DESIGN OF A HYBRID CONTROLLER FOR SOLAR AND OCEAN WAVE ENERGY HARVESTER

by

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LIST OF ABBREVIATIONS

4FDP81	Four Fuel Diversification Policy in 1981
5FP2000	Fifth Fuel Policy in 2000
ac	alternating current
ADC	Analogue to Digital Converter
ANN	artificial neural networks
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
CAES	Compressed Air Energy Storage
CCP	Capture/Compare/PWM
CNC	computer numerical control
dc	direct current
FiT	Feed-in-Tariff
GTFS	Green Technology Financial Scheme
GUI	Graphical User Interface
HRES	Hybrid Renewable Energy System
Hs	Height significant
Hz	Hertz
ITA	Investment Tax Allowance
km^2	kilometer square
knot	one nautical mile
LCD	Liquid Crystal Display
Mosfet	Metal oxide semiconductor field effect transistor
MP	Malaysia Plant
NDP80	National Depletion Policy in 1980
NEP79	National Energy Policy in 1979

NGTP	National Green Technology Policy
ORE	Ocean Renewable Energy
OTEC	Ocean Thermal Energy Conversion
OPT	Ocean Power Technologies
OWC	Oscillating Water Column
OWEC	Overtopping Wave Energy Converter
PID	Proportional–Integral–Derivative
PS	Pioneer Status
PV	Photovoltaic
PWM	Pulse Width Modulation
RBH	Rawdhat Bin Habbas
RE	Renewable Energy
REBF	Renewable Energy Business Fund
RF	Radio Frequency
SEA	South East Asia
SEAREV	Système électrique autonome de récupération de l'énergie des vagues
SMES	Superconducting Magnetic Energy Storage
SOWEH	Solar and Ocean Wave Energy Harvester
SPICE	Simulation Program with Integrated Circuit Emphasis
SREP	Small Renewable Energy Programme
SREP	Small Renewable Energy Power Program
SSG	Seawave Slot-Cone Generator
SWAN	Simulating Waves Nearshore
UART	Universal Asynchronous Receiver/Transmitter
V	Volt

VSM	Virtual System Modelling
WET	Wave Energy Turbine
Wh/m^2	Watt Hour per meter square
WW3	WaveWatch III

LIST OF SYMBOLS

%	Percentage
Ω	Ohm
ΔI_{out}	Ripple current
ΔV_{out}	Ripple voltage
A	Ampere
AH	Ampere Hour
C	Capacitor
D	Duty cycle
F	Farad
f	Frequency
H	Henry
H_2	Hydrogen
Hs	Wave Height
I_{bnb}	Buck and boost current
I_{out}	Output current
kWh/m^2	kilowatt-hours per square meter
km	kilometer
kn	knot
kW	kilo Watt
kW/m	kilo Watt per meter
L	Inductor
m	meter
mA	mili Ampere
ms	mili second

m/s	meter per second
MW	Mega Watt
MWp	Mega Watt peak
P_{out}	Output power
psu	practical salinity unit
R_L	Load Resistor
rpm	revolutions per minute
Te	wave energy period
V_{bnb}	Buck and boost voltage
Vgen	Generator voltage
V_{in}	Input voltage
Vld	Load voltage
V_{out}	Output voltage
V_{ref}	Reference voltage

Reka Bentuk Pengawal Hibrid Solar dan Gelombang Lautan Penuai Tenaga

ABSTRAK

Tesis ini membentangkan pendekatan pelaksanaan sistem hibrid antara Photovoltaik dan gelombang lautan. Sumber-sumber tenaga yang boleh diperbaharui ini sangat banyak, bersih dan bermanfaat berbanding bahan api fosil yang sedia ada. Kaedah biasa mengekstrak tenaga daripada sumber-sumber ini biasanya digunakan untuk menjana sumber tenaga secara tunggal untuk pengeluaran tenaga. Melalui sistem hibrid, integrasi dua atau lebih sumber boleh dilakukan. Penggabungan sumber gandaan tenaga ini akan melengkapkan dan menyokong mana-mana kekurangan mengiringi sumber-sumber ini. Walau bagaimanapun, kerumitan sistem akan meningkat berkadaran dengan jumlah sumber lantas menyebabkan sistem menjadi rumit. Maka, kaedah kawalan yang betul diperlukan bagi pengurusan sumber yang berkesan. Oleh itu, kajian ini dijalankan untuk membangunkan satu pengawal bagi dua modul sistem penuai, Photovoltaik dan penukar tenaga gelombang untuk sistem kuasa hibrid. Pengawal ini perlu sepenuhnya mengeksploitasi ciri-ciri potensi tenaga dengan memanfaatkan ia ke tahap maksimum. Kajian ini menyediakan kaedah yang berkesan untuk menuai Photovoltaik dan ombak lautan. Sumber Photovoltaik bergantung pada keamatan cahaya matahari manakala turun naik tenaga ombak lautan tidak sesuai melalui kaedah penuaian konvensional. Pengawal yang dibangunkan akan mengintegrasikan Photovoltaik dan gelombang lautan serta mengimbangi turun naik kuasa. Integrasi yang betul telah berjaya dilaksanakan melalui modul penukar ronta dan galak. Modul penukar tenaga gelombang yang dibangunkan menggunakan mekanisme roda bergigi searah manakala unit penjana telah diekstrak daripada motor kipas siling mini. Sistem pemantauan tambahan telah ditambah dengan merelisasikan penghantaran tanpa wayar kepada pengendali. Pembangunan Photovoltaik dan penukar gelombang ombak mencapai kemajuan pesat dengan kuasa purata yang dihasilkan masing-masing adalah 76.91mW dan 82.237W. Pengawal yang dicadangkan cemerlang dalam prestasi dan menghasilkan pengurusan tenaga hibrid berkesan dengan pengukuran kecekapan pengekstrakan kuasa pada 58%. Sistem hibrid ini telah berjaya dilaksanakan dalam sempadan skop yang telah ditetapkan.

Design of a Hybrid Controller for Solar and Ocean Wave Energy Harvester

ABSTRACT

This thesis presents an approach of hybrid system implementation between Photovoltaic and ocean waves. These renewable energy sources are abundant, clean and beneficial compared to existing fossil fuel. Common method of extracting energy from these sources normally utilized a single energy source for energy production. Through hybrid system, two or more sources integration is possible. Merging of multiples energy sources will complement and support any inadequacy attribute accompanying these sources. However, system complexity will increase as source increases resulting in complicated system. Thus a proper controlling method is required for effective source management. Therefore, this research was initiated to develop a controller for two system harvester modules, Photovoltaic and wave energy converter for hybrid power system. The controller should fully exploit energy potential characteristic by harnessing it to the maximum. This research provides an effective method of harvesting Photovoltaic and ocean waves. Photovoltaic source is dependable toward sun intensity while the ocean waves' intermittent energy is unsuitable through conventional harvesting method. The established controller will integrate Photovoltaic and ocean waves and compensate power fluctuations. Proper integration was successfully executed through buck and boost converter module. The wave energy converter module was developed using ratchet mechanism and the generator unit was extracted from mini ceiling fan motor. An additional monitoring system was added and performs wireless transmission to operator. The developed Photovoltaic and Wave Energy Converter (WEC) sources progress rapidly with average power produced are 76.91mW and 82.237W respectively. The proposed controller excels in performance and produce effective hybrid energy management with measured with power extraction efficiency at 58%. The hybrid system was successfully executed within the prescribe scope boundaries.

CHAPTER 1

INTRODUCTION

This chapter initiates the research work reported in this thesis. First, the fundamentals of the research background and its significant effect is presented first and concluded by an overview pertaining to the research topic. Then, brief descriptions on the study system and research objectives are outlined. The system limitations and thesis outline are given at the end of this chapter.

1.1 Overview

Gradual depletion of natural resources and its effect towards the environment are on the rise. Rapid energy demand from developing country also worsens the problem. The extensive used of coal, petroleum, and other fossil fuels, through combustion process lead to the emission of harmful substances to the atmosphere. These limited sources are affecting the earth supply storage. According to Bose (2013), the world coal reserves will last for about 200 years, oil reserve is expected to be exhausted in 100 years and gas is expected to last for about 150 years. These challenges have raised awareness and prompted immediate action (Darmani, Arvidsson, Hidalgo et al., 2014). Thus, the requirement of an alternative energy production promoted the efforts to utilize renewable energy sources as the preferable energy source.

The phrase renewable energy is acquired from a large scope of resources, in which all are based from self-renewing energy sources such as sunlight, wind, waves, the earth's internal heat and biomass. Renewable energy is more beneficial than the conventional energy sources; it is clean, minimizes environmental impacts, produces minimum secondary wastes and is sustainable based on current and future economic and social needs (Manzano-Agugliaro, Alcayde, Montoya et al., 2013). Its resources are abundant worldwide with 1000 times more energy reaches the surface of the earth from the sun than is released today by all fossil fuels consumed (Bull, 2001).

1.2 Renewable Energy Scenario in Malaysia

Malaysia's rising population growth and economic development increases energy demand. Malaysia is currently dependent on fossil fuels such as coal, oil and natural gas to generate electricity. The global trend of extreme energy consumption is quite reflective towards Malaysia as it progress towards achieving an industrialized country.

Typical situation in Malaysia's energy mix (oil, gas, coal and hydroelectric) is depicted in Fig. 1.1(Energy_Commission/SuruhanjayaTenaga(ST)Malaysia, 2014). The graph provides an overview of Malaysia's energy supply for more than a decade. Significant downwards trend is visible with oil losing 1.5% of its share to 32.5% in 2012. Hydropower contributes the lowest share in energy supply even though Malaysia is surrounded with substantial hydroelectric resources. Consequently, primary energy mix are formed on fossil fuel resources (coal, oil and gas), forcing tremendous pressure on the depleting natural resources.

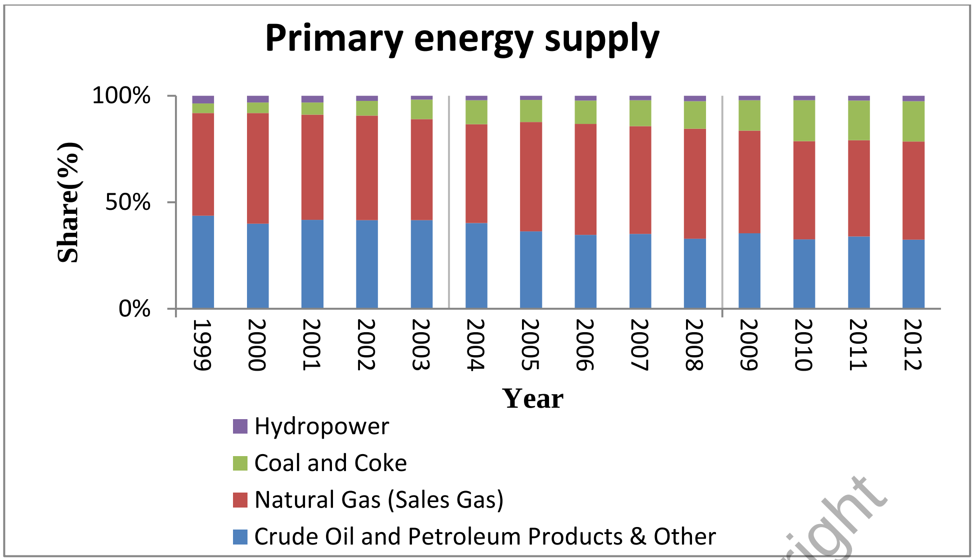

Figure 1.1: Primary energy supply.

These depleting sources are the byproduct of growing demand and consumption interaction occurs globally. The degree of energy consumption scenario in Malaysia for more than a decade could be viewed in Fig. 1.2 (Commission/SuruhanjayaTenaga(ST)Malaysia, 2014). Progressive approach towards industrialized nation is highly reflected by the strong dominance of industry and transport sector throughout the period. Consequently, these dominant sectors imposed a heavy load on Malaysia’s energy sustainability, efficient resource utilization and environmental safeguarding.

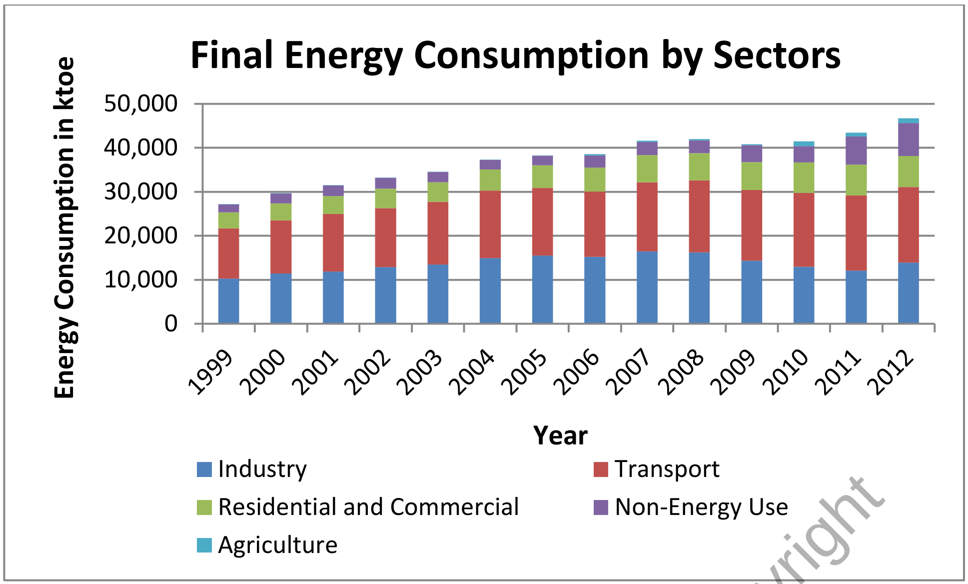

Figure 1.2: Final energy consumption by sectors.

Nevertheless, the large scale exploration of renewable energy source during the last decade is proven to be advantageous. Today, renewable energy source supply 14% of the total world energy demand, and is expected to increase significantly from 30% to 80% by 2100 (Manzano-Agugliaro, Alcayde, Montoya et al., 2013). Figures from Hitam (1999) estimated solar power to be four times the world fossil fuel resources in Malaysia. On average, the annual solar irradiations in Malaysia is from 4.21 kWh/m^2 to 5.56 kWh/m^2, with Northern region and some places in East Malaysia receives highest solar radiation (Azhari, Sopian, Zaharim et al., 2008). The transition period between monsoons presents the lowest solar radiation at 0.61 kWh/m^2 in December.

The convenience of being surrounded by large coastline could contribute to Malaysia energy sustainability (Chong & Lam, 2013). Having 4675 km long coastline, longest straits in the world, constant flow rate up to 4 m/s and average current speed of 2 m/s are sufficient for exploring potential ocean renewable energies prospect. Tidal current energy, tidal barrage, ocean thermal energy conversion (OTEC), power wave energy and salinity gradient power are extensively accepted as an effective technique for harnessing ocean energy. Carefully examined and executed, these renewable energy prospects could be utilized to their maximum potential for better efficiency in energy conversion.

Guided by future demands, Malaysia has initiated step towards alternative energy specifically renewable energy to alleviate Malaysia's dependency over fossil fuels and managing its growing demand for energy. Initial steps taken appear from the 7th Malaysia Plan (7MP) to 10th Malaysia Plan (10MP) aimed to promote utilization of renewable energy resources and efficient use of energy (Hashim & Ho, 2011). Concerted effort, such as Small Renewable Energy Programme (SREP) (May 2001) contributed 56.7MW (energy mix) from 286MW of its actual potential (Mustapa, Leong Yow, & Hashim, 2010) and Malaysia aimed to raise it to 2,000MW by 2020. Renewable energy capacity in Malaysia is less than 1% of total electricity generation in Malaysia. By utilizing only 5% of renewable energy in the energy mix will save the country RM 5 billion (US$ 1.32 billion) for a period of 5 years (Hashim & Ho, 2011).

1.3 Hybrid Renewable Energy

Limitations of conventional power production method such as power fluctuations, intermittent renewable sources such as solar and wind requires support with other utility generation resources. Current method of harnessing single energy generation systems such as solar, wind, biomass, geothermal, hydropower and diesel are not realistic in terms of cost, reliability and efficiency. Since, different renewable energy resources can complement each other; taken together they can optimize effective and efficient energy production. Thus, a single source energy production may evolve to a variety of energy production systems comprising a renewable energy based hybrid system that offers a better option than a single source based system.

A hybrid power system refers to a system having two or more components combined for the purpose of efficient utilization of resources. For example, wind energy source integration to an existing solar system will provide support during peak power load and perform system matching. Through proper technology selection, the system could also perform energy storage for future usage.

A controller is an integral part of a hybrid power system. Primarily, it involved power electronics based DC-DC converter to extract maximum energy from sources (Nema, Nema, & Rangnekar, 2009). A controller will determine and assign active and reactive output power dispatch from each energy source while maintaining its output voltage at the desired level. Normally, each source is equipped with a local controller to provide improvement that corresponds to the current information. The operating features may consist of on-grid or off-grid operation mode and changes in combination of energy sources supplying the load.

Hybrid energy systems are becoming an essential part of the energy planning process to supply remote areas such as India, Thailand, Spain, South Africa and Australia. Growing research focused on the performance analysis and the development of efficient power converters resulting in the development of reliable and cost-effective system.

This thesis research was planned to tackle drawbacks arise from hybrid power system implementation. Through common Photovoltaic (PV)/wind based controller, improvements are made for possible PV/wave hybrid configuration. This thesis also presents a manageable solution in providing data monitoring package for PV/wave hybrid configuration.

1.4 Problem Statement

Conventional hybrid configuration may consist of wind/PV, thermal/solar, PV/hydro/biomass etc. The PV condition is heavily affected by weather conditions which require integration of supporting energy source such as wind, biomass, thermal etc. These hybrid systems normally operated from a fixed location to maximize energy capture from the prevailing surrounding conditions. Constructing these hybrid systems require supporting structures such as extracting plant for thermal, hydro and biomass; tall towers for wind turbines hence incurred additional cost on the existing system. While stable large and rigid structures is affecting the surrounding ecosystem thus, hampered the growth of hybrid power system.

Current hybrid controller normally focused on wind/PV configuration and its variation making the feature impractical for non-PV/wind hybrid power system configuration. Control strategy for power management may consists of voltage regulation, state-based strategy by evaluating sensed conditions to set an operating mode, state machine, and the use of a programmed algorithm. To achieve effective working conditions, the control strategy is usually being integrated as a part of hybrid system controller along with source controller, storage management and system monitoring.

However, conventional control schemes employed do not provide an easier approach in term of implementation. System configuration requires intricate design to accomplish optimal result prompting an increase in complexity level which will incur additional cost and time. It is therefore desirable that the proposed controller is capable of attaining effective and optimal performance with minimal impacts toward implementation, operation and its environment.