Faculty of Engineering

SIMULATION AND PROTOTYPE DESIGN OF HYBRID RENEWABLE ENERGY HARVESTING SYSTEM

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SIMULATION AND PROTOTYPE DESIGN OF HYBRID RENEWABLE ENERGY HARVESTING SYSTEM

MUHAMMAD SYUKRI BIN NURULHAK

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ABSTRACT

In this era of globalization, the energy harvesting technology for renewable energy has improved to combat the concern in energy conservation, global warming, and excessive waste materials. Additionally, the problem of getting continuous and reliable energy and power supply will become a real issue in the future. The energy harvesting technology can be an alternative to the current power generation and can lead to a potential of getting more reliable power supply for everyone. By combining multiple renewable energy harvesting system, more power can be continuously generated, and the efficiency of energy output will increase. This paper focus on the development of hybrid renewable energy harvester system consists of photovoltaic, piezoelectric and wind energy. The performance and the capabilities of the system are recorded are analyse under different conditions and parameters.

ABSTRAK

Pada era globalisasi ini, teknologi penuaian tenaga untuk tenaga yang boleh diperbaharui telah menjalani penambahbaikan untuk mengatasi permasalahan berkaitan penjimatan tenaga, pemanasan global, dan bahan buangan yang berlebihan. Selain itu, masalah untuk mendapatkan tenaga dan bekalan kuasa yang berterusan akan menjadi isu pada masa hadapan. Teknologi penuaian tenaga boleh manjadi alternatif kepada penjanaan kuasa yang sedia ada dan boleh membawa kepada potensi untuk mendapatkan bekalan kuasa yang boleh dipercayai untuk semua orang. Dengan menggabungkan pelbagai jenis sistem penuaian tenaga yang boleh diperbaharui, lebih banyak tenaga boleh dihasilkan, dan kecekapan tenaga akan bertambah. Kertas kerja ini menumpukan pada pembangunan sistem penuaian tenaga untuk tenaga yang boleh diperbaharui jenis hibrid yang terdiri daripada fotovoltaik, piezoeletrik dan tenaga angin. Prestasi dan kebolehan sistem tersebut direkodkan dan dianalisis di bawah keadaan dan parameter yang berlainan.

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EH	-	Energy Harvesting
IoT	-	Internet of Things
PV	-	Photovoltaic
HAWT	-	Horizontal Axis Wind Turbine
VAWT	-	Vertical Axis Wind Turbine
TEG	-	Thermoelectric Generator
RF	-	Radio Frequency
DC-DC	-	Direct Current to Direct Current
DC-AC	-	Direct Current to Alternating Current
AC-DC	-	Alternating Current to Direct Current

CHAPTER 1

INTRODUCTION

1.1 Background

Energy harvesting refers to the harnessing of readily available energy from the surrounding into electrical energy [1]. Some of the energy harvesting technology covers the conversion of light, kinetic, thermal and radio frequency via various mechanism such as photovoltaic, piezoelectric, and thermoelectric [2]. The electrical energy gathered can be use directly or stored for later use. The energy harvesting technology can be an alternative for places with no power grid or places that is not suitable for solar panels and wind turbines installation. Energy harvesting also has become one of the most-rapid growing technologies in the current year. It is estimated that the market size of energy harvesting can reach up to USD 817.2 Million by 2026 [3]. The motivation of adopting the energy harvesting technology for renewable energy comes from the concern in energy conservation, global warming, and excessive waste materials.

However, the energy harvested is in small amounts and adequate for low-power application such as remote sensing, body implants and most wireless applications [4]. For start, some of the IoT devices can integrate the energy harvester system for its own sustainability since it can be operated in low power. The Internet of Things or IoT can be describes as billions of physical devices that are linked to the internet to connect and exchange data [5, 6]. The IoT devices can be everything if it connected to the internet and can be interacted or controlled. It can be as small as switching on the lamps using smartphone application or exchanging massive data back and forth using thousands of sensors for monitoring system.

The self-sustainable operation of IoT devices is one of the main importance that have been discussed by many researchers. For long term accessibility, the usage of disposable battery can be ignored, and it can be charged by itself. The energy harvesters are divided into four groups that is based on their power output, which are high power (more than

10W), medium power (between 1W to 10W), low power (between 1mW to 1W) and ultra-low power (below 1mW) [7]. From the low-power devices, the energy harvesting system can move on to powering up the medium to high power devices. This can lead to the integration of energy harvesting technology into various industries such as transportation, automotive, power generation and more. There are already some existing energies harvesting devices and application such as photovoltaic solar energy at rooftop that convert light into electric energy or using wind energy to convert mechanical energy to electrical energy.

This is where the energy harvesting structure become hybrid with the combination of more energy harvesting system to produce more energy. Combining multiple sources of energy can maximised the peak energy as well as providing energy when some of the sources are unavailable [4]. There have been many research and experiment regarding hybrid energy harvesting such as solar-wind harvester, electromagnetic/piezo-electric harvester and solar-wind energy harvester [7]. Theoretically, the combination of more than one energy harvester can produce more energy and more efficient.

This paper presents the study of four types of energy harvester which are photovoltaic, piezoelectric, thermoelectric and radio frequency. The energy harvester will be combined and merged to create the hybrid energy harvester. The energy harvester will be tested using simulation and some of them will be implemented into hardware design depending on the availability and convenience.

1.2 Problem Statement

Theoretically, the hybrid energy harvester would be better than the single energy harvester. The power generation capacity can increase by merging multiple energy harvester to power the supply. However, most of the usage for renewable energy harvester are only using single energy harvester, for example photovoltaic energy. The method would be by harnessing energy from multiple sources such as photovoltaic, piezoelectric and wind energy.

Single energy harvester will lose its abilities to harvest energy at a certain time and condition when not functioning properly. For example, photovoltaic energy harvester only works wonder under the sun and will lose its abilities to harvest energy when it is raining or at night

The continuity of harvesting energy even when the other energy harvesters are not functioning properly is where hybrid energy harvester come in to yield maximum power output. There is also a lacks reports in hybrid renewable energy harvesting system particularly by comparing the simulation and prototype development works. So, this project will investigate the potential and feasibility of hybrid renewable energy to always generate energy continuously using simulation and hardware prototype.

1.3 Objectives

There are three objectives that served as a guideline for accomplishing this project, which are,

1. To simulate and build the prototype of the hybrid renewable energy harvesting system consists of photovoltaic, piezoelectric and wind energy.
2. To analyse the capabilities of hybrid renewable energy harvester to continue harvesting energy when one or more are not functioning well.
3. To compare the performance of hybrid renewable energy harvester on different conditions and parameters.

1.4 Research Significance

From this project, it is hoping that this project could give useful finding regarding hybrid renewable energy harvesting system (photovoltaic, piezoelectric and wind energy), such as generating continuous power for numerous applications. From there, the better energy harvesting system could be developed in the future for the application of renewable energy in everyday life. More devices and hardware would benefit from energy harvesting system for the self-sustainability, saving energy and reduce waste.

1.5 Scope

To fulfil the objectives, the scopes of project study are:

i. Simulation for renewable hybrid energy harvester consists of photovoltaic and wind energy using MATLAB 2021a.

ii. Prototype for renewable hybrid energy harvester using photovoltaic, piezoelectric and wind energy that have low specifications.

iii. Data collections are done on different day that provides different parameters and weather conditions that gives variety of data pattern.

iv. Applying display system for data and parameters monitoring and recording.

1.6 Thesis Outline

This paper presents the information about energy harvesting system including the simulation and prototype of the hybrid energy harvesting system.

Chapter 1 presents an introduction about this paper including the general information about energy harvesting technology and its application in real world.

Chapter 2 presents the extensive literature review for the relevant topic. Firstly, introducing about four types of energy harvesting system which are photovoltaic, piezoelectric, thermoelectric and radio frequency. Each of the energy harvesting system are explained including the types of material used and its efficiency. Other works and finding from researchers will be included as a reference and research gap.

Chapter 3 presents about the methodology of creating the simulation and prototype of energy harvesting system. For the first part, the simulation is done using MATLAB and other available software to simulate the energy harvesting system. The second part is making a design and prototype of hybrid energy harvesting system for photovoltaic, piezoelectric and wind energy. The output voltage and power will be calculated and then compare with the simulation. The prototype will also be tested under different condition to find out the performance of the system.

Chapter 4 presents the results and discussion for the simulation and prototype. The output voltage and power will be calculated and then compare with the simulation. From here, the analysis will be done to find out if it is efficient enough to generate enough power and if it can generate continuous power for long-term usage.

For Chapter 5, the conclusion is introduced and include some of the improvement that can be done in the future.

Chapter 2

LITERATURE REVIEW

2.1 Overview

Energy harvesting (EH) is a process or technique where the ambient energy is converted into an electricity. The ambient energy come from the surrounding such as light, thermal, motion, and radio frequency. This chapter discusses different types of EH systems and how it works. The photovoltaic energy will be discussing in detail such as the panel types, current-voltage curve, efficiency, and light intensity effects. In thermoelectric energy, the Seebeck effect and thermoelectric generator will be discovered [9]. For mechanical energy, the wind and piezoelectric energy will be discussed. In radio frequency energy, it seems to be popular but have lower power output. Then, the energy storages will be discussed that is essential for energy harvesting. Other than that, DC-DC converter and power inverter will be discussed. Finally, the summarisation is presented at the end of this chapter.

2.2 Energy Sources

The background of the energy sources will be discussed here. As mentioned in the overview, there are many types of energy sources that can be harvested from the environment. The environment energy can come from natural source or man-made activities. Some of the sources including solar radiation, mechanical vibration, radio frequency, thermal and turbine [9]. Solar energy comes from the sunlight. The photovoltaic converts the light into electricity using some semiconductor materials. For thermal energy, the differences across dissimilar materials will create electricity based on Seebeck effects [7]. Piezoelectric creates electric charges based on the mechanical stress applied on the material. The vibration also can create some energy on piezo plate. For wind energy, it uses turbine that transform kinetic energy from the wind into mechanical energy. The radio frequency energy can be harvested in a very small amount and collected through the antenna. It approximately harvested around 100 picowatts per square centimetre [8]. From all this energy sources, the energy transducer is needed to convert it to electrical energy. It is important to find out which energy sources can output the most power density for power generation. Table 2.1 shows the comparison of energy sources and their power density [10].

Table 2. 1 Power densities for variety of energy sources [10].

Sources	Power Density ($\mu W/cm^2$)
Light Source (Outdoor)	10000 (Under the direct sun) 150 (Overcast or cloudy day)
Light Source (Indoor)	100
Thermal Energy	10-800
Radio Frequency	0.1 – 1

From the Table 2.1, it is shown that solar energy has the highest power density than the other energy sources, while radio frequency have the lowest power density.

2.3 Solar Energy Harvesting System

Solar energy harvesting system take and convert the solar energy into electricity by using Photovoltaic (PV) cells. The solar panel is used to convert the light into an electricity by using the photo-electric effect [8]. When sun cast light upon a solar cell, the light that is absorbed into semiconductor generating electron–hole pairs, which divide and transport charges towards the electrodes [11]. Solar energy is abundance at outside especially during daytime. Solar energy also can be harvested indoor enclosed environment likes school and offices by using artificial light for various application relating to low power consumption devices [9]. For outside situation, there is an inconsistency of solar illumination that is affecting the PV efficiency.

So, the Maximum Power Point Tracking (MPPT) Algorithm is used to improve the efficiency of a photovoltaic energy harvesting system [8]. It is basically the DC-DC converter that improves the connection between the PV panels and the energy storage. MPPT views the output of panels and compare it to the energy storages, then it analyses what is the best power that can be put out to charge the energy storages. After that, it is converted to best voltage to get the maximum ampere into the energy storage [12].

Another factor that needs to be taken for the efficiency is the types of solar PV modules that will be discussed in detail after this section.

2.3.1 Photovoltaic Panel Types

Solar panel or PV module is a combination of many photovoltaic cells installed in a framework. The combination of solar panel is called PV panel, while the collection of PV panel is called an array. Solar panels are made from crystalline silicon since they are abundance on earth, high durability and used widely in microelectronics industry [13]. The most common solar panel types are monocrystalline, polycrystalline, and thin film [14]. The types of solar panel made are based on the types of silicon used. Different silicon types also have different method of creating photovoltaic cells. Adding to that, each silicon modules have different efficiency and cost based on the silicon purity and production method. The explanation of each silicon modules are as follows [13], [14],

1. Monocrystalline Silicon Modules

   The silicon is made using the crystal pulling method. Higher cost than the other types of solar panel but have the best efficiency even in low-light condition [8]. Average energy performance of 546.82Wh with daily average photovoltaic panel efficiency of 6.65%. Another research shown about 15-20% efficiency and have decent heat tolerance.
2. Polycrystalline Silicon Modules

   Have the easiest production method which is using the casting method. However, it has lower cost than monocrystalline with lower efficiency. Average energy performance of 517.52Wh with daily average photovoltaic panel efficiency of 5.38%. Another research shown about 13-16% efficiency.
3. Thin Film

   Thin Film are made by putting a thin layer of photovoltaic materials onto a solid surface like glass [15]. It forms a lightweight sheet that is flexible. Thin film has the lowest cost among the three types of solar panel and the lowest efficiency. It has the general efficiency of around 10-13%.