct Torque Control Schemes
FLC	-	Fuzzy Logic Controller
FLSs	-	Fuzzy Logic System
FNN	-	Fuzzy Neural Network
FSs	-	Fuzzy Sets
GA	-	Genetic Algorithm
GNFPID	-	Genetic Neural Fuzzy Proportional Integral Derivative
GUPFC	-	Generalized Unified Power Flow Controller
IAC	-	Indirect Adaptive Controller
IGA	-	Improved GA
IPMSM	-	Interior Permanent Magnetic Synchronous Machine
IT2	-	Interval Type-2

IWP	-	Inertia Wheel Setup
LE	-	Large Error
LMI	-	Linear Matrix Inequality
LQR	-	Linear-Quadratic Regulator
ME	-	Medium Error
MIMO	-	Multiple-Input–Multiple-Output
MLP	-	Multi-Layer Perceptron
MPC	-	Model Predictive Control
NA	-	Neural Algorithm
NCS	-	Nonlinear Control Systems
NN	-	Neural Network
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PLC	-	Programmable Logic Controller
PLL	-	Phase-Locked Loop
PMSM	-	Permanent Magnetic Synchronous Machine
PSO	-	Particle Swarm Optimization
PSS	-	Power System Stabilizer
RBF-NN	-	Radial-Basis Function Neural Network
RGA	-	Real-Valued Genetic Algorithm
RNNs	-	Recurrent Neural Networks
RTWEC	-	Real-Time Workshop Embedded Coder
SA	-	Simulated Annealing
SE	-	Small Error
SFL	-	Sugeno Fuzzy Logic
SFM	-	Sugeno Fuzzy Model
SLM	-	Single Linked Manipulator
SMA	-	Snake-robot-based Manipulator Actuators
SMC	-	Sliding-Mode Control
SQL	-	Structured Query Language
SOM	-	Self-Organizing Map
SPMSM	-	Surface Permanent Magnetic Synchronous Machine

T 1,T2	-	Type-1,Type-2 Fuzzy Logic
T/S	-	Transient Stability
TEB	-	Tracking-Error-Based
TGA	-	Traditional Genetic Algorithm
TLA	-	Teacher Learning, Algorithmic
T-S	-	Takuge-Sugeno
T-SFM	-	Takuge_Sugeno Fuzzy Model
TSK	-	Takagi-Sugeno-Kang
UFLS	-	Under Frequency Load Shedding
ZN	-	Ziegler Nichols

LIST OF SYMBOLS

e	-	Errors
$\dot{e}$	-	Close loop error dynamics
u	-	Control input
$\dot{x}$	-	Lyapunov stable around the operating point
$V(x)$	-	Lyapunov function
$\dot{V}$	-	Derivative of Lyapunove function candidate V
A_i	-	Linguistic variables
$f(i)$	-	Linear function
m	-	Mass
L	-	Long
$\ddot{\Theta}$	-	Angle
G	-	Ground acceleration
T	-	Dynamic model equation
$u_j(k)$	-	Individual control input for discrete time
$A_j^{'}$	-	T-S fuzzy model stable equation
K_j	-	Individual gain matrices
B	-	Common input matrix
B_j	-	Constraint matrix
μ_j^i	-	Membership function of the fuzzy
δ_j	-	Membership function percentage
δ_i	-	Position quantity
$\dot{x}(t)$	-	T-S fuzzy model
f , $h1$, $h2$	-	Norm bounds of the controllers are designed to make

		the T-S fuzzy model Lyapunov stable
c_j	-	Neural redial center
$G(s)$	-	Transfer function
K_p	-	Proportional gain of PID controller
K_d	-	Derivative gain of PID controller
K_i	-	Integral gain of PID controller
ΔV_t	-	Incremental change in terminal voltage
ΔV_{ref}	-	Incremental change in reference voltage
B	-	Weighting factor
0_{sh}	-	Overshoot
T_s	-	Settling time
T_r	-	Rising time
E_{ss}	-	Steady-state error
τ_e	-	Exciter time constant
τ_g	-	Generator time constant
τ_s	-	Sensor time constant
τ_a	-	Amplifier time constant
K_a	-	Amplifier gain
K_e	-	Exciter gain
K_g	-	Generator gain
K_s	-	Sensor gain
r	-	Rules
Ø	-	Gaussian parameter
C_j	-	Node centre
h_j	-	Gaussian form of the radial function
Γ	-	The momentum factor and
η	-	The learning rate for the neural network

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CHAPTER 1

INTRODUCTION

1.1 Overview

Improving the stability, achieving high efficiency and enhancing the voltage response of electric power system even under disturbance in real industrial situation are ever-demanding quest. The stability of power system is defined as the ability to remain in a state of operational equilibrium under normal operating conditions and to recover a suitable state of balance in the presence of a disturbance. Instabilities in the power system are caused by many different ways depending on the operating mode and system configuration. The generation of electrical power depends on synchronous machines. Therefore, an essential condition for acceptable system operation is the synchronization of power systems. The feature of stability is critically guided by the power angle relationships and the dynamics of generator rotor angles. Instability which occurs in case of large disturbances is the relative angular instability which occurs because of large disturbances that cause loss of synchronisation among machines. Instabilities may also arise because of events that do not cause loss of synchronisation with a good protection system. A system containing a synchronous generator supplying an induction motor load during transmission may become unstable because of the failure of load voltage and current (active and reactive power). It is indeed customary to analyse the stabilities of a power system subjected to transient events. These events might be weak or strong depending upon the event types [1]. The transient voltage stability in electric power systems is relatively a new domain of research and much of it are still unexplored. The voltage stability can be divided into short–term (transient), mid-term and long-term stability phenomena.The mid-term phenomena represent the transition from short-term to long-term responses. In mid-term stability studies the focus is on synchronizing power oscillation between machines including the effects of some of the slower phenomena and possibly large voltage or frequency excursions. Typical ranges of time periods are, (i) Short-term or transient: 0-10 seconds, (ii) Mid-term: 10 seconds-few minutes and (iii) Long-term: few minutes-10’s of minutes [1]. The transient stability is primarily concerned with the maintenance of synchronism for large disturbances which is our main focus. There are two types of disturbance in voltage stability, namely the small and large-disturbances. The large one concerned with the system's ability to control voltages following a large disturbance such as system faults, loss of generation or circuit’s contingencies.

Conversely, the small-disturbance voltage stability deals with the system's ability to control voltages following small perturbations such as incremental changes in system load. Many issues related to the voltage stabilities under disturbances are far from being understood due to lack of comprehensive models and careful simulation. One of the outstanding and challenging problems in this area is in the control of the voltage response with the associated severe faults, where the voltage at the terminals of the synchronous generator can drop significantly. Consequently, this temporary drop in the terminal voltage is a reduction in the all-important ability or overall efficiency to transfer synchronizing power out of the generator. Therefore, the solution to this problem is to achieve the terminal voltage return as soon as possible depending on generator’s Automatic Voltage Regulator (AVR) inside the excitation system. The essential function of an excitation system is to provide direct current to the synchronous generator machine field winding. In addition, the excitation system performs control and protective functions essential to the satisfactory performance of the power system by controlling the field voltage and field current.

The control functions include the control of voltage and reactive power flow, and the enhancement of system stability. The factors responsible for the precise control of voltage and current response need in-depth studies. The protective functions ensure that the capability limits of the synchronous machine system and other equipment are not exceeded [1]. The performance requirements of the excitation system are determined by considering the synchronous generator and the power system [1]. The basic requirement is that the excitation system supply and automatically adjusts the field current of the synchronous generator. This maintains the terminal voltage as the output varies within the continuous capability of the generator. In addition, the excitation system must be able to respond to a transient disturbance with field, forcing consistent with the generator instantaneous and short-term capabilities. From the power system viewpoint**,** the excitation system should contribute to effective control of voltage and enhancement of the system stability. It must be capable of responding rapidly to a disturbance to enhance the transient stability and also modulates the generator field to improve small-signal stability. The excitation systems are classified into three broad categories based on the excitation power source used [1]. These excitations are Direct Current (DC), Alternating Current (AC) and static structures.

The DC excitation utilizes DC generators as a source of excitation power and provides current to the rotor of the synchronous machine through slip rings. The exciter may be driven by a motor or the shaft of the generator. It may be either self-excited or separately excited. The separately excited, the exciter field is supplied by a pilot exciter comprising a permanent magnet generator. The AC excitation systems utilize alternators (ac machines) as sources of the main generator excitation power. These excitation systems of this category utilize alternators (ac machines) as sources of the main generator excitation power. Usually, the exciter is on the same shaft of a turbine generator. The AC output is rectified either by controlling or non-controlled rectifiers to produce the direct current needed for the generator field.There are two types of AC excitation systems such as stationary rectifier and rotating rectifier. The other broad category called Digital Excitation Systems (DECS) comprised of microprocessor–based control device intended for generator power management. Programmability of system parameters and regulation settings enables the DECS to be used in a wide range of application which provides greater flexibility [1] in excitation system optimization. The excitation system supply and automatically adjusts the field current of the synchronous generator and keep constant generator terminal voltage by AVR. The main objective of the AVR is to control the terminal voltage by adjusting the generator exciter voltage. The AVR must keep track of the generator terminal voltage all the time under any load condition and maintains the voltage within pre-established limits. Meanwhile, the Proportional Integral Derivative (PID) inside the AVR is responsible for the optimal control of AVR system. PID controller possesses three coefficients namely differential, proportional and integral coefficients. In most modern system, AVR is a controller that senses the generator output voltage (and sometimes the current) and then initiates corrective action by changing the exciter control in the desired direction.

Thus, the AVR plays a crucial role with respect to transient stability by attempting to maintain terminal voltage under faulty conditions. It also ensures a fast terminal voltage recovery profile after the fault is cleared under transient conditions. Determining the mechanisms responsible for transient response and speedy voltage recovery are the key issues in power systems.

1.2 Research Background

It is a prerequisite for stable electric power service to develop the AVR of the synchronous generator with a high potency and a prompt response. The foremost purpose of the AVR is to control the terminal voltage and regulate the generator exciter voltage by maintaining the stability of the generator terminal voltage all the time under any load and operating conditions. On most modern systems, the AVR is a controller that senses the generator output voltage (sometime current) and initiates corrective action by changing the exciter control in the desired direction.

These investigations concerning the improvement of the research process in the control system engineering propose different approaches to achieve better solutions.

A design method for determining the PID controller parameters of the AVR system using the real coded genetic algorithm (RGA) method has been proposed [2]. A hybrid Genetic Algorithm (GA) and bacterial foraging method has been developed to precisely tune the PID controller of an AVR [3]. The application of fuzzy system propose a replacement of the PI controller by a fuzzy logic controller to improve the transient performance of the DC link under fast load variations [4]. In another proposal a new fuzzy logic control based under frequency load shedding scheme has been implemented in mini hydro type-DG operating inislanded mode [5]. The transient stability enhancement of the power system interconnected with wind farm by Generalized Unified Power Flow Controller (GUPFC) having grid frequency switching similar multi-pulse converters has been demonstrated [6].

The performance of current hybrid fuzzy PID controller is somewhat poor and the changes in the system parameters require a new adjustable variable of PID controller. To overcome this difficulty, a hybrid system of fuzzy and fuzzy self-tuning PID controller have been developed [7]. The power system stabilizer for damping both local and global modes of an interconnected system based on the neuron fuzzy (hybrid) system has been developed [8]. An adaptive-network-based fuzzy logic Power System Stabilizer (PSS) is [9]. Propose the application of an adaptive fuzzy logic controller to both single and multi-machine power system simulation is previously reported [10]. The design and stability analysis of Takagi-Sugeno-Kang (TSK) -type full-scale fuzzy PID controller has been introduced [11].

There is a pressing need for the inclusion of on-line dynamic security assessment capabilities in energy management systems. The nonlinear time series is used to predict the transient stability of the system [12] as a possible solution. In this method, first the post-fault state trajectory is predicted with nonlinear time series forecasting algorithm and then by Controlling Unstable Equilibrium Point (CUEP) concept and kinetic and potential energies at CUEP clearing time, the transient stability of the system is assessed. A distributed computing approach for piecewise analysis of synchronous fault in Transient Stability (T/S) studies for large-scale electrical network exploitation has been reported [13]. The increasing stability related complication in power systems involve electromechanical oscillations that need to be controlled. A systematic approach to design an optimal controller to damp the electromechanical oscillations based on bioinpired GA and Particle Swarm Optimization (PSO) techniques have been proposed [14]. An emergency control scheme known as the combined Under Frequency Load Shedding (UFLS) and generator tripping has been developed in order to stabilize the system when unstable faults occurred in a power system [15]. The performance of the combined Under Frequency Load (UFL) Sand generator tripping scheme has been compared with the conventional control scheme and found to be efficient.

Computational techniques such as GA and fuzzy logic have been used for analytic solution [11, 16-18] which resulted the control field for implementing the real time manipulation based on the neural network. Furthermore, it has been established that Radial-Basis Function Neural Network (RBF-NN) has the ability to approximate any continuous function with any arbitrary accuracy [19, 20]. A tuning fuzzy logic approach to determine the optimal PID controller parameters in the AVR system by developing a fuzzy system can give the PID parameters on-line for different operating conditions [21]. A Linear-Quadratic Regulator (LQR) method has been implemented to improve the PID controller for a universal second-order system which required a good selection of weighting functions for acceptable performance [22]. An RGA and a PSO algorithm with new fitness function methods have been proposed to design a PID controller for the AVR system [23, 24].

A design method for determining the PID controller parameters of the AVR system using the PSO method has been proposed [25-27]. PSO is a population-based optimization technique, which is enthused by social performance patterns of organisms such as bird flocking and fish schooling. Undoubtedly, both GA and PSO are subjected to computational burden and memory expenses and are not appropriate for online applications. Nowadays, the most popular controller techniques are fuzzy controllers in which expert knowledge can be incorporated into the design [21, 28, 29]. Most fuzzy controllers that are used in industry have the same structure of simulated PID as incremental PD or PID controllers. The drawback of both fuzzy logic control and Lyapunov-like madman type FLC is that the parameters associated with the FLC are heuristically updated. Neural networks have been widely used in the identification, estimation, and control of nonlinear systems offline estimation.

The following conclusions are summarised in Table 1.1. A critical review is presented describing the advantages and disadvantages of the previous methods and some review to overcome much of the existing complexity by combining GA, RBF-NN, and Sugeno fuzzy logic approaches to determine the optimal PID controller parameters in the AVR system.

Table 1.1 : Critical review to describe the advantages and disadvantages of the previous methods.

Author year	**Proposed Technology**	**Advantages**	**Disadvantages**
Mohammadi 2009[30]	New evolutionary methods for optimal design of PID controllers for AVR system	Successful in providing globally optimal results, due to high efficiency and lower computation time.	Off-line computational burden and algorithm complicated
Ahmed 2006[31]	Simulated Annealing Optimized and Neural Networks Self-Tuned PID Voltage Regulator for a Single-Machine Power System	The optimization search is based on a suitable objective function.	ANN is trained off-line.
Ramya 2013[32]	Optimization of synchronous generator excitation controller parameters	Good response of the excitation controller tuning by RGA.	Computational burden and require large memory storge
Hasanien 2013[33]	Design Optimization of PID Controller in AVR system using Taguchi combined GA method	The PID controller in the AVR system minimize the swing of the terminal voltage.	The analysis of variance depends on selection of the influential design variables.
Madinehi 2011[34]	Optimum design of PID controller in AVR system using intelligent methods	Intelligent controller design in an AVR system by using two techniques.	Long controller time response.

The limitations of the existing work are the design of the novel fuzzy controller by combining GA and RBF-NN approaches in order to maintain the terminal voltage within pre-established limits and enhancing the transient response of synchronous generator under severe disturbances. The effective maintenance of the terminal voltage within pre-established limits and enhancing the transient response of the synchronous generator under severe disturbances is accomplished by using proposed fuzzy PLC controller in industrial control. This work addressing rang issues by using optimal PID gains obtained by combined GA and RBF-NN for various operating conditions are used to develop the rules based on the Sugeno fuzzy system. This algorithm effectively searches for a high-quality solution and improves the transient response of the AVR system.

1.3 Problem Statement

The transient voltage stability in electric power systems is significant and challenging issue requires to be addressed. The precise control of transient (short-term) stability primarily concerned with the maintenance of synchronism for large disturbances remains a major challenge. An important problem associated with severe faults, where the voltage at the terminals of the synchronous generator can drop significantly. The consequence of this temporary drop in terminal voltage is a reduction in the all-important ability to transfer synchronizing power out of the generator.

Therefore the solution is to get the terminal voltage back up as soon as possible. This depends on generator's AVR. The generator's AVR works through the excitation system to maintain constant generator terminal voltage.Despite some studies, the design of efficient AVR (AVR with genetic, neural and fuzzy voltage controller) system is still lacking and not much work is carried out to develop the mechanism of voltage recovery and to improve transient response in the AVR system by using the combination of genetic, neural and fuzzy technics. Thus, the AVR plays a crucial role with respect to transient stability in maintaining terminal voltage under fault conditions. The controller system also ensures a fast terminal voltage recovery profile after the fault is cleared under transient conditions.

The modern power systems are non-linear and highly complex with continuous variations in their operating conditions over a wide range. The role of nonlinearity requires further attention. Lately, the most popular controller techniques are called intelligent and are developed with expert knowledge incorporated into the design. No comprehensive model, simulation, or systematic experiments yet exist to determine the mechanism of controller response, transient voltage stability enhancements, and efficiency.

Generally, AVR controls the terminal voltage by adjusting the generator exciter voltage, while the AVR system optimal control is performed by the PID inside the AVR. The drive of the approach is to design a high-sensitivity fuzzy PID controller depending on a hybrid model by combining the GA, RBF-NN, and Sugeno fuzzy logic and insert instead of traditional PID controller (PID or lead–lag controllers) of the AVR.

A novel Genetic Neural Fuzzy Proportional Integral Derivative (GNFPID) controller is used to achieve high stability, fast response and keeps track of the generator terminal voltage continually and under any load condition. It maintains the voltage within pre-established limits for enhancing the transient response of synchronous generator under severe disturbances. A novel Genetic Neural Fuzzy Proportional Integral Derivative (GNFPID) controller is used to achieve high stability, fast response and keeps track of the generator terminal voltage continually and under any load condition. It maintains the voltage within pre-established limits for enhancing the transient response of synchronous generator under severe disturbances.

1.4 Research Objectives

The objectives of the study are the following:

i. To design novel, Fuzzy Controller tuned genetically via Genetic-Neural Algorithm (GNFPID) for improving the AVR responses.
ii. To enhance the transient stability responses for the synchronous generator voltage controller (GNFPID).
iii. To develop Simulink and experimental models of synchronous generator suitable in studying the transient stability response of the large scale power system.
iv. To compare and validate the results of novel approaches (GNFPID) with other intelligent methods such as LQR, PSO, RAG and binary-coded GA.
v. To determine the mechanism of improved transient response, voltage stability enhancements and efficiency under severe fault.

1.5 Scope of the Research

The scope of the research is as follows:

i. The GA integrated by RBF-NN has been applied to generate the optimized parameter values of the fuzzy rule base and also in tuning the associated membership function parameters.
ii. The RBF-NN is used to enhance the PID parameters obtained from GA.
iii. The enhanced PID parameters are used to design the fuzzy PID controller (GNFPID) one-time tuned by excitation parameters (K_e,τ_e) and a second time tuned by generator parameter (K_g,τ_g).
iv. The proposed GNFPID controllers are inserted in the AVR system to enhancement the transient response of the synchronous generator terminal voltages.

v. These enhancements are well investigated through the simulated results by using MATLAB.
vi. The experimental result is achieved by transfer of data design of the GNFPID controller from MATLAB to programmable logic controllers (PLC) for implementing the practical AVR system in the experimental model.
vii. Detailed analysis includes a compare-and-validate of the results of the novel approach GNFPID with other intelligent methods.

1.6 Significance of The Study

The prime focus of this research is to design and characterize an intelligent system for a synchronous generator voltage controller highly suitable for industrial AVR system application. Through the fuzzy PID controller tuned by genetic and neural-network algorithms, a modified powerful controller called GNFPID is achieved, which is further used in a synchronous generator AVR system. The transient voltage stability enhancements obtained from this novel fuzzy controller are comparable with other conventional methods. By using this novel fuzzy controller with a complete model of synchronous generator it is possible to study the transient stability response of a synchronous generator in a large-scale power system. This methodology is beneficial for improving the power system operation control in terms of their stability, generator terminal voltage and enhancing the transient response of synchronous generator.

1.7 Thesis Organization

The thesis is organized as follows:

Chapter 1 begins with a general introduction and a brief overview showing the importance and growing demand of research on the power system stability. The main objectives, problem statements, scope and significance of the research are highlighted in this chapter.

Chapter 2 deals with the literature review related to intelligent control system. The classified control methods for overall intelligent control such as fuzzy, neural and GA are reviewed at length.

In Chapter 3 the research methodology is described by incorporating relevant schematic diagrams and theory relevant to our research. The MATLAB Simulink and data transfer design from MATLAB to PLC implemented in the AVR in experimental setups are described in detail for the diagnostics and measurements.

Chapter 4 presents the simulation results and discussions on simulation based on the novel design GNFPID controller, model, and present the experimental results and discussions on implementing novel design controller GNFPID by PLC type SIMATIC IPC427C. Simulation and experimental results are compared and validated with existing conventional methods.

Chapter 5 summarizes the main findings signifying the strength of the research, major contribution, fulfillment of the objectives and a few suggestions for further work in this important research domain.

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