SIMULATION OF A HYBRID PHOTOVOLTAIC/FUEL CELL ENERGY SYSTEM

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DEDICATION

This thesis is dedicated to my beloved wife, my dearest parents, sister, and friends
who have given me continuous support and
encouragement to pursue my dreams.

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ABSTRACT

Basically, Malaysia energy production has been always generated from crude oil and natural gas. Currently, Malaysia has 13GW of electrical generation capacity. According to Malaysia Suruhanjaya Tenaga, as of July 2007, a total of 19,023 MW power generation capacity connected to the Malaysian National Grid, with a maximum demand(MD) of 13,340 MW. Total electricity generation for 2007 is 108,539 GW·h with a total consumption of 97,113 GW·h or 3,570 kW·h per capita. In 2007 also, the Malaysia consumes about 514 thousand barrels (23.6 million tonnes) of oil daily against a production of 755 thousand barrels (34.2 million tonnes) per day. Research shows that Malaysia only has 33 years of natural gas reserves, and 19 years of oil reserves. As Malaysia are moving towards further growth and development, the demand for energy is increasing every day and then. With that kind of scenario, Malaysian government is looking for other alternative measures as to mitigate the matter and hereby this renewable energy sources surface out and comes into the big picture. For the time being, 16% of Malaysian electricity generation is hydroelectric, the remaining 84% being thermal. The solar generating system is soon to follow and catch up with the latest technology in hands.

ABSTRAK

Secara dasarnya, pengeluaran tenaga Malaysia telah sentiasa dihasilkan daripada minyak mentah dan gas asli. Pada masa ini, Malaysia mempunyai 13GW kapasiti penjanaan elektrik. Menurut Suruhanjaya Tenaga Malaysia, Julai 2007, sejumlah 19.023 MW kapasiti penjanaan kuasa yang disambungkan ke Grid Kebangsaan Malaysia, dengan permintaan maksimum (MD) 13.340 MW. Jumlah penjanaan elektrik bagi tahun 2007 adalah 108.539 GW • h dengan penggunaan sejumlah 97.113 GW • h atau 3.570 kW • h per kapita. Pada tahun 2007 juga, Malaysia menggunakan kira-kira 514,000 tong (23.6 juta tan metrik) minyak setiap hari terhadap pengeluaran sebanyak 755,000 tong (34200000 tan) setiap hari. Kajian menunjukkan bahawa Malaysia hanya mempunyai 33 tahun rizab gas asli dan 19 tahun rizab minyak. Memandangkan Malaysia sedang bergerak ke arah pertumbuhan dan pembangunan seterusnya, permintaan untuk tenaga semakin meningkat setiap hari dan kemudian. Dengan jenis yang senario, kerajaan Malaysia sedang mencari langkah-langkah alternatif lain untuk mengurangkan perkara ini dan dengan ini sumber tenaga boleh diperbaharui permukaan keluar dan datang ke dalam gambaran yang lebih besar. Buat masa ini, 16% daripada penjanaan tenaga elektrik di Malaysia adalah hidroelektrik, baki 84% menjadi haba. Sistem penjanaan solar tidak lama lagi untuk mengikuti dan mengejar dengan teknologi terkini di tangan.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Today, the energy we use is mainly from fossil fuels such as oil, gas and coal. They are non-renewable and soon it will be completely depleted. Malaysia domestic oil reserves are expected to dry up by the end of this decade and gas reserves by 2040. However, with the rapid growth of population and industrialization throughout the world, somehow it has trigger a drastic increment trending towards electrical energy demand. Not forgetting the restrains that exist towards the development of electric power transmission line, which leads to high load density and contributing power quality concerns. Hence, as been attracted to the attention of power system, many researchers and designers had come with a reliable solution, especially for rural and remote areas which then renewable energy becomes the hot topic to talk about.

1.2 Problem Statement

Renewable Energy Sources (RES) such as wind and solar power systems which previously still under research and study, have now gained famous in the last decade as one of future prospects of energy resources. However, this wind and solar power system

have their own problems and limitations related to the inconsistency and uncertainty of the power that they produce. The inevitable weather conditions will definitely be a problem and need to be overcome in some design criteria, which later as to justify, overdesign and oversize of the system parameter is performed to meet much reliable load demand. The other approach is moving towards integration of renewable resources together, as to enhance the reliability performance of the system, whereby using the advantage of one source to compensate for the drawback of another. With this, evolved the hybrid systems, which in this project will look into the simulation of hybrid photovoltaic and fuel cell system and to conclude and justify the propose effective controller which can gain Maximum Power Point Tracking (MPPT) and taking the grid-connection into account.

1.3 Objective of Project

The objective of this project is to investigate and review the various control techniques which supposed to be used together with Power Conditioning Unit in this Hybrid Photovoltaic and Fuel Cell System as to obtain Maximum Power Point Tracking in grid-connection line. This control techniques found, and the hybrid model will be later be simulated using MATLAB/Simulink simulation package and the results will later be analyzed for further future improvement. In order to accomplish this objective, it is vital to understand the fundamental knowledge of the hybrid Photovoltaic-Proton Exchange Membrane Fuel Cell Energy System based on the literature review done.

1.4 Scope of Project

Firstly, the Fuel Cells System itself is a wide area as there many type of Fuel Cells. This project scope and focused on Proton Exchange Membrane Fuel Cell, or also known as PEM Fuel Cell only. Secondly, most of the project is related to MATLAB/Simulink Design &Simulation. Hence, in order to complete the project, one must have strong knowledge in MATLAB/Simulink. On top of that, as to develop the hybrid model, a lot of research and literature review need to be done. Some papers already describe the topologies used to develop this hybrid model. And some papers shares the problems arise in obtaining the output result. Finally, for this paper, the scope of project is up until the simulation results only. Hopefully, it will be useful as for reference to other students and researchers.

1.5 Project methodology

In order to accomplish the PROJECT OBJECTIVE, initially some study should be made throughout the literature review done from previous related Thesis, International IEEE Journals, Case studies, Technical Research & Reviews and some Text books. Later from the deduced sets of mathematical equations formula obtained from each photovoltaic and fuel cell system case studies, a comprehensive design module should be made and simulated through the Matlab/Simulink package. It will further on develop a hybrid system as integration of photovoltaic and fuel cell system which require a complete review on various control techniques used. This project require a lot of simulation as to obtain the best result, and hence the mastering of Matlab/Simulink package is vital and a must.

1.6 Thesis organization

Chapter 1: This chapter describes the introduction to the hybrid Photovoltaic/Fuel Cell energy system as the sources of alternative energy with their basic historical background. In addition to that it provides introductory explanations about problem statement, project objectives, scope and methodology.

Chapter 2: This chapter will cover the literature review done for the hybrid Photovoltaic /Fuel Cell Energy System. There are many methods and topologies as seen from the published Technical Papers which can be used for reference.

Chapter 3: This chapter emphasizes more on the modeling process of each subsystem of hybrid Photovoltaic/Fuel Cell Energy System and development of the Simulink block diagrams in MATLAB/Simulink.

Chapter 4: This chapter will look into the the results obtained from MATLAB Simulation for each stage in the Hybrid Photovoltaic/Fuel Cell Energy System.

Chapter 5: This chapter elaborate further case study on Fit-In Tariff which already being implemented in Malaysia and also on the real-time development of Photovoltaic System which emerge as potential resources for residential area.

Chapter 6: This chapter gives the conclusion of the entire work, and some additional works have been suggested for future development.

REFERENCES

[1] Saifur Rahman, Kwa Sur Tam "A feasibility study of photovoltaic-fuel cell hybrid energy system", IEEE Transactions on Energy Conversion, Vol. 3, No. 1, March 1988

[2] Antonio Luque, Steven Hegedus "Handbook of photovoltaic science and engineering"

[3] Gil Knier " How do photovoltaic work", Science@NASA Headline News

[4] Emil A. Jimenez-Brea, "Control of Alternative Energy Hybrid System for Residential and Low Power Applications", A thesis submitted in partial fulfillment for the degree of Master of science in Electrical Engineering, University of Puerto Rico, 2009.

[5] Dachuan Yu, Engine Research-Advance Power Sources, Caterpillar Inc. , S.Yuvarajan, Elect Eng Dept. North Dakota State University "Load Sharing In Hybrid Power System with a PV Panel and a PEM Fuel Cell" IEEE Applied Power Electronics Conference, March 2006. pg 1245 – 1249

[6] Zhenhua Jiang, Department of Electrical Engineering, University of New Orleans "Power Management of Hybrid Photovoltaic -Fuel Cell Power Systems", IEEE 2006

[7] Loc Nguyen Khanh, Jae-Jin Seo, Yun-Seong Kim, and Dong-Jun Won, "Power-Management Strategies for a Grid-Connected PV-FC Hybrid System", IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 25, NO. 3, JULY 2010, pg 1874 – pg 1882

[8] Kyoungsoo Ro, Saifur Rahman, Center for Energy and the Global Environment Virginia Polytechnic Institute and State University "Two-loop controller for maximizing performance of a grid-connected PV-Fuel Cell Hybrid Power Plant" IEEE Transactions on Energy Conversion, Vol. 13, No. 3, September 1998, pg 276 – 281

[9] Akrem Mohamed Elrajoubis, "Simulation of a hybrid photovoltaic/wind energy system",
A Thesis submitted in partial fulfillment for the degree of Master of Electrical Power, Universiti Teknologi Malaysia, 2010.

[10] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, Member, IAENG, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK", San Francisco, USA, WCECS 2008, October 22 - 24, 2008.

[11] Sonal Panwar, Dr. R.P. Saini, "Development and Simulation of Solar Photovoltaic model using Matlab/simulink and its parameter extraction", International Conference on Computing and Control Engineering (ICCCE 2012), 12 & 13 April, 2012

[12] Matthew Martin, "Performance Optimization of Small Scale Photovoltaics", A thesis submitted in partial fulfilment for the requirement of degree in Master of Science in Renewable Energy Systems and the Environment, University of Strathclyde, 2010

[13] Yuncong Jiang, Jaber A. Abu Qahouq, and Mohamed Orabi, "Matlab/Pspice Hybrid Simulation Modeling of Solar PV Cell/Module", IEEE 2011, pg 1244 –pg 1250

[14] Fuel Cell Handbook (Seventh Edition), EG&GServices, Parsons Inc., DEO of Fossil Energy, National Energy Technology Lab, Nov 2004

[15] Chong Kiat Shiu, "Dynamic Modeling and Simulation of a Stand–Alone Solid Oxide Fuel Cell Energy System" A Thesis submitted in partial fulfillment for the degree of Master of Electrical Power, Universiti Teknologi Malaysia, 2010.

[16] J. Larminie and A. Dicks, *Fuel Cell Systems Explained*. New York:Wiley, 2001.

[17] *Fuel Cell Handbook (Fifth Edition)*,EG&GServices, Parsons Inc., DEO of Fossil Energy, National Energy Technology Lab, Oct. 2000.

[18] Sandip Pasricha, *Student Member, IEEE,* and Steven R. Shaw, *Senior Member, IEEE, "*A Dynamic PEM Fuel Cell Model", IEEE Transactions on energy conversion, VOL. 21, NO. 2, JUNE 2006

[19] J. A. Smith, M. H. Nehrir, V. Gerez, and S. R. Shaw, "A broad look at the workings, types, and applications of fuel cells," in *Proc. IEEE Power Eng. Soc. Summer Meeting*, vol. 1, Chicago, IL, Jul. 2002, pp. 70–75.

[20] Caisheng Wang, Nehrir, M.H., Shaw S.R., "Dynamic Models and Model Validation for PEM Fuel Cells Using Electrical Circuits", IEEE Transactions on Energy Conversion, Vol.20, Issue 2, June 2005

[21]. Emil A. Jimenez-Brea, "Control of Alternative Energy Hybrid System for Residential and Low Power Applications**",** A thesis submitted in partial fulfillment for the degree of Master of science in Electrical Engineering, University of Puerto Rico, 2009.

[22]. Muhammad H.Rashid. "Power electronics circuits, devices, and applications", (3th Edition).University of West Florida.: Tom Robbins, 2004.

[23] N. Mohan, T. M. Undeland and W. P. Robbins, Power Electronics – Converters, Applications, and Design, John Wiley & Sons , Inc., 2003.

[24] Gyu-Yeong Choe*, Jong-Soo Kim*, Byoung-Kuk Lee*, Chung-Yuen Won*,"Comparative Study of Power Sharing Algorithm for Fuel Cell and Photovoltaic Hybrid Generation System" The 2010 International Power Electronics Conference

[25] Li Wei, "Modeling, Control and Simulation of A Small Photovoltaic Fuel Cell Hybrid Generation System", Power System Technology (POWERCON), 2010 International Conference

[26] Ying Liu "Advanced control of photovoltaic converters" , Thesis submitted to the Department of Engineering, University of Leicester for the degree of Doctor of Philosophy, April 2009.

[27] C. Liu, B. Wu and R. Cheung, Department of Electrical & Computer Engineering, Ryerson University, Toronto, Ontario, "ADVANCED ALGORITHM FOR MPPT CONTROL OF
PHOTOVOLTAIC SYSTEMS" Canadian Solar Buildings Conference Montreal, August 20-24, 2004 Refereed Paper

[28] http://**ecee.colorado.edu**/ecen2060/matlab.html.

[29] www.mathworks.com/products/**matlab/**

[31] Handbook on the Malaysian Feed-in tariff for the promotion of renewable energy

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LIST OF ABBREVIATIONS

PEM	-	Proton Exchange Membrane
PV	-	Photovoltaic
MPPT	-	Maximum Power Point Tracking
DC	-	Direct Current
HVDC	-	High Voltage Direct Current
AC	-	Alternating Current
GT	-	Gas Turbine
BUS	-	Busbar

LIST OF SYMBOLS

k	-	Kilo
V	-	Volt
P	-	Real Power
Q	-	Reactive Power
M	-	Mega
W	-	Watt
VAr	-	Volt-ampere-reactive
s	-	second
t	-	time
Hz	-	Hertz
f	-	Frequency
%	-	Percentage