UNIVERSITI PUTRA MALAYSIA

OPTIMAL SIZING OF HYBRID TIDAL, PHOTOVOLTAIC AND BATTERY SOURCES OF ENERGY

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By

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A methodology for calculating the optimum size of the hybrid tidal, photovoltaic and battery by considering the uncertainty of renewable sources is proposed. In the method the uncertainty is investigated using the water velocity and sun irradiation probability functions. The numbers of solar arrays, tidal turbines and battery were considered as optimization variables which have been determined by the particle swarm optimization algorithm.

In the sizing problem, cost is proposed as the objective function of the algorithm, which is calculated by the Net Present Cost method. The cost function includes capital, replacement, and operation and maintenance costs for each unit of renewable source for a hybrid with 20 years life time. One of the constraints that is considered in the sizing problem is, maintaining the reliability in a specific value. The Equivalent Loss Factor index is considered as reliability index which should be in the range [0, 0.1] as ideal reliability for the system. In the proposed method sequential Monte Carlo method is used to consider the uncertainty in renewable sources. In order to compare the previous methods and proposed method, cost and reliability indices are regarded as comparison factors. The cost that is calculated in the sizing problem with the hourly data of sun radiation and water velocity is considered as the reference of comparison. In addition the reliability factor that is proposed with the Monte Carlo method is regarded as the ideal reliability index.

Moreover, the sizing problem is also investigated without considering the uncertainty with the average data of sun irradiation and water velocity. The results of simulation with average data reveals that the total cost is 21% less than the cost which uncertainty is taken into account in renewable sources with Monte Carlo method, however the reliability index for the simulation with the average data calculated with the Monte Carlo method, shows that the system reliability in this case is, 177% less than ideal reliability index.

In fact, using the average data of water velocity and solar irradiation leads to lower cost, but it gives wrong design for the system as it cannot supply the load

completely. Therefore considering the uncertainty in renewable sources give more realistic view to the sizing problem.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

OPTIMAL SAIZ AIR PASANG SURUT HIBRID, FOTOVOLTA DAN BATERIMEMANDANGKAN KETIDAKPASTIAN PASANG SURUT DAN FOTOVOLTA KUASA

Oleh

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Dengan kaedah Monte Carlo. Bagaimanapun boleh percayaan bagi simulasi.

Dengan data purata dikira dengan kaedah Monte Carlo, menunjukkan bahawa ke boleh percayaan system dalam ke sini adalah, 177% kurang daripada indeks ke boleh percayaan ideal. Satu kaedah untuk mengira saiz optimum hybrid pasang surut, fotovolta dan bateri dengan_mempertimbangkan ketidaktentuan sumber yang boleh diperbaharui dicadangkan.Dalamkaedah yang ketidakpastian itu disiasat menggunakan halaju air dan kebarangkalian penyinaran matahari.Bilangan array solar, turbin air dan bateri dianggap sebagai pembolehubah pengoptimuman yang telah ditentukan oleh algoritma penambahbaikan ‘Particle Swarm Optimization’.

Dalam masalah saiz, kos adalah dicadangkan sebagai fungsi objekti falgoritma, yang dikiradengan kaedah Kos bersih semasa. Fungsi kostermasuk modal, penggantian, dan operasi dan penyelenggaraan kosbagi setiap unit sumber yang boleh diperbaharui untuk hybrid dengan masa 20 tahun hidup. Salah satu kekangan yang dipertimbangkan dalam masalah saiz adalah mengekalkan kebolehpercayaan dalam nilai tertentu. Yang Indeks Faktor Kehilangan dianggap Setara sebagai indeks kebolehpercayaan yang sepatutnya dalam julat [0,0.1] sebagai kebolehpercayaan yang sesuai untuk sistem. Dalam kaedah yang dicadangkan berurutan kaedah Monte Carlo digunakan untuk mempertimbangkan ketidakpastian dalam sumber-sumber yang boleh diperbaharui. Bagi membandingkan kaedah terdahuludan kaedah yang dicadangkan, kosdan kebolehpercayaan indeks dianggap sebagai faktor-faktor perbandingan. Kos yang dikira dalam masalah saiz dengan data setiap jam sinaran matahari dan halaju air dianggap sebagai rujukan perbandingan. Selain factor kebolehpercayaan yang dicadangkan dengan kaedah Monte Carlo dianggap sebagai indeks kebolehpercayaan yang ideal.
Selain itu, masalah saiz juga disiasat tanpa mengambil kira ketidakpastian dengan data purata penyinaran matahari dan halaju air. Keputusan simulasi dengan data purata mendedahkan bahawa kos keseluruhan adalah 21%

kurang daripada kos yang tidak menentu diambilkira dalam sumber yang boleh diperbaharui

Malah, dengan menggunakan data purata halaju air dan sinaran suria membawa kepada mengurangkan kos, tetapi ia member rekabentuk salah bagi system ini kerana ia tidak bolehmembekalkan beban sepenuhnya. Oleh itu memandangkan ketidaktentuan dalam sumber yang boleh diperbaharui memberikan gambaran yang lebih realistic kepada masalah saiz itu.

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LIST OF ABBREVIATIONS

BBO	Biogeography Based Optimization
CC	Capital Cost
CDF	Cumulative Distribution Function
DOD	Depth of Discharge
EENS	Energy Expected Not supplied
ELF	Equivalent Loss Factor
FC	Fuel Cell
GA	Genetic Algorithm
GAMS	Generalized Algebra Modeling System
LCC	Life Cycle Cost
LEC	Levelised Energy Cost
LOEE	Loss of Energy Expectation
LOLE	Loss of Load Expected
LPSP	Loss of Power Supply Probability
LUC	Life Cycle Unit Cost
MC	Maintenance Cost
MCDA	Multi-Criteria Decision Analysis
ML	Maximum Likelihood
NPC	Net Present Cost
PDF	Probability Density Function
PSO	Particle Swarm Optimization
PV	Photovoltaic
RC	Replacement Cost
REPG	Relative Excess Power Generation
SOC	State of Charge
UEP	Unutilized Energy Probability

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays there is growing interest in green power generation systems which is due to surge in consumption of energy, increase in cost and limited remaining of fossil fuels. During the previous decades, because of expensive equipment which was required to generate electrical energy from renewable sources, this kind of energy at that time was not profitable and economical. However in the last years due to huge progress in different aspect of these sources, implementing of them has become not only practicable but also cost-effective. [1,2].

Hybrid tidal, photovoltaic and battery is proposed as a new combination of renewable sources that is utilized to produce electrical energy. The power that is generated by tidal turbines depends on water velocity while the power generation of the photovoltaic arrays depends on the solar radiation. Due to dependency of these sources to climate condition, it is necessary to consider the contribution of this factor in determining the capacity of these sources to supply the electrical demand.

In order to utilize solar and tidal energy resources efficiently and economically, the size optimization is very important for design of tidal and solar power generation systems with battery bank. The sizing optimization method can lead to have the lowest investment with a reasonable and full use of tidal system, photovoltaic system and battery bank, so that the system can work at optimum condition with optimal configuration in terms of investment and reliability requirement of the load demand.

In this study, a stand-alone hybrid of renewable energy system consisting of tidal, photovoltaic and battery is proposed. Tidal and PV are the primary power sources of the system to benefit the full advantage of renewable energy and the battery is also used in the system for short-time backup.

1.2 Solar Energy

Solar energy is the most enormous energy in the world and also a ubiquitous form of energy in the world. The total amount of solar energy that is absorbed by oceans, Earth atmosphere and lands is approximately 4 million exajoules (EJ) per year. The amount of energy that is beamed onto the Earth in each hour by the sun is more than adequate energy to satisfy the world energy needs for a whole year. Solar energy is the technology utilized to harness the sun's energy and make it useable. In order to harness this energy several technologies have been introduced like solar photovoltaics, solar architecture, solar heating and solar thermal electricity.

1.3 Tidal Energy

More than two-thirds of the earth is covered by the oceans and seas and immense extent of energy is stored in them**.** Hence tidal power has lots of potential to generate electricity in future. Predictability of tide can be an advantage compared with wind and solar powers. Recent technical developments both in design and turbine technology reveal that total energy which can be obtained from this sources is much higher than it is previously predicted, Moreover its related costs like economical cost may be decreased to competitive levels.

Tidal energy is the only energy in the world that its energy drawing depends on the Earth-Moon orbital specifications and in lower extent in the Earth-Sun system. Other natural sources that are utilized by human technology relate directly or indirectly to the sun such as, fossil fuel, conventional hydroelectric, wind, biofuel even nuclear energy makes use of mineral components in the Earth.

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Regarding the fact that the Earth tides are finally due to gravitational action and reaction between the Moon and Sun and the Earth rotation, tidal power is considered practically inexhaustible and can be classified as a renewable energy resource. The average, seawater, is more than eight hundred times denser than air; in addition, the astronomic behavior of tides mechanism leads to an essentially predictable resource, however it can be subjected to climate fluctuations.

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1.4 Research Motivation and Problem Statement

There has been soaring interest in utilizing renewable energy resources for many years which stems from ever increasing energy consumption all over the world. In the last decades generating electrical energy was not cost effective as the equipment prices was too high, however nowadays due to development in technology, implementing renewable energies is highly reasonable and beneficial.

Hybrid solar, tidal and battery is a new combination for renewable energy that is used to produce electrical energy in coastal areas where accessibility to the main power network may be hard. In this hybrid, solar and tidal sources are the main sources and battery acts as a backup source. The power generations of photovoltaic arrays are related to solar radiation and this issue for tidal turbines is associated with the water velocity. Therefore due to this dependency of these renewable sources to weather situations, it is necessary to ponder these factors in determining the needed capacity of these renewable sources to supply the electrical demand.

In this thesis electrical powers for photovoltaic and tidal units, which are based on solar radiation and water velocity respectively, are considered as uncertain values and have been calculated by real data. Moreover, by take uncertainty into account in electrical power generations, a more factual view of reliability index and cost can be achieved. In order to consider probability model of electrical power for solar and tidal units in case of sizing determination, probability density function (PDF) of solar radiation and water velocity is used.

In case of determining the optimal size of photovoltaic and tidal units, the main aim is minimizing the cost and maximizing the reliability index by taking the uncertainty into account for tidal and photovoltaic power. The number of solar panels, tidal turbines and batteries are the unknown quantities of the aim function.

In case of estimating cost, Net Present Cost method is used that includes investing, transferring and maintenance costs by considering the project life. In addition, the reliability index that is utilized is Equivalent Load Factor. In fact the uncertainty of renewable sources in this study is presented by a method in reliability index. The method that is utilized to consider probability model for renewable sources in capacity determination calculation, is Monte Carlo. In the sizing optimization case as it has already mentioned the main aim is minimizing the costs by considering ideal reliability index. The unknown parameters for optimal sizing are calculated by an intelligent optimal algorithm which is Particle Swarm Optimization. By this algorithm the best capacity for the combination of power source will be achieved.

1.5 Aim And Objectives

This study is going to present a comprehensive method in order to calculate the optimum size of a hybrid of renewable sources by considering the uncertainty in renewable sources and maintaining the desirable reliability.

The objectives of this work are:
1. to determine the optimal number of tidal turbines, solar arrays and batteries by Particle Swarm Optimization algorithm,
2. to validate the standard reliability for the proposed system by considering the uncertainty with Monte Carlo Method and compare it with other methods, and
3. to determine the minimum cost for the hybrid tidal, solar and battery proportionate with satisfied reliability.

1.6 Scope of Research

The research is carried out based on the tidal and solar data in of Medford a city in Oregon State in the United State of America for 8 and 32 years respectively. This is a coastal city in the west of the US. Some reasons caused that this city is chosen as the scope of the research like, vicinity to the sea, suitable solar radiation during a year and having precise meteorology for sun radiation and water velocity for several years.

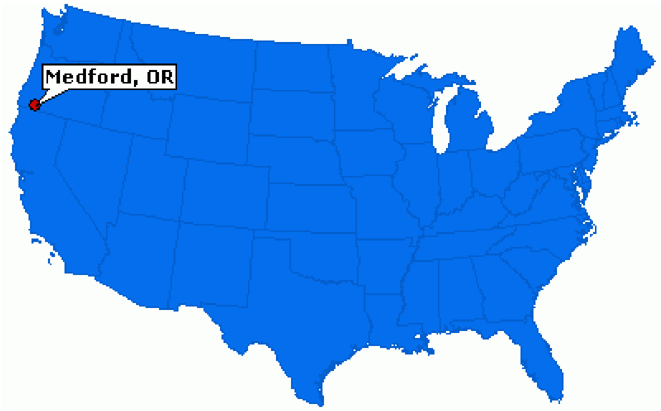

Figure 1-1: Location of the Medford

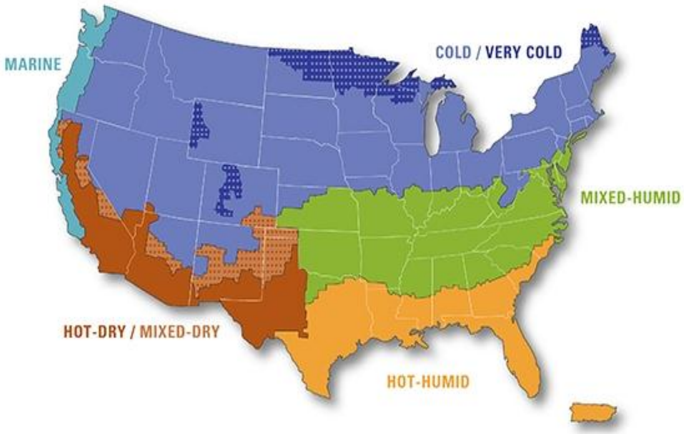

Figure 1-2: United States map based on the different climate [3]

Medford sits in a rain shadow between the Cascade Range and Siskiyou Mountains called the Rogue Valley. As such, most of the rain associated with the Pacific Northwest and Oregon in particular skips Medford, making it drier and sunnier than the Willamette Valley. Medford's climate is considerably warmer, both in summer and winter, than its latitude would suggest, with a Mediterranean climate . Summers are akin to Eastern Oregon, and winters resemble the coast. Here, summer sees an average of 57 days over 90 °F (32 °C) and 11 days over 00 °F(38 °C). Medford also experiences temperature in the winter that fog is so thick that visibility could be reduced to less than five feet. These inversions can last for weeks; some suggest this is because the metropolitan area has one of the lowest average wind speeds of all American metropolitan areas. The heavy fog returns nearly every winter with the inversions lowering air quality for several months without relief [4]. By considering these meteorological facts we conclude that Medford is a city that is located in the marine area with suitable solar radiation and low average wind speed.

1.7 Outline of the Thesis

The structure of this thesis is as follows:
Chapter 1 provides the overview of the research where the kind of hybrid that is defined and also some information about solar and tidal energy is briefly explained. Research motivation and problem statement, aim and objectives and scope of the research are set out as the guideline of completing this thesis.

Chapter 2 includes the summary of related studies in this issue and also the methods are compared with each other by mentioning their advantages and disadvantages.

Chapter 3 provides some necessary information regarding hybrid systems; moreover, the suggested method is presented and it illustrates how to achieve the optimal size of the hybrid tidal-photovoltaic and battery which is a stand-alone system. In this chapter also power strategy management and also a method for calculating and minimizing the cost are presented.

Chapter 4, simulation result is demonstrated, both new and old methods are simulated to compare the suggested method and old methods. This is due to the fact that there no reference is available that has investigated this hybrid yet. Therefore by this comparison we can ascertain the precision of our new suggested method.

Chapter 5, conclusion and some suggestions are presented for further studies.

In this case by 30% increase in variances, the cost is decreased by 16.88% in compared with the reference cost. As it can be seen the sensitivity of sizing optimization is little for little changes in both PDFs, however by large increase in the variance of PDFs the sensitivity will be increased as well.

Table 4-11: cost and optimum numbers of tidal turbine, solar array and battery by increasing the coefficient in both PDFs of sun irradiation and water velocity

Increase coefficient	Number of Solar Array (N_S)	Number of Tidal Turbine (N_T)	Number of Battery (N_B)	Total cost (10^6\$)
0.3	153	74	258	4.078

4.4 Summary

Results of sizing the hybrid tidal, photovoltaic and battery with PSO algorithm reveal the optimum number for each source. In addition they show that considering the uncertainty in the sources in the sizing calculations leads to more reliable information for the system design compared with using the average data. Although the cost of the system with average data is lower, its reliability is 177% less than the condition when uncertainty is taken into account and the system which is designed by average data cannot supply the load totally.

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