DYNAMIC MODEL OF DISTRIBUTION NETWORK CELL USING SYSTEM IDENTIFICATION APPROACH

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Dynamic Model of Distribution Network Cell Using System Identification Approach

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LIST OF ABBREVIATIONS

AC	Alternating Current
ANN	Artificial Neural Network
CCG	Converter Connected Generator
CCT	Critical Clear Time
CKHT	Continuous Kernel Hough Transforms
DC	Direct Current
DDPMG	Direct-Drive Permanent Magnet Generator
DFIG	Double Fed Induction Generator
DFIGWT	Double Fed Induction Generator Wind Turbine
DG	Distributed Generation
DMS	Distribution Management System
DNC	Distribution Network Cell
DNO	Distribution Network Operator
FSIG	Fixed Speed Induction Generator
FSWT	Fixed-Speed Wind Turbine
IG	Induction Generator
PM	Permanent Magnet
PWM	Pulse Width Modulation
RES	Renewable Energy Sources
WT	Wind Turbine

LIST OF SYMBOLS

A, B, C, D	Coefficient of the state space matrices
C	Capacitance
E_g'	Voltage behind the transient reactance of generator
E_m'	Voltage behind the transient reactance of motor
H_g	Inertia of generator
H_m	Inertia for motor
$H(s)$	Transfer function equation
I	Identity matrix for transition matrix
I_{dc}	Capacitor dc current
K_q	Scaling factor
$P_G,\ Q_G$	Active and reactive power of the converter-connected generator part
$P_I,\ Q_I$	Constant current part of the ZIP model
$P_L\ ,\ Q_L$	Active and reactive power of the composite load model
P_m	Mechanical power
$P_P,\ Q_Q$	Constant power part of the ZIP model
$P_Z,\ Q_Z$	Constant impedance part of the ZIP model
P_{ZIPO}, Q_{ZIPO}	Active and reactive power of the static ZIP model at steady state
T_{dg}'	d-axis time constant of generator
T_{dm}'	d-axis time constant for motor
T_m	Mechanical torque

$U(s)$	Input vector of transfer function
V	Bus voltage
V_{DC}	Capacitor dc voltage
V_{DG}, I_{DG}	d- axis voltage and current at the grid side of converter
V_o	Nominal bus voltage
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
V_r	Rotor voltage of generator
$X_g,\ X_g'$	Reactance and transient reactance of generator
$X_m,\ X_m'$	Reactance and transient reactance of motor
$Y(s)$	Output of transfer function
δ_g	Angle between E' and V of generator
δ_m	Angle between E' and V of motor
ω_g	Electrical speed of generator
ω_m	Angular frequency of motor
ω_s	Angular velocity of stator

Model Dinamik Untuk Sel Rangkaian Pengagihan Dengan Menggunakan Pendekatan Sistem Pengenalpastian

ABSTRAK

Penjanaan berpusat biasanya diistilahkan sebagai rangkaian pasif. Kini, penyambungan penjanaan teragih (DG) ke penjanaan berpusat ini telah mengubah perspektif rangkaian pasif menjadi rangkaian kuasa aktif. Penyambungan DG ini kepada rangkaian pengagihan juga dikenali sebagai Sel Rangkaian Pengagihan (DNC) aktif. Walau bagaimanapun, DNC aktif ini biasanya mempunyai had-had kerana kekangan masa hitungan dan mempunyai dimensi sistem rangkaian yang besar. Model dinamik DNC aktif menyediakan penyelesaian bagi had ini kerana ia menawarkan perwakilan sistem tanpa kuasa yang mudah tanpa mengubah ciri-ciri dan tingkah laku dinamik DNC. Oleh itu, kajian ini bertujuan untuk membangunkan model DNC aktif yang mewakili ciri-ciri dinamik rangkaian pengagihan. Pembangunan model yang dibentuk menggunakan pendekatan Sistem Pengenalpastian. Model yang digunakan dalam kajian ini adalah terdiri daripada model fungsi pindah yang mempunyai lapan belas parameter. Model fungsi pindah ini terdiri daripada gabungan penjana aruhan dua suapan sebagai model penjana dan model beban komposit. Model beban komposit ini terdiri daripada galangan malar, arus malar dan kuasa malar (ZIP) sebagai beban statik dan motor aruhan sebagai beban dinamik. Model yang dibangunkan kemudian dirumuskan di bawah rangka kerja sistem pengenalan sebelum prosedur penganggaran parameter dijalankan. Prosedur penganggaran parameter dilaksanakan menggunakan perisian MATLAB dengan mengambil kira masukan (V, f) dan keluaran (P, Q). Prosedur penganggaran parameter ini dinilai melalui nilai sepadan terbaik model fungsi pindah yang dibangunkan. Akhir sekali, prestasi model yang dibentuk di nilai melalui kerosakan tiga fasa ke bumi pada kedudukan yang berbeza seperti di Bus 1, 2, 3, 4 dan Bus 5 untuk kajian gangguan kecil dan besar. Perbandingan graf dilaksanakan bertujuan untuk menilai perbandingan bagi nilai sepadan terbaik daripada model fungsi pindah. Model fungsi pindah pada asalnya mempunyai lapan belas parameter. Keputusan daripada kajian menunjukkan terdapat empat parameter yang mempunyai nilai-nilai sifar bagi semua kes kajian. Daripada penyiasatan, ia membuktikan bahawa empat parameter ini tidak terlibat dalam prosedur anggaran parameter. Oleh itu, empat parameter yang mempunyai nilai sifar ini boleh diabaikan dan model asal fungsi pindah boleh dibentuk semula dengan mengurangkan parameter model fungsi pindah baru kepada empat belas parameter sahaja.

Dynamic Model of Distribution Network Cell Using System Identification Approach

ABSTRACT

The centralised generation is generally a passive network. The interconnection of distributed generation (DG) to this centralised generation have changed this passive network perspective to become an active power network. This DG interconnected to distribution network is also called active Distribution Network Cell (DNC). However, this active DNC normally has limitations because of computational time constrains and huge dimensions of the network systems. The dynamic model of this active DNC provides a remedy for these limitation since it offers a simple representation of the system without effecting the DNC dynamic characteristics and behavior. Thus, this research aims to develop an active DNC model that represents the dynamic characteristics of the distribution network. The model development deployed the System Identification approach. The model used in this research is a transfer function model which has eighteen parameters. The transfer function model is comprised of double-fed induction generator as the generator model and for the load part, the composite load model is used which contains the static constant impedance, constant current and constant power (ZIP). This ZIP is combined with the induction motor as dynamic load. The developed model then formulated under system identification framework before the parameter estimation procedure is conducted. The estimation procedure used is the nonlinear least square optimisation and was conducted in MATLAB software which considered the input (V, f) and output (P, Q). The parameter estimation procedure evaluation is considered by the best fit values of the transfer function model. Lastly, the performance of developed equivalent model is evaluated under three phase to ground fault at different fault such as Bus 1, 2, 3, 4 and Bus 5 for small and large disturbance studies. The graphical comparison of the estimated responses and measured responses are done using the best fit values. The original transfer function model has eighteen parameters. The results indicated there are four parameters that have zero values for all cases studies. From investigation, it is proven that these four parameters are not involved in parameter estimation procedure. Thus, these four zeroes parameter can be ignored and the original transfer function model can be reconstructed to a new reduced transfer function model which has only fourteen parameters.

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, the environmental pollution has become a major concern in people daily life and a possible energy crisis has led people to develop new technologies for generating clean and renewable energy. As one of the most recently used power generation system, distributed generation (DG) is highly expected to contribute in the future use of electricity since most of DG are using renewable energy sources. The interconnection of a large and massive scale of distributed generation nowadays is according to its important and crucial role in the development of future power grid. From engineering point of view, the control, high efficiency and grid integration techniques are the most cutting-edge research and developments for this new system.

This increasing penetration of distribution generation has resulted in different views of distribution network and gives an opportunity to introduce a new concept and approach in distribution power system. In distribution network, as a result of integration of DG, the active Distribution Network Cell (DNC) system will be much complex with addition of new technology devices being applied. Thus, the development of operation and control stategies for the distribution network is rapidly increased.

In power system dynamic studies, typically the distribution network is represented by simple equivalent load model. This simple equivalent load model is widely used in large power systems. However, the increasing of DG interconnections with this large power system at distribution network level has change the reliability of this simple equivalent load model. The future of power system network is now dependent on new and more reliable techniques to operate and control this new concept of power system. Thus, there is a need for a new modelling technique to develop an equivalent model that represents this new type of power system concept without significantly increasing the computational effort.

1.2 Problem Statement

Nowadays, the power distribution system required a fast and systematic network in order to quickly estimate the impact of disturbances on power system dynamic response and behavior. The distributed generation (DG) units which are normally connected to the grid are the crucial way to achieve the requirement for this power distribution network. The model of distribution network for these DG units that also called active Distribution Network Cell (DNC) has a huge potential in future to be widely used. However, there are limitations in modeling the active DNC because of computational time constrains and huge dimensions of the network systems. Thus, the development of the equivalent dynamic model of active DNC is extremely important in order to achieve nowadays power system requirements.

1.3 Objectives

The modelling of active DNC required a new method and approach resulted from increased complexity in power system network due to DG additions in distribution networks. Thus, the main aim for this research is to develop an active DNC model that represents the dynamic characteristics of the distribution network. Therefore, to achieve this aim, the following objectives must be completed:

i. To develop a dynamic equivalent model of active distribution network cell (DNC).
ii. To investigate the values of model parameters using non-linear least square optimisation and best fit value.
iii. To validate the performance of the developed equivalent model.

1.4 Scopes of Work

The scope of work for this project is to develop an equivalent dynamic model of distribution network cell by using system identification approach. The model is developed based on converter connected generator with composite load model. The model is developed using a linear state space model adopted from research by Samila Mat Zali in 2012. The state space model is then converted into transfer function model.

After completed with the model, the parameter estimation procedure was used to obtain the best value for the unknown parameters in the model. The transfer function estimation using System Identification Toolbox in MATLAB software is used to achieve desired values for the parameters. The last step is to evaluate the performance of the developed model through a case study network for various system configurations and topologies.

1.5 Outline of the Dissertation

This dissertation is organized in five chapters as follows:

Chapter 1: Introduction

This chapter presents the general information of the dissertation. The overview and background about the distribution network cell and the need for active DNC dynamic model are explained in this chapter. The scope for conducting the project and the organization of this dissertation are also included in this chapter.

Chapter 2: Literature Review

In this chapter, the overview and theories of several fields involved in this project will be discussed. The related past works about this dissertation title is also presented in this chapter. Theoretical explanation for distribution network cell and comparison between active DNC and passive DNC is presented. Modelling for DNC is briefly discussed together with the load modelling types. System identification theory about black-box, white-box and grey-box is stated, and the theory for power system generator type and function is also discussed. At the end of this chapter, an overview about the common technique used for parameter estimation is presented.

Chapter 3: Methodology

This chapter covers the procedures and approaches used in conducting this research. This chapter starts with further explanation about the procedures in developing the dynamic model of active DNC. It includes the load modelling part, the generator modelling and the transfer function modelling of active DNC. Furthermore, the parameter estimation technique used in the simulation is explained. It follows by system identification methods and procedures.

Chapter 4: Result & Discussions

This chapter presents the results and discussions for the performance of the developed model based on a case study network. The model performance is validated for different disturbances, various fault locations and different network topologies.

Chapter 5: Conclusion & Recommendation

Overall conclusion about the conducting this project and recommendation for future works are presented in this last chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The distribution network cell is typically a combination of very complex system, containing generation parts, loads, and the transmission lines. The evaluation for all these systems normally required a very complex calculation and consumed a lots of time. The modelling of distribution network cell is one of the approaches that can be applied to evaluate the performance of this distribution network cell. Although modelling of distribution network cell is a mature topic with a lot of significant research and efforts, the interest for this matter is kept on expanding. This situation is fuelled by the appearances of new, non-conventional types of loads and requirement to operate a modern electric power networks with the penetration of many types of generation and power electronic devices in secure and effective manner.

2.2 Review of Past Work

The distribution network cell is using a variety of massive technology and approach. The development of dynamic model for this distribution network cell allows researchers to solve many problems on power system stability. This dynamic model is normally used in simulating transient rotor angle stability for both synchronous and induction machines. The synchronous generator is considered the most used electrical generator machine worldwide (Soroudi, et. al., 2010). But recently, the induction machines are widely used for wind based power system. Most of the research and development of this dynamic model using induction machines as a generator is actively being done recently (Short, 2004).

2.2.1 Dynamic Equivalent Model in Power Systems

Network modelling and connectivity analysis is one of the techniques being used in power system network to avoid a vast number of dummy stations and dummy buses in building distribution network database, and make the users to define the radial network easily and visually (Chen, et. al., 1998). In real project, these approaches are proven to be flexible and efficient. The distribution management system (DMS) is one of the examples where this network modeling and connectivity analysis techniques can be applied (Chen, et. al., 1998).

In 2007, Aleksandra Krkoleva *et al.* have studied a characteristic response of distribution network cell based on the effect of cell structure and configuration which have been classified as groups having similar voltage, and the corresponding power responses are identified qualitatively, for both external and internal fault, with the emphasis on the influence of cell structure and composition (Krkoleva, et. al., 2007). As result, they have identified that the cases with higher DG penetration have shorter recovery times following internal and external disturbances and allow for higher share of dynamic loads in the DNC. Moreover, regardless of DG penetration and generation mix, voltage at supply bus in case of DNC with pure static loads always recovers to its pre-disturbance value.

The research on characteristic of distribution network cell is continued by Mu Wei and Zhe Chen in 2011. They have stated that the distribution generation system is more vulnerable to frequency and voltage disturbances due to the smaller inertia feature of the DG generators. Therefore, they have investigated the characteristic of distribution generation system respectively from wind turbine power plants including its loads. The comparison between two type of wind turbine which is Fixed-Speed Wind Turbine (FSWT) and the Double Fed Induction Generator (DFIG). In these studies, they found that the FSWT is more sensitive on load shedding with different loads characteristic compared to DFIG (Wei and Chen, 2011).

Mao Yanbin *et al.* in 2010 have suggested that the interconnection of large-scale distributed generation with power grids brings about significant impacts on the grid patterns, the topologies and the network performances of the future power grids (Mao, et. al., 2010). He had analyzed and verified some existing statistical indices used in bulk power grids and proposed some basic principles for the research on the impacts of distributed generation on the topological characteristics of power grids (Mao, et. al., 2010).

The studies in dynamic equivalence of distribution networks were also being done by X. Feng, Z. Lubosny and J. Bialek in 2006. In this research, it proposed that a proper equivalence method is supposed to maintain the main dynamic characteristic of power system whilst optimally reduce the size of the system. They have focused on deriving the dynamic equivalent of distribution network and in the same time, taking distributed generator into consideration. In these studies, the researchers found that this equivalent method is very useful for deriving a network with high complexity and unknown structure (Feng, et. al., 2006).