CONTROL OF HYBRID STANDALONE POWER GENERATION SYSTEMS USING FUZZY LOGIC CONTROL

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to as a person we need to keep moving forward. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done step by step.

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ABSTRACT

Standalone photovoltaic system used mainly for the residential load tends to have issues in inconsistent power supply and voltage fluctuation. This issue inevitable due to the characteristic of most renewable power generation in producing intermittent power to the load. Energy storage system such as battery and fuel cell functions to support the system by providing compensation to the power generation system when the power generated is less than required. Numerous control strategies are implemented into photovoltaic system to control the dc-dc converter such as proportional integral derivative (PID) control, sliding mode control (SMC) method and the fuzzy logic control (FLC) technique. Fuzzy logic control is a system that are capable of regulating the voltage flow of the energy storage system by controlling the converter. This work proposes design of fuzzy logic control system for standalone photovoltaic-battery hybrid system and standalone photovoltaic-fuel cell hybrid power generation system. The photovoltaic hybrid system size is also calculated to provide load supply to the residential load in Malaysia. Fuzzy logic control system is designed to focus on the voltage regulation and stability of the DC bus. Similar to battery, fuel cell would function as the energy storage system for the hybrid system for this project. Both hybrid system is simulated using MATLAB/Simulink simulation to obtain the voltage of the DC Bus. The implementation of fuzzy logic control in the photovoltaic-battery system shows a positive result in maintaining the DC bus voltage at the reference voltage. As for the photovoltaic-fuel cell system, the implementation of fuzzy technique does not show a huge difference in regulating the voltage at DC bus.

ABSTRAK

Sistem fotovoltaik tersendiri yang digunakan untuk beban kediaman mempunyai pelbagai masalah terutamanya dalam bekalan kuasa dan turun naik voltan yang tidak konsisten. Isu ini tidak dapat dielakkan kerana ciri penjanaan kuasa terbaharu menghasilkan kuasa tidak teratur kepada beban. Sistem simpanan tenaga seperti bateri dan sel bahan api berfungsi untuk menyokong sistem alternatif dengan membekalkan pampasan kuasa kepada sistem penjanaan tenaga elektrik apabila daya kuasa yang dihasilkan kurang daripada keperluan pengguna. Pelbagai strategi kawalan digunakan ke dalam sistem fotovoltaik untuk mengawal konverter dc-dc seperti kawalan derivatif integral proporsional (PID), kaedah kawalan mod gelongsor (SMC) dan teknik kawalan logik kabur (FLC). Sistem kawalan logik kabur merupakan sistem yang mampu mengawal aliran voltan sistem simpanan tenaga dengan mengawal sistem konverter. Projek ini mencadangkan reka bentuk dan pemodelan sistem kawalan logik kabur untuk sistem hibrid Fotovoltaik-Bateri mandiri dan sistem penjanaan kuasa hibrid Fotovoltaik - sel bahan api mandiri. Saiz sistem hibrid fotovoltaik juga dikirakan untuk membekalkan bekalan beban kepada beban kediaman di Malaysia. Sistem kawalan logik kabur direka untuk memberi tumpuan kepada peraturan voltan dan kestabilan bas DC. Bateri dan sistem sel bahan api akan berfungsi sebagai sistem simpanan tenaga untuk sistem hibrid fotovoltaik. Kedua-dua sistem hibrid disimulasi dengan menggunakan simulasi MATLAB / Simulink untuk mendapatkan voltan Bus DC. Dengan mengaplikasikan kawalan logik kabur dalam sistem bateri fotovoltaik menunjukkan hasil positif dalam mengekalkan voltan bus DC pada voltan rujukan. Manakala bagi sistem sel bahan bakar fotovoltaik, penerapan teknik kabur tidak menunjukkan perbedaan besar dalam mengatur voltan pada bus DC.

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Chapter 1

INTRODUCTION

1.1 Background of PV system

Solar based renewable energy generation has been very common in Malaysia. Due to the geographical location of Malaysia which located at the equator line, Malaysia receives solar energy from the sun for the whole year. Therefore, solar based energy generation are ideal for people living in Malaysia. A stand-alone photovoltaic system is a power generation system that are designed to operate independently from the electric utility grid. It is made up of individual photovoltaic modules or panels that are generally designed and sized. These modules are then combined into arrays to supply certain direct current or alternative current electrical loads. The simplest stand-alone photovoltaic system is a direct-coupled system, where the output of the photovoltaic module or array is connected to the electric load. Since there is no electrical energy storage in the direct-coupled systems, the system can only be operated during sunlight hours. [1] Hence this design is suitable for simple applications that does not require high power rating such as simple solar thermal water heating system and ventilation fan. Figure 1.1 shows a simple diagram that reflects the direct-coupled system.

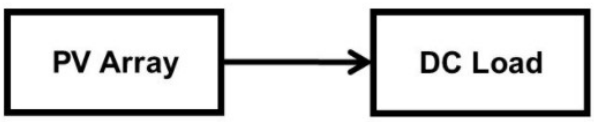

Figure 1-1: Direct coupled system. [1]

Photovoltaic system with energy storage system is more practical and commonly used. It is generally comprising of solar charging modules or photovoltaic arrays, storage system, DC-DC converter and charge controller system or regulators. An inverter may also be included in the system to convert direct current generated from by the PV modules to alternating current which are required to supply certain appliances. [2] The function of the storage device is to support the load power demands when the PV module is not operated especially during the absent of sunlight. The energy storage system provided the power to the load when the available power generated by the PV module is less than the power needed at the load bus. When the power generated by the PV module is more than the power demanded by the load, the PV module are able to supply power to charge the storage device. A simple block diagram in figure 1.2 shows the stand-alone PV system using battery as the storage device.

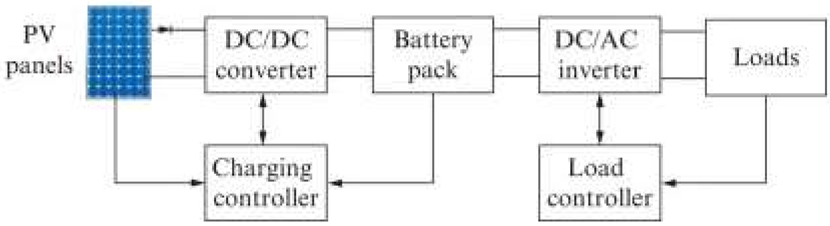

Figure 1-2: Standalone PV system. [2]

The DC-DC converter in between PV modules and storage device shown in Figure 1.2 has the function to secure all available energy generated from the PV module and supply to the battery, in another words, to charge the battery until maximum capacity. The battery will then discharge the power to the load through another DC-DC converter or DC-AC converter depending on the characteristic of the load bus. When there is solar energy available, the DC-DC converter will be disabled. The power supply to the load will be from the storage devices, which in this case is the battery. [3]

1.2 Electrical Energy Storage System

Electrical energy storage system is a very crucial element to support the energy generation system. The reason is because the performance of the energy storage system in the overall energy generation affects heavily on the efficiency as well as the total cost of the operation. [4] Many research had been conducted to explore the different types of energy storage system and the suitability of each device with different energy generation system. Many of the research that were conducted have the similar purpose which is to reduce the cost of the operation in the system and to find a long lasting and vulnerable energy storage device for the energy generation system especially in renewable power. There are four main classifications of the energy storage system. Figure 1.2 shows the detail classifications of various type of storage devices.

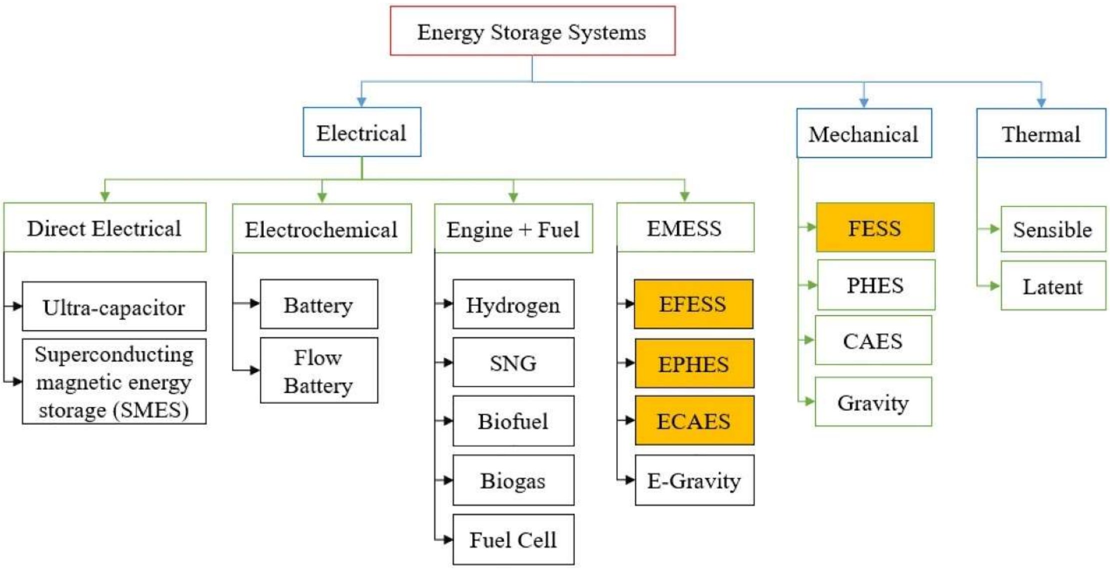

Figure 1-3: Type of storage devices. [5]

Mechanical energy storage system is conducted by transforming the energy produce by the PV module into both mechanical and electrical energy. During charging operation, the electrical energy is converted into mechanical energy in the form of potential energy such as pump hydro storage or kinetic energy like flywheel storage and even in the form of pressurized gas in compressed air energy storage. When the load demand is high, the stored energy is then converted back to the electrical energy to supply to the load. [6] As for thermal energy storage application, it is applied by storing heat or cold storage medium using different parameters such as temperature, place and power. [7] However due the size of the storage application, it is mostly applied in industry that has large area such as industrial factories and residential buildings. Electrochemical energy storage is storage application that uses electrostatic and electrical charges to store energy. This application includes batteries such as lead acid and lithium ions, capacitors storage, and electromagnetic energy storage (SMES). Battery has been primary used as the energy storage devices in most of electrical applications and devices. This energy storage is electrochemical devices that consist of multiple cells which connected either in series or parallel to generate voltage through the chemical reaction between the conductor and the electrolytes. [8]

Battery is commonly used for energy storage device for storing energy produced by the PV module during daytime and supplying to the electrical load when needed. Besides, this battery is also used in advanced PV system to supply energy to the tracker control systems to operate maximum power point (MPP) to supply the electrical loads with stable voltages. [9] However, due to the limitation of the accessibility time and energy in recharging the battery, problems like overcharging and undercharging often occurs and such will contribute to the degradation of the overall system. One of the solutions in overcoming this issue is by using a charge controller. A charge controller is a mechanism that used to control the battery system or the storage device and prevent the overcharging and undercharging issue from happening.

Hydrogen storage and biofuels are characterized under chemical storage system. Hydrogen storage system further classified into four categories which are hydrogen pressurization, absorption of metal hydrides, adsorption of hydrogen and liquefaction of hydrogen. [6] Fuel cell is one of the energy management storage system that uses hydrogen to produce energy. Fuel cells are environmentally friendly and produce zero harmful waste. It usually generates electricity with no noise pollution due to absence of moving parts. The efficiency of fuel cell generally at the range of 50% to 60%. The various types of fuel cells are based from the type of electrolyte, cell operating temperature and the fuel used in its operation. [10]

1.3 Problem Statement

In recent years, photovoltaic power generation system has been well-known especially in residential application. Many people use standalone photovoltaic power generation system as their primary or secondary energy sources to supply power to their residential load. Despite its abundance of benefits such as producing electricity without harmful waste and getting source from the nature [11], this renewable energy system has its own constrains. As the source of this system is obtained from the Sun's solar energy, it falls to its intermittent characteristic of nature as the irregular irradiance resources and inevitable natural causes such as weather and climate change would affect the power generated by the system [12]. Besides that, the uncertainty of load consumption used in the standalone photovoltaic power generation system would also cause the fluctuation in the voltage generated thus a backup energy storage system is needed to support the system [13]. Different power electronic devices such as DC-DC converters, inverters, active power filters, and voltage regulators is utilised to fix this issue. In recent years, electronic based DC-DC converters has shown to be more efficient as compared to the conventional power conversion techniques with its advantages in size reduction, and low effect towards voltage ripples and electromagnetic interference. [14] Different control strategies are implemented to manage the DC-DC converters includes proportional integral derivative (PID), slide mode control (SMC), model predictive control (MPC), state space modelling (SSM) and fuzzy logic control (FLC). [15, 15] Fuzzy logic control is a non-conventional and non-linear control technique that are suitable to be apply in DC-DC converters for standalone photovoltaic power generation system due to its ability to generate accurate solutions based on ambiguous or approximate information. [16] Fuzzy controllers are simple, robust and independent of the non-linearities that does not required any complex mathematical modelling which are commonly used in conventional control strategies. Thus, it can effectively regulate the output voltage generated in the power system. [17] In this project, fuzzy logic system is implemented in DC-DC converters of two photovoltaic – battery hybrid system and photovoltaic – fuel cell hybrid system to regulate the DC link voltage that are supply to the load.

1.4 Research Objectives

The objective of this project includes:

1. to design a controller for PV – Battery Hybrid system using Fuzzy Logic Control system.
2. to design a controller for PV – Fuel Cell Hybrid system using Fuzzy Logic Control system.
3. to simulate the design for both PV – Battery and PV – Fuel Cell system in Matlab/Simulink software and analyse the system.

1.5 Scope of study

This project focus on the implementation of the fuzzy logic control system into the hybrid standalone power generation system which in this case the control of the photovoltaic hybrid power generation system. Fuzzy logic control system is designed and implemented to photovoltaic – battery hybrid system and photovoltaic – fuel cell system. The fuzzy logic controller is implemented to control the dc-dc converter of the system. Each system is simulated using MATLAB Simulink software MATLAB® software is a commercially available simulation software, developed by MathWorks, and able to execute in Microsoft Windows© 10 operating system. The DC Bus voltage of both simulation models using MATLAB Simulink is analyzed.

1.6 Report Outline

Overall, this report consists of five main chapters which illustrate the project in detail. These include introduction, literature review, methodology, result and discussion, and conclusion. The first chapter is about the introduction of this project. This chapter describes on the background of the project, followed by problem statement that influence the development of the project, project objectives, research gap and scope of the project, lastly the organization of project report.

Chapter 2 summarizes the literature review of the project research information. This chapter would provide information of previous works of others and relevant fundamental background related to the project. The research information gathered would help to support the project in terms of concepts, project hypothesis and theoretical analysis that would be referred in this project.

In Chapter 3, the methodology for development of the photovoltaic hybrid system for both battery and fuel cell hybrid model is explained. In this chapter, the fuzzy logic controller that are implemented in the hybrid system to control the operations of the charging and discharging of the battery as well as the operation of the fuel cell is discussed. Flow chart and block diagram of both system is shown to further explain and describe the mechanism of the overall system.

Chapter 4 presents the simulation results of this project. The result and data obtained from the simulation of photovoltaic – battery system and photovoltaic fuel cell system using fuzzy logic control is analyzed and discussed in this chapter.

Finally, the last chapter, Chapter 5 presents the conclusion of this project. The conclusion and future works related to this project will be discussed in this chapter.

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