DESIGN AND ANALYSIS OF POWER ELECTRONIC CONVERTER TO HARVEST OCEAN-CURRENT ENERGY

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DEDICATION

This thesis is dedicated to whoever the reader.
Yes, it’s you.
No one else, just you.
Because I know you are here
to do good things for future.

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ABSTRACT

An ocean current is a continuous, directed movement of ocean water generated by the forces acting upon this mean flow, such as breaking waves, wind, Cariole's force, temperature and salinity differences and tides caused by the gravitational pull of the Moon and the Sun. Depth contours, shoreline configurations and interaction with other currents influence a current's direction and strength. However, one of ocean current characteristic is varying-speed which will also vary the output of an energy converter. This project presents the comparison of two power electronic converter designs for hydrokinetic turbine system equipped with a permanent magnet synchronous generator (PMSG), to harvest ocean current energy by injecting ocean current speed data as input of overall system. An AC-DC uncontrolled rectifier is used as first stage of power conversion while two DC-DC converters (Buck-boost and SEPIC) are being compared for second stage. The proposed power conversion system model is designed to maintain constant DC output voltage with almost zero ripples for battery charging by using PI-control method. MATLAB/Simulink is used to simulate the proposed systems. The obtained result shows that the averaged output voltage is at 25.85V. With PI-control method, the output voltage maintains at small ripple.

ABSTRAK

Arus lautan adalah pergerakan air laut yang berterusan yang juga mempunyai aliran yang purata, bergantung pada daya yang bertindak pada, seperti gelombang putus, angin, daya Cariole, perbezaan suhu dan kemasinan dan pasang surut yang disebabkan oleh tarikan graviti Bulan dan Matahari. Kontur kedalaman, konfigurasi garis pantai dan interaksi dengan arus lain juga mempengaruhi arah dan kekuatan arus. Walau bagaimanapun, salah satu ciri arus laut adalah kelajuan yang berbeza-beza yang juga akan mengubah pengeluaran penukar tenaga seperti alat jana-kuasa. Projek ini membentangkan perbandingan dua reka bentuk sistem penukar kuasa turbin hidrokinetik yang dilengkapi dengan Penjana Segerak Magnet Kekal (PMSG), untuk menuai tenaga arus lautan dengan menggunakan data kelajuan arus lautan sebagai data pemasukan keseluruhan sistem. 'AC-DC Converter' yang tidak memerlukan kawalan, digunakan sebagai tahap pertama penukaran kuasa, sementara 'DC-DC Converter' (Buck-boost dan SEPIC) dibandingkan untuk tahap kedua. Model sistem penukaran kuasa yang telah dicadangkan adalah dirancang untuk mengekalkan voltan keluaran berterusan dengan riak hampir sifar untuk pengecasan bateri dengan menggunakan kaedah kawalan PI. MATLAB/Simulink digunakan untuk mensimulasikan sistem yang dicadangkan. Hasil yang diperoleh menunjukkan bahawa voltan keluaran rata-rata berada pada 25.85V. Dengan kaedah kawalan PI, voltan keluaran mengekalkan pada riak yang sangat kecil.

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LIST OF ABBREVIATIONS

PMSG	-	Permanent Magnet Synchronous Generator
SEPIC	-	Single Ended Primary Inductance Converter
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
AC	-	Alternating Current
DC	-	Direct Current
BLDC	-	Brushed-less Direct Current
BLDCG	-	Brushed-less Direct Current Generator.
BJT	-	Bipolar Junction Transistor
MOSFET	-	Metal-Oxide Semiconductor Field-Effect Transistor
IGBT	-	Insulated Gate Bipolar Transistor
GTO	-	Gate Turn OFF Thyristor
IGCT	-	Insulated Gate Commutated Thyristor
EMF	-	Electromotive Force
SOC	-	State of Charge
RAM	-	Random Access Memory

LIST OF SYMBOLS

β	-	Pitch angle of blade
ρ	-	Density
λ	-	Tip Speed Ratio
τ	-	Torque
α	-	Duty cycle
Δ	-	Delta or ‘Changes of’
ω	-	Angular speed

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Renewable energy sources are well-known by community nowadays and some sources come from ocean, which are known as tidal and wave that have been currently active supplying energy for daily demands on certain countries. However, these two sources can be categorized as non-continuous energy source as both are depending on wind and gravity-interaction. A big problem for electrical systems is temporary variability in renewable energy. Tides are considered predictable because of their daily periodicity. However, the durability and quality of the electricity produced by the tidal stream is unknown. To counter the problem, ocean has another source of renewable energy which is ocean-current or sometimes known as deep-sea current or marine current. The ocean-current flows continuously 24 hours which could be a great opportunity to counteract non-linear energy sources.

Strong ocean currents are formed by a combination of temperature, salinity, wind, bathymetry and earth's rotation. The sun acts as the primary driving force, causing differences in winds and temperature which affect ocean currents. Since ocean currents are roughly steady in both speed and flow and hold large quantities of energy, there are several suitable locations for deploying devices such as turbines for energy extraction. Turbines capable of capturing the ocean currents' kinetic energy may be indistinguishable from other marine current turbines and operate according to the same principles. They may however be planned or engineered in tidal channels for lower flow speeds compared to currents and may not need to account for reversal flow. A major difference is where the instruments can be placed – geographically as well as in the water column. Fast ocean currents appear to be more offshore than tidal currents in coastal or inland waters. This results in deployment to deeper water. As ocean currents in the water column are strongest higher, fixed substructures to support a turbine are becoming impractical for harnessing ocean energy. Conversely, instruments may be suspended or connected to buoyant structures bound to the seabed from moored surface platforms. Electricity is generated by coupling a generator to the turbine from the ocean currents, and power is delivered back to shore through subsea cable.

The main concern about ocean-current energy is the speed of the seawater varies over time. As generator connected to a shaft of mechanical energy converter or turbine, the electrical power will be varied in terms of voltage, current and frequency. Maximum power point tracker (MPPT) of mechanical part will be incapable to catch-up the rapid changes of water speed which is similar to wind energy converter. Plus, the absence of MPPT is a method of cost reduction but the output remains inconsistent.

This is when, power electronics converter becomes valuable for the adaptation of varying electrical parameters from generator output. Type of converter depends on type of electrical source and load, which only either AC-AC, AC-DC, DC-AC or DC-DC. In order to decide which converter type to be used, decision of generator type to be used has to be prior and load type comes in second place. Generator type has to be less maintenance and robust for underwater application.

Apart from power diode, other power electronics switches are inoperable without controller. Open-loop controller is not commonly used as it gives no guarantee of desired output towards changes of input and load behavior. Closed-loop controller is then reliable technique to get the desired outputs. Most known and common control scheme for power electronic sector is PI-control scheme. There are others type of proposed control schemes that also gives good control on the output but it also depends on the behavior of overall system. This is due to some control schemes might not be able to handle complex feedback parameter of a complex system at which more complex control scheme is needed.

1.2 Problem Statement

Various topologies of power electronic converter system have been discovered to adapt different kind of situations. For application of ocean-current harvesting system, it is still unknown of which topologies suitable for ocean-current characteristic. Designing of mechanical power converter should be prioritized before designing type of generator to be used. Then, type of converter can be properly designed with known type of load.

Ocean-current behavior can be compared with river-current behavior as both are continuously flowing. However, river can be considered as having very less speed propagations if to be compared with ocean-current. This can be concluded as varying ocean-current speed varies generator output voltage.

Suitable control scheme for ocean-current harvesting system is not yet been discovered but similar system such hydrokinetic generation system can be a reference. However, the dynamic behavior of ocean-current is needed to design controller input parameters.

1.3 Research Objectives

The objectives of the research are:

(a) To design and simulate Buck-boost and SEPIC converters to harvest ocean-current energy.

(b) To design PI-control scheme for closed-loop feedback control for Buck-boost and SEPIC.

(c) To gain consistent DC output voltage for battery charging.

1.4 Scope of Study

For this project, ocean-current speed data will be focused on Peninsular Malaysia North-East Coastal area and it will be used to test proposed control scheme. The project focuses on designing two proposed circuit topologies which will also be considering cost and components. The size of the system is limited to battery size of 10Ah. The project is limited to simulation in MATLAB/Simulink and MATLAB/PID-Tuner App.

1.5 Significance of study

This study helps in analysing appropriate ocean-current energy harvesting system by considering the ocean-current speed profile. The analysis of dynamic behavior of ocean-current speed may be useful for further studies and commercial application.

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