DYNAMIC MODEL OF DISTRIBUTION NETWORK CELL USING ARTIFICIAL INTELLIGENCE APPROACH

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Dynamic Model of Distribution Network Cell using Artificial Intelligence Approach

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LIST OF ABBREVIATIONS

AC	Alternating Current
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANN	Artificial Neural Network
CCG	Converter Connected Generator
CIGRE	International Council on Large Electric Systems
DC	Direct Current
DDPMG	Direct-Drive Permanent Magnet Generator
DER	Distributed Energy Resources
DFIG	Doubly Fed Induction Generator
DG	Distributed Generation
DNC	Distribution Network Cell
FC	Fuel Cell
FIS	Fuzzy Inference System
FL	Fuzzy Logic
FSIG	Fixed Speed Induction Generators
GUI	Graphical User Interface
HS	Harmony Search
I	Constant Current
IG	Induction Generator
IM	Induction Machine
LV	Low Voltage
MIMO	Multi Input Multi Output
MISO	Multi Input Single Output

MTG	Micro Turbine Generation
MV	Medium Voltage
P	Constant Power
PI	Proportional Integral
PMG	Permanent Magnet Generator
PMU	Synchronized Measurement Units
RMSE	Root Means Square Error
SISO	Single Input Single Output
SOFC	Solid Oxide Fuel Cell
TS	Takagi-Sugeno
UK	United Kingdom
WT	Wind Turbine
Z	Constant Impedance
ZIP	Constant Impedance, Constant Power and Constant Current

LIST OF SYMBOLS

P, Q	Active and reactive power
P_L , Q_L	Active and reactive power of the composite load model
P_G, Q_G	Active and reactive power of the converter-connected generator part
P_{ZIPO}, Q_{ZIPO}	Active and reactive power of the static ZIP model at steady state
$\widehat{P}$, $\widehat{Q}$	Active and reactive power output response from fuzzy model
δ_g	Angle between E′ and V of generator
δ_m	Angle between E′ and V of motor
ω_g	Angular frequency of generator
ω_m	Angular frequency of motor
ω_s	Angular velocity of stator
A_i	Antecedent linguistic term (constant)
V	Bus voltage
C	Capacitance
I_{dc}	Capacitor dc current
V_{DC}	Capacitor dc voltage
V_{dc}	Capacitor dc voltage
A, B, C, D	Coefficient matrices
B_i	Consequent linguistic term
P_I, Q_I	Constant current part of the ZIP model
P_Z, Q_Z	Constant impedance part of the ZIP model
P_P, Q_Q	Constant power part of the ZIP model
D	Damping factor

x1	Data from fuzzy model
T'_{dg}	D-axis time constant of generator
T'_{dm}	D-axis time constant for motor
V_{dg}, I_{dg}	D- axis voltage and current at the generator side of converter
V_{DG}, I_{DG}	D- axis voltage and current at the grid side of converter
$\varepsilon(\theta)$	Error
$\varepsilon_P(\theta)$, $\varepsilon_Q(\theta)$	Error for active and reactive power
E_{FD}	Excitation voltage
ω_i	Firing strength
f	Frequency
f(x), g(x)	Functions
$\mathcal{R}_i$	Fuzzy if-then rule
H_g	Inertia of generator
H_m	Inertia for motor
$\tilde{x}$	Input (antecedent) linguistic variable
x_f	Input crisp variable
u	Input vector
$\bar{y}$	Mean of y_m
P_m, Q_m	Measured active and reactive power
y_m	Measured output
T_m	Mechanical torque
$\mu_{B'}$	Membership degree for fuzzy set B'
V_o	Nominal bus voltage
$\bar{\omega}_i$	Normalized firing strengths

$\tilde{y}$	Output (consequent) linguistic variable
f_i (x)	Output function
O_i^1	Output layer 1
O_i^4	Output layer 4
y_i	Output linguistic variable
y	Output vector equation
V_{qg}, I_{qg}	Q- axis voltage and current at the generator side of converter
V_{QG}, I_{QG}	Q -axis voltage and current at the grid side of converter
X_g, X_g'	Reactance and transient reactance of generator
X_m, X_m'	Reactance and transient reactance of motor
K_q	Scaling factor
P_s, Q_s	Simulated active and reactive power
$\hat{y}$	Simulated model output
x	State vector
$\dot{x}$	State vector equation
F	The number of elements
p_i, q_i, r_i	The parameter set
n	Total number of data
x2	Training data
V	Voltage
E_g'	Voltage behind the transient reactance of generator
E_m'	Voltage behind the transient reactance of motor

Model Dinamik Sel Rangkaian Pengagihan menggunakan Pendekatan Buatan Kecerdasan

ABSTRAK

Tujuan projek ini adalah untuk membangunkan model dinamik sel rangkaian pengagihan (DNC) dengan menggunakan pendekatan buatan kecerdasan. Peningkatan jumlah teknologi janaan teredar (DG) telah membawa kepada kesukaran dalam pemodelan model DNC. Pemodelan beban mudah tidak lagi boleh dipercayai dalam membentangkan model DNC. Dalam projek ini, model setara dinamik bagi DNC adalah terdiri daripada penjana penukar berkaitan dan model beban komposit. Model ini telah dibangunkan dalam bentuk ruang keadaan tujuh susunan. Model ini diambil daripada Samila Mat Zali pada tahun 2012. Anggaran parameter bagi model ini telah dibangunkan menggunakan sistem kabur. Nilai parameter telah dikemaskini melalui penyesuaian sistem kesimpulan neuro-kabur (ANFIS). Sambutan kuasa aktif dan reaktif daripada model kabur telah dibandingkan dengan sambutan daripada model penuh DNC untuk pelbagai jenis gangguan. Sambutan model penuh DNC telah diperolehi dari model rangkaian pengedaran UK 11 kV. Model ini telah dibina menggunakan perisian DigSILENT PowerFactory. Sambutan daripada model penuh DNC juga telah diambil dari Samila Mat Zali pada tahun 2012. Prestasi model kabur telah disahkan dengan mengira nilai ralat punca min kuasa dua (RMSE) dan nilai penyuaian terbaik. Prestasi model kabur juga dibandingkan dengan model pengenalpastian sistem, yang telah dilakukan oleh Samila Mat Zali pada tahun 2012. Keputusan menunjukkan bahawa model kabur lebih ringkas kerana hanya beberapa parameter sahaja yang terlibat dalam membangunkan model yang sama. Keringkasan ini dicerminkan dalam masa pengiraan yang rendah. Kecekapan juga baik berdasarkan nilai RMSE yang rendah dan nilai penyuaian terbaik yang tinggi. Kesimpulannya, model setara dinamik bagi DNC berdasarkan pendekatan sistem kabur telah berjaya membangunkan.

Dynamic Model of Distribution Network Cell using Artificial Intelligence Approach

ABSTRACT

The aim of this project is to develop a dynamic model of distribution network cell (DNC) using artificial intelligence approach. The increasing number of distributed generation (DG) technology has lead to difficulty in modeling the DNC model. The simple load modeling is no longer reliable in presenting the DNC model. In this project, the equivalent dynamic model of DNC consists of the converter-connected generator and the composite load model. The model was developed in the form of seven order state-space model. This model was adopted from Samila Mat Zali in 2012. The parameter estimation of the model was developed using fuzzy system. The parameter value was updated through adaptive neuro-fuzzy inference system (ANFIS). The active and reactive power responses from the fuzzy model were compared with the response from the full DNC model at various types of disturbances. The response of full DNC model was obtained from the UK 11 kV distribution network model. The model was built in DigSILENT PowerFactory software. The full DNC model was also adopted from Samila Mat Zali in 2012. The performance of the fuzzy model was validated by calculating the value of root means square error (RMSE) and the best fit value. Later, the performance of the fuzzy model was also compared with the system identification model by Samila Mat Zali in 2012. The results obtained shown that the fuzzy model was more simple as only a few parameters involved in developing the equivalent model. This simplicity was reflected in the low computational time. The efficiency was also good based on the low RMSE value and high best fit value. In conclusion, the equivalent dynamic model of DNC based on fuzzy system approach was successfully developed.

CHAPTER 1

INTRODUCTION

1.1 Background

An electricity distribution network is the final stage in the delivery of electricity to end users. A distribution system's network carries electricity from the transmission system. The transmission system enables the bulk transfer of electrical energy from generated by power plants to electrical substations located near demand centers. The combined transmission and distribution network is known as the power grid.

The conventional power system is currently faced with three problems which are gradual exhaustion of fossil fuel resources, poor energy efficiency and environmental pollution. In order to counter these problems, power is generated locally at distribution network by using non-conventional or renewable energy sources, to cope with the energy demand. According to the Global Status Report 2007, about 18.4% of the final global energy consumption came from renewable energy sources in 2006, with 13% coming from traditional biomass, which is mainly used for heating, 3% from hydroelectricity and other 2.4% accounted from new renewable energy sources like small hydro, modern biomass, wind, solar, geothermal, and bio fuels (M. S. Ali, et. al., 2011). The distributed generation (DG) approach allows the use of new renewable energy sources.

DG is small-scale energy generation that created the electricity closer to the customers who use it. There are many types of DG sources, including smallhydroelectric power, wind energy, biomass energy, solar energy, and geothermal energy. Most DG relies on a generator, which is used to convert mechanical energy into electrical energy. Many types of generators are used in DG technologies, such as the synchronous generator, the induction generator, and the doubly fed induction generator.

There are many advantages to DG, including high reliability and power quality, particularly when combined with energy storage. Besides, using DG can lower our energy bill because the generators are closer to the load. DG also uses smaller plants, which may reduce construction time and investment cost. Since DG runs on renewable energy, it can minimize environmental impact and may reduce emissions. The requirement of DG in distribution networks increasing rapidly since DG has many advantages.

The rapid growth of DG has created many challenges to the distribution network structure. When DG became connected to the distribution network, simple equivalent load modeling was no longer reliable for creating distribution network cell (DNC) models. This leads to increasing difficulty in modeling the distribution network for system dynamics studies, especially the modeling of various distribution networks' components in detail. The detailed data for the components of the distribution network is not always available. This lack of component data and the increase in network complexity limit the applicability of the conventional methodology for development of dynamic equivalents of the distribution network.

Therefore, there is a need for new modelling tools and equivalent models for distribution networks that represent the behaviour of the network at the point of connection accurately, without significantly increasing computational effort. In particular, the new tools and models need to handle the increased complexity of the distribution network, caused by the increasing penetration of various types of DGs, effectively. New tools and simulation approaches are required to address this subject and to quantify the dynamic characteristics of the system.

In this project, the equivalent dynamic model of a distribution network cell was developed using artificial intelligence approach. The equivalent dynamic model consists of a converter connected generator and composite load model. The model is constructed in the form of nonlinear seventh order state-space model. The outputs for this model are active and reactive power, which is based on voltage input frequency as the input. A parameter estimation procedure was conducted. The parameter estimation procedure was done in order to get the best value for the unknown parameters of this dynamic model. This procedure was developed using an artificial intelligence approach based on fuzzy system. The updated parameters value is obtained using Adaptive Nuero-Fuzzy Inference System (ANFIS). After that, the output responses of the developed model in a fuzzy system was compared with the measured responses from the full distribution network in order to evaluate the performance of the equivalent dynamic model of DNC. The comparison was made by calculating the value of Root Means Square Error (RMSE) and best fit value.

1.2 Problem Statement

Previously, distribution networks were considered as passive DNC, which are designed to accept bulk power from transmission systems and distribute it to customers. When, DNC is connected with DG, it cannot be considered a passive DNC anymore. A distribution network in which DG units are connecting to the grid is called an active Distribution Network Cell (DNC). According to CIGRE definition (CIGRE Working

Group C6.11, 2011), active DNC is a system put in place to control a combination of distributed energy resources (DER), mainly generators, loads and storage.

Therefore, in the future it will not be possible to use a simple equivalent load model in developing the DNC model for power system dynamics studies since DG acts as a generator, but at the same time it must be considered as a load. Simple equivalent load modeling is no longer reliable in representing the dynamic characteristics of the network. A need for new tools and simulation approaches are required to quantify the dynamic characteristics of the system.

1.3 Project Objective

The rapid increase in DG technologies in distribution networks has created a challenge in modeling DNC. In this project, a dynamic equivalent model of DNC was developed using artificial intelligence approach. There are three objectives that were followed in order to develop the model, which are:

i. The first objective is to develop an equivalent dynamic model of the DNC using an artificial intelligence approach. A dynamic model of a DNC consists of converter-connected generator and a composite load model. The model was developed in the form of nonlinear seventh order state-space model.

ii. The second objective is to develop parameter estimation using fuzzy approach. Parameter estimation is the process used to obtain the best value for the unknown parameters of the equivalent dynamic model of the DNC.

iii. The last objective is to validate the dynamic equivalent model of DNC in large power systems stability studies under small and large disturbances. The performance of the equivalent model should be demonstrated by comparing the output responses of the develop model with the measured responses from the full DNC model.

1.4 Scope of Project

This project scope aimed to develop an equivalent dynamic model of the DNC using artificial intelligence approach. An equivalent dynamic model of DNC consists of a converter-connected generator and a composite load model. The model was developing using a nonlinear seventh order state-space model. This model was adopted from research by Samila Mat Zali in 2012.

Then, parameter estimation procedure was used in order to get the best value for an unknown parameter model. A fuzzy system was chosen as the parameter estimation method because it has a faster dynamic response. First, the model was developed in a fuzzy system using MATLAB software, then the parameters were updated using the ANFIS. After getting the best values for the unknown parameter model, output responses from the developed equivalent model of DNC in a fuzzy model was compared with the measured responses from the full DNC model in order to evaluate the performance of the equivalent dynamic model of DNC. The response from full DNC model was also adopted from Samila Mat Zali in 2012. The RMSE and best fit value was calculated to observe the performance of the equivalent model.

1.5 Report Outline

This report organized in five chapters for the whole study, in modelling the equivalent dynamic model of DNC using artificial intelligence approach.

In Chapter 1, the introduction of this project is discussed in detail. The problem statements are mentioned in this chapter. The project objectives are then discussed as guidelines for this research. The scope of the project in modelling the equivalent dynamic model of DNC in MATLAB software is described.

Chapter 2 presents about the literature review for this project. It includes a study on modelling of loads, generators and dynamic model of distribution network cell. From the review of past works, it was discovered that there was no research on developing artificial intelligence approaches like fuzzy system and ANFIS in modelling the of the DNC dynamic model. This project is aimed to accomplishing that.

The methodology and scheme used in developing the model is discussed in Chapter 3. There is a step-by-step explanation on the development of the equivalent dynamic model of DNC. The parameter estimation procedure also discussed here. The process used for validation of the model also stated in this chapter.

Chapter 4 contains the results and analyses. The best values of the parameters obtained are presented here. It also includes the graphical comparison between the response of DNC fuzzy model and full DNC network model. The performance of the developed equivalent model was evaluated for different disturbance, various fault locations and different network configurations. The validation results are presented in this chapter. The validation was done by calculating the root means square error (RMSE) and best fit value. This chapter also includes the comparison result of RMSE and best fit value between the developed fuzzy model and the system identification model by Samila Mat Zali, 2012. The comparison was performed in order to assess the effectiveness of the developed fuzzy model.

Finally, the conclusion is presented in Chapter 5. The research process is summarized, as well as the performance of the equivalent DNC model in fuzzy. The recommendations for this project which are important for the future work are also listed here.