HARMONIC MODELING IN POWER DISTRIBUTION SYSTEM USING TIME SERIES SIMULATION

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requirements for the award of the degree of
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Specially dedicated to my beloved parents, husband
and for those who have
encouraged, guided, supported and inspired me

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ABSTRACT

Harmonic distortion is one of the major power quality concerns. The non-linearity of customer loads caused the occurrence of harmonic distortion that leads to degradation of power system components. Therefore, harmonic studies have become an important part in power system modeling, simulation and analysis. The needs for harmonic modeling and simulation are to determine the existence of dangerous resonant conditions and to verify that the distortion level complies with the standard harmonic limits. This research is to model time-series harmonic analysis. An integration of Open Distribution System Simulator (OpenDSS) with Microsoft Visual C++ and Microsoft Excel into an application for time-series simulation control is presented. Harmonic power flow analysis is performed by using OpenDSS interfaced with C++ to simulate the time-series simulation. The impact of practical harmonic loads measured from commercial, industrial and residential sectors on different distribution network systems are investigated. Two test case studies, with and without harmonic loads are modeled to show the usefulness of time-series simulation. IEEE test feeder and practical power distribution system are used as the test system for both case studies. The impact of harmonics on the test systems is studied by using the measured harmonic data obtained from logging sites. The simulation results were compared with the standard harmonic limits to ensure the compliance of distortion levels. Simulation results obtained show that total harmonic distortion has a significant effect on the losses of the system, mainly on the lines, cables and transformer losses. The losses of the system with harmonics for both types of the test system showed an increment compared to the system without harmonics. Hence, this proves that when harmonics exist within the system, losses increase. Based on the simulation results acquired using the developed application, the system losses and the level of harmonic distortions in the electric power distribution network are easily obtained for each interval of time-series. The developed application saves computational time as well as providing a method that is cost effective.

ABSTRAK

Herotan harmonik merupakan salah satu daripada masalah utama kualiti kuasa. Ketidaklurusan beban pelanggan telah menyebabkan berlakunya herotan harmonik yang membawa kepada kerosakan komponen sistem kuasa. Oleh itu, kajian harmonik telah menjadi penting dalam permodelan sistem kuasa, simulasi dan analisis. Keperluan untuk permodelan dan simulasi harmonik adalah untuk menentukan kewujudan keadaan resonan berbahaya dan untuk mengesahkan bahawa tahap herotan mematuhi had piawaian harmonik. Penyelidikan ini adalah untuk memodelkan analisis siri masa harmonik. Integrasi OpenDSS dengan Microsoft Visual C++ dan Microsoft Excel kepada satu aplikasi kawalan simulasi siri masa telah dibentangkan. Analisis aliran kuasa harmonik telah dilakukan menggunakan OpenDSS dengan C++ untuk simulasi siri masa. Kesan beban harmonik praktikal yang diukur dari sektor komersil, perindustrian dan perumahan pada sistem rangkaian pengagihan yang berbeza dikaji. Dua kes kajian, dengan beban harmonik dan tanpa beban harmonik dimodelkan untuk menunjukkan kegunaan simulasi siri masa. Sistem rangkaian IEEE dan sistem pengagihan kuasa praktikal digunakan sebagai sistem ujian untuk kedua-dua kajian kes. Kesan harmonik ke atas sistem ujian dikaji dengan menggunakan data harmonik yang diperolehi. Keputusan simulasi dibandingkan dengan had piawaian harmonik untuk memastikan kepatuhan tahap herotan tersebut. Keputusan simulasi yang diperolehi menunjukkan bahawa jumlah herotan harmonik mempunyai kesan ke atas kehilangan kuasa sistem, terutama pada talian, kabel dan pengubah. Kehilangan kuasa sistem dengan harmonik untuk kedua-dua jenis sistem ujian menunjukkan peningkatan berbanding dengan sistem tanpa harmonik. Maka, ini membuktikan apabila harmonik wujud di dalam sistem, kehilangan kuasa meningkat. Berdasarkan kepada keputusan simulasi yang diperolehi menggunakan aplikasi yang telah disiapkan, kehilangan kuasa sistem dan tahap herotan harmonik dalam rangkaian pengagihan kuasa elektrik mudah diperolehi untuk setiap selang siri masa. Aplikasi yang dibangunkan menjimatkan masa pengiraan dan juga menyediakan satu kaedah yang kos efektif.

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LIST OF ABBREVIATIONS

COM	-	Component Object Model
DC	-	Direct Current
DLL	-	Dynamic Link Library
EHV	-	Extra High Voltage
EMTDC	-	Electromagnetic Transients for Direct Current
EPRI	-	Electric Power Research Institute
FFT	-	Fast Fourier Transform
HV	-	High Voltage
HVDC	-	High Voltage Direct Current
IEC	-	International Electrotechnical Commission
IEEE	-	Institute of Electrical and Electronics Engineers
MV	-	Medium Voltage
OpenDSS	-	Open Distribution System Simulator
PCC	-	Point of Common Coupling
PSCAD	-	Power System Computer Aided Design
PSS	-	Power System Simulator
PV	-	Photovoltaic
SMPS	-	Switch Mode Power Supplies
THD	-	Total Harmonic Distortion
THDI	-	Total Harmonic Distortion of Current
THDV	-	Total Harmonic Distortion of Voltage
TNB	-	Tenaga Nasional Berhad
UPS	-	Uninterruptible Power Supplies
VAR	-	Volt Ampere Reactive
VFD	-	Variable Frequency Drives
XLPE	-	Cross Link Polyethylene

LIST OF SYMBOLS

θ	-	Angle
π	-	Pi = 3.142
f	-	Frequency
h	-	Harmonic order
I	-	Current
L	-	Inductance
R	-	Resistance
V	-	Voltage
Y	-	Admittance matrix

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CHAPTER 1

INTRODUCTION

1.1 Background

The use of electrical energy is a natural part of life in developed countries all around the world. Electrical energy is used in every aspect of living, working and travelling, and in any sector such as residential, commercial, and industrial. Nowadays, the use of energy efficient equipment that consist of power electronic devices increases rapidly in our country, as saving of electrical energy is the main target of industrial consumer and also electric utility companies. Before, the utilization of energy efficient equipment was not in a major scale. Now, due to modern developments, the equipment became easily available. Their reliability has improved, and cost becomes manageable. Therefore, the use of this equipment grew rapidly and its utilization increased. Consequences of large usage of these equipment, is that it gives rise to the harmonic distortions on the electrical power system and pollutes the system. Harmonic is one of the major power quality problems. Harmonic causes the voltage and current waveform of the system to distort, which will lead to the degradation of all the system components. Therefore, it is very much needed to model the power distribution system components with the consideration of harmonic penetration.

1.2 Objectives

The objective of this research is to model and analyze harmonic analysis time-series by using simulation utilizing Open Distribution System Simulator (OpenDSS). The overall objectives are as follows:

i. To develop an integrated application of time-series simulation control using OpenDSS with Microsoft (MS) Visual C++ and Microsoft (MS) Excel.
ii. To validate the power flow simulation results of OpenDSS using Power System Simulator (PSS) Adept, which is used by the industry such as Tenaga Nasional Berhad (TNB).
iii. To investigate the impact of practical harmonic loads measured from commercial, industrial and residential sectors on different distribution network systems.

1.3 Scopes

The scopes of this research can be summarized as follows:

i. OpenDSS is used to model and simulate the power system for harmonic analysis.
ii. The time-series simulation is performed using OpenDSS by utilizing the measured harmonic data obtained from industrial, commercial and residential sectors.
iii. IEEE test system and practical distribution network system are used as distribution system model to study the harmonics impact.
iv. MS Visual C++ interfaced with OpenDSS is used for custom control for the time-series simulation.
v. MS Excel interfaced with OpenDSS is used for data exchanging interface for input and output data.
vi. PSS Adept is used to validate the power flow solution of OpenDSS simulator tool.

1.4 Problem Statement

Harmonic distortion is one of the major power quality concerns for electric utility companies and consumers. The non-linearity of customer loads caused the occurrence of harmonic distortion in the power system. The increasing use of nonlinear loads being connected to the power system network had magnified the power quality problems. Distortion of sinusoidal current and voltage waveforms due to harmonics cause increases in system losses, possible equipment loss of life, over currents or over voltages resulting from resonances and interference in the communication system. This concern has drawn much attention from utilities, manufacturers of equipment and users.

Harmonic studies have become an important part in power system modeling, simulation and analysis. The need for harmonic modeling and simulation is to be able to model and simulate power quality phenomena. Besides that, the existence of dangerous resonant conditions can be determined and the distortion level can be verified to comply with the standard harmonic limits.

Simulator tool for power system components are also important not only for calculating power quality indices but also for understanding the propagation characteristics of the disturbance. The selection of a simulator tool depends on the problems to be analyzed. The simulator selection should commensurate with the accuracy of the available data parameters within the simulator tools. Therefore, it is important to understand the algorithms used by the tools in order to have better ideas with respect to the impact of model complexity and accuracy on the solution results.

The problem that this research aimed to solve is the application of time-series simulation of harmonic analysis utilization to real network practices. This application presented an integration of OpenDSS with MS Visual C++ and MS Excel for time-series simulation. OpenDSS definitely has the capabilities to perform power flow analysis as well as harmonic analysis solution. However, harmonic analysis can only provide the solution for one snapshot of time. Hence, the integration would enable OpenDSS to conduct harmonic analysis over a period of time within the time-series.

OpenDSS simulator tool is chosen due to numerous reasons. OpenDSS is being chosen over PSCAD solely because OpenDSS analysis mode is solved in the frequency domain which makes it the best tool to perform harmonic analysis. OpenDSS computational time is faster compared to Matlab Simulink. Besides that, OpenDSS has the time-series simulation ability and easy data exchange interface (COM DLL) in which SKM-Power Tools does not have.

OpenDSS requires to be compared with standard software that has been used by the industry. Measurements of practical harmonic loads are needed to resolve the analytical results of harmonic studies and to determine compliance with guidelines. Time-series simulation of harmonic analysis is performed to observe and analyze the periodic trend of the time-series whether there is any existence of odd behavior conditions. The sum of harmonic losses from all transformers and cables within the distribution system is computed for each time step within the time-series. The THD of currents and voltages obtained are analyzed throughout the time-series for any irregularities or standard harmonic limits violation. If this approach is applicable to the real world practice, any sign of abnormalities within the interval of time-series can be detected and analyzed.

1.5 Significance of Study

The rise of harmonics level in our country's electrical power system has drawn many concerns from utilities, industrial, commercial and residential consumers and other users. The contribution of this research is the developed integrated application of OpenDSS. The system losses and the level of harmonic distortions in electrical power distribution network are easily obtained for each interval of time-series using the developed application. The developed application also saves computational time as well as providing a method that is cost effective.

Therefore, the outcome of this research is important in improving power quality with effective cost. Power system components which are affected by harmonics will have longer life and the cost of maintenance is reduced. Consumers will also obtain benefits from the application approach taken in this research since utility companies are able to provide better power quality. System design engineers can use the application approach in planning of electrical system and control engineers will be able to use the method in controlling harmonic voltage. Last but not least, this work would be able to contribute to the national development of our very own country.

1.6 Thesis Outline

Chapter 1 provides a brief introduction of harmonics in power system and background. The objectives and the problem statement of the project were also stated. The areas that the project will be focused on were explained in the scope of study.

Chapter 2 provides the literature review in the areas of harmonics. The definitions, the sources and effects of harmonics, harmonic analysis were discussed in details. Harmonic distortions and standards regarding on harmonic conditions were briefly explained in this chapter. An introduction to OpenDSS was presented. Time-series harmonic simulation was described. Previous research is discussed. This chapter, in general, is intended to provide an overview on modeling of power distribution systems for harmonic analysis and research improvements to be made based on the previous research.

Chapter 3 describes the methodology taken throughout the project. The distribution network systems modeled were chosen in this chapter. The collection and selection of measured data from three logging sites were done.

Chapter 4 presented the development of an integrated application of OpenDSS with MS Visual C++ and MS Excel. The step by step process of integrating OpenDSS with MS Visual C++ and MS Excel for time-series harmonic simulation is thoroughly explained in this chapter. The flow chart of the written C++ programming script is provided within this chapter.

Chapter 5 describes the time-series harmonic simulation of the test system using OpenDSS software. Two types of cases were investigated, which are cases of test system with and without harmonic penetration. Two different network systems are modeled and simulated. The simulated results were obtained, analyzed and discussed. Validation of OpenDSS with PSS Adept is performed within this chapter to prove the accuracy of the power flow solution.

Chapter 6 discusses the conclusion of the project and recommendations that can be done to improve the research.

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