

DYNAMIC MODELING OF A STAND-ALONE PEM FUEL CELL CONNECTED TO
ADJUSTABLE SPEED DRIVE

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Dedicated to my beloved father and mother...And to all my lecturers at UTM

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ABSTRACT

Fuel cell has a good potential as a stand-alone generation system and as energy supplied to Adjustable Speed Drive (ASD) model. This is because of its low operation temperature (70°C until 90°C) and also it has a good dynamic response. In this project, Proton Exchange Membrane (PEM) fuel cell is used as energy source. Dynamic modeling of a stand-alone PEM fuel cell which connected to several types of ASD system had been modeled by using Matlab/Simulink software. The PEM fuel system has several important sections, namely, fuel cell controller, fuel cell and power conditioning unit. Integrated and proportional controllers are used to control the fuel cell or the hydrogen flow rate that enters the PEM fuel cell. Simulation results show that fuel cell output power can fulfill the load demand in a short duration. Single-phase ASD and three-phase ASD are reviewed as loads in this project and their individual harmonics are investigated based on simulation results. Results also show that ASD generates harmonics to the line voltage and current. A method to reduce harmonics distortion in a network of ASD is proposed in this project. As a result, by combining different types of ASD as network, significant reduction on total harmonics distortion can be obtained.

ABSTRAK

Sel bahan api mempunyai potensi yang besar sebagai sistem penjana sendiri dan sebagai sumber tenaga kepada model ASD. Ini adalah kerana suhu operasinya yang rendah iaitu antara 70°C sehingga 90°C serta mempunyai sambutan dinamik yang baik. Di dalam kajian ini, sel bahan api ini dijadikan sumber tenaga bagi sebuah sistem lengkap yang dibina. Satu pemodelan dinamik bagi penjana sel bahan api PEM yang disambungkan kepada model ASD telah dibina dengan menggunakan perisian Matlab/Simulink. Sistem bekalan kuasa sel bahan api PEM mempunyai beberapa bahagian yang penting, iaitu, unit pemproses bahan api, unit sel bahan api, dan unit penyelarasan kuasa. Pengawal perkadaran dan terkamir digunakan untuk mengawal kadar aliran hidrogen atau bahan api yang memasuki unit sel bahan api PEM ini. Hasil keputusan simulasi menunjukkan kuasa keluaran sel bahan api dapat memenuhi permintaan beban dengan kadar yang segera. ASD satu fasa dan ASD tiga fasa telah digunakan sebagai beban di dalam kajian ini dan herotan harmonik individu telah di kaji daripada keputusan simulasi. Keputusan simulasi juga menunjukkan bahawa ASD menyumbang kepada herotan harmonik kepada voltan dan arus talian. Kaedah untuk mengurangkan herotan harmonik telah dikemukakan di dalam kajian ini dan keputusan simulasi menunjukkan bahawa dengan menggabungkan beberapa jenis ASD yang berlainan di dalam satu rangkaian, herotan harmonik dapat dikurangkan.

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LIST OF SYMBOLS

°C	-	Degree Celcius
V	-	Volt
I	-	Current
T	-	Temperature
Ω	-	Ohm
A	-	Ampere
W	-	Watt
F	-	Farads
H	-	Hendry
K	-	Kelvin
s	-	Second
atm	-	Atmosphere
kg	-	Kilogram
D	-	Duty ratio
°F	-	Degree Fahrenheit
\$	-	Dollar
Hz	-	Hertz
rpm	-	Revolutions per minute
DC	-	Direct Current
AC	-	Alternate Current
HP	-	Horse power

LIST OF ABBREVIATIONS

PEM	-	Proton Exchange Membrane
FC	-	Fuel Cell
ASD	-	Adjustable Speed Drive
VSD	-	Variable Speed Drive
PAFC	-	Phosphoric Acid Fuel Cell
MCFC	-	Molten Carbonate Fuel Cell
SOFC	-	Solid Oxide Fuel Cell
CO	-	Carbon Monoxide
CO ₂	-	Carbon Dioxide
SO ₂	-	Sulfur Dioxide
NO _x	-	Nitrus Oxide
H ₂	-	Hydrogen Gases
H ₂ O	-	Water
PV	-	Solar Power
THD	-	Total Harmonic Distortion
PWM	-	Pulse Width Modulation
CSI	-	Current Source Inverter
VSI	-	Voltage Source Inverter
L	-	Inductor
C	-	Capacitor
R	-	Resistor

CHAPTER 1

INTRODUCTION

1.1 Project Background

Since 1960s, world population increased double and this value is expected to rise drastically in the future. Because of that, power electricity demand will also increase for residential, industry and commercial used. Electricity power usually delivered to consumer through a long transmission lines from generation sites. There are three main conventional generation method be used which are hydro power, thermal and nuclear. These three methods are facing their own problems. Hydro generation system has many advantages and one of them is its friendly environmental effect while generate electricity constantly. However, hydro generation need a large dam to operate. Construction of a dam involves a large amount of money and a suitable geographical area because this construction flooded lower area, inundate river, destroy the water quality and damage flora and fauna territory. So, dam construction area need to be observed attentively to stop all of the consequences. Thermal generation produced by combustion of three main fuel which are coal, oil and gas where steam will turn the turbine. This fuel combustion creates pollution and contributes to green house effect. CO, CO₂, SO₂, NO_x gases and also hydrocarbon generate from fuel combustion bring diseases to human, reduce the ozone, produce acid rains and other bad effects. Thermal generation needs large area for its fuel storage and its need to be built near river or sea for steam condensation purposes where this will increase water temperature and further destroy sea creatures. Besides

that, world fuel sources have been decrease and coal is expected to deplete in 125 years (Nasar 1994). Nuclear power plant can produce electricity about 11% of world electricity needs and also can generate high electric power with a small amount of uranium source (Darvill 2004). However, nuclear reactor produces dangerous radioactive solid waste and these items need proper management to reduce its effects to human and also environment. High cost is required for this purpose and also for safety aspects. Because of that, power generation that utilizes nuclear power is not widely commercial. Due to all these facts, interest on renewable energy increased from time to time. There are many types of renewable energy such as wind, solar, wave, biomass, fuel cell, and also geothermal. Wind, solar and wave cannot be applied widely because the geography area and also the climate need to be considered. Fuel cell is a better choice for residential, mobile and stationary application. Fuel cell has many advantages such as high efficiency, no combustion, and can be stored anywhere compared to others. Fuel cell is a first-rate electricity source because it can produce constant power in full load. PEM fuel cell is used in this project because it is a suitable type for residential, commercial and also industry application. PEM fuel cell use solid polymer as its electrolyte and this polymer are a good conductor for proton and a better insulation for electrons. This fuel cell unit only needs about 70-90°C for its operation temperature and also has a high power density.

1.2 Problem Statement

Fuel cell generation technology can fulfill the electricity demand and solve the power transmission problem facing nowadays. Increase in energy demand contribute to new construction of power plant and new transmission lines need to be built to connect the generation side to customer. However, construction of transmission lines is quite difficult in rural area and electromagnetic radiation effects from transmission lines can also bring harm to human. Because of that, renewable energy using fuel cell technology is being implemented in many places. Nowadays, ASD is usually used as motor control

at most factories and other industry applications. ASD normally supplied by grid utilities but in order to reduce the dependent on conventional generation, ASD can also been powered by using renewable energy such as solar, wind and also fuel cell. In this project, PEM fuel cell is been used to supply electricity to ASD model. In order to build the prototype of one unit fuel cell, the cost is quit expensive, so simulation model had been designed in Matlab/Simulink software and this can be the best solution.

1.3 Objectives

The following are the main objective for this research project;

- i) To develop a dynamic modeling of a stand-alone proton exchange membrane (PEM) Fuel Cell generation system.
- ii) To connect PEMFC generation system to an ASD via power conditioning units.
- iii) To study harmonic issues involved in the complete system.
- iv) To reduce the total harmonic distortion of the system.

1.4 Scope of Project

In order to achieve the objectives that have been stated, there are several important parts that need to be covered. This includes the literature review about PEM fuel cell, ASD, power conditioning unit, controller for fuel cell, power quality, and also harmonics part. Then, the elements of fuel cell and adjustable speed drive have been studied and main component of both systems are identified. Equations of fuel cell system are also important in order to model a stand-alone fuel cell generation system.

Once the entire elements and equations determined, a complete dynamic modeling of the system is developed by using Matlab/Simulink software. Then, a suitable converter and inverter was designed for this complete generation system. As this generation system is connected to load which are the ASDs, the power quality issues were discussed and the system was identified either it can supply enough power to the load or not. More discussion on harmonics distortion for complete system and way to reduce harmonics is introduced in this project.

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