Faculty of Engineering

# Iterative Simulation-Based Design of a Multi Input Controller for a Hybrid Renewable Energy System

Abdullahi Inusa

Doctor of Philosophy

2021

# Iterative Simulation-Based Design of a Multi Input Controller for a Hybrid Renewable Energy System

Abdullahi Inusa

A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

(Electrical Engineering)

Faculty of Engineering

UNIVERSITI MALAYSIA SARAWAK

2021

## DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

……………………………

Signature

Name: Abdullahi Inusa

Matric No.: 15010115

Faculty of Engineering

Universiti Malaysia Sarawak

Date:

**ACKNOWLEDGEMENT**

Every life endeavour comes with its individual motivations; Allahamdulillah, thanking Allah (SWT) for his infinite mercies for making it possible for me to witness the completion of my PhD pursuit. I also put forth many prayers that may it be beneficial to entire humanity, my family, and self by Allah's grace. Aamiin ya Rabbil Alamin.

I sincerely appreciated my supervisor's efforts in diverse form, Associate Professor Dr Thelaha bin Hj Masri who encouraged and supported me in different ramifications throughout the study period at Universiti Malaysia Sarawak. His expertise in the study remains with me as an indelible guided footstep to emulate. Similarly, I thank my co-supervisor Professor Dr Wan Azlan Wan Zainal Abidin for his enormous support and encouragements at hard times. Many thanks go to my family that included wife Hajiya Hannatu Musa, children Dr Abba A. Yunusa MBBS, Aisha A. Yunusa ICAN, Muhammad A. Yunusa student Engineer, and Ibrahim A. Yunusa who have been considerate during the study period for living on very meagre resources as when tuition and rent fee becomes due. I also thank the Department, Faculty and the Universiti Malaysia Sarawak for their wonderful supports on their humanly resourcefulness.

I appreciated my colleagues and good friends like Mr. Melvin who translate abstract to Bahasa Malaysia, Dr Salisu M Lawan, Dr Saidu Adamu Abubakar, the university that contributed in many ways toward the successful completion of this thesis. Thanks a lot. Jazakumullahu Khair.

## ABSTRACT

Sustainable energy supply is a priority need for socioeconomic and entrepreneurial development of communities in remote areas. Especially, in a developing country like Malaysia, providing sustainable energy to these areas has become a challenging task for the government. From past records, a micro-hydro plant hardly works for more than one year continuously without having problems like stalling or breakdowns due to ecological / technical problems. Generators fuel has been very expensive and further away from remote villagers. The enhancement of single source standalone renewable energy to hybrid structure will provide alternative power supply as standby to the consumer load. The one important component to this method is the automated control units that could monitor all resources' conditions and decides which source of power supply is on standby. The Micro-Hydro is the main source and solar photovoltaic with the other energy resources are at standby. With that, in this study, a design of an iterative sequential controller for multiple inputs, single output power system was considered and proposed. Micro hydro and solar photovoltaic renewable energy, energy storage and Utility grid are used as alternative standby resource, determined by priority. The projected concept is interactive user friendly, flexible, visually analytical for remote standalone hybrid renewable energy station regulator. The design apply algorithm to implement object oriented finite-state machines model constructed from Simulink to obtain multiple-input single-output profile. The model-depicted curves of sequential transition trajectory contour, logic truth table, etc. in the practical selection for project work. The hybrid design of controller improved the standalone renewable energy system sustainability and alleviate other challenges at lower cost.

**Keywords:** Hybrid renewable energy resource, iterative simulation-based, design Sustainability, modelling, Finite-state machines

***Reka Bentuk Berasaskan Simulasi Iteratif Pengawal Hibrid untuk Sistem Tenaga Boleh Diperbaharui Hibrid***

***ABSTRAK***

*Bekalan tenaga lestari adalah keperluan utama bagi pembangunan sosioekonomi dan keusahawanan masyarakat di kawasan terpencil, terutama di negara membangun seperti Malaysia. Menyediakan sistem tenaga lestari ke kawasan-kawasan ini telah menjadi tugas yang mencabar bagi pemerintah. Dari kajian lalu, loji hidro mikro yang dipasang di kawasan-kawasan tertentu telah didapati tidak berfungsi selepas lebih dari satu tahun disebabkan mengalami masalah dan kerosakan berpunca daripada faktor-faktor ekologi dan teknikal. Bahan bakar untuk sistem janakuasa elektrik (generator) pula sangat mahal dan terletak jauh daripada penduduk kampung yang tinggal di kawasan terpencil. Dengan itu, pengenalan kepada sistem tenaga boleh diperbaharui berstruktur hibrid akan menyediakan bekalan kuasa alternatif sebagai penyelesaian kepada pengguna. Satu komponen penting dalam kaedah ini adalah unit kawalan automatik yang dapat memantau keadaan semua sumber dan memutuskan pilihan sumber bekalan kuasa yang sesuai untuk pengguna. Dalam kajian ini, sistem tenaga hidro mikro diambil sebagai sumber utama selain sistem tenaga solar dan sumber tenaga lain yang lumrah digunakan. Dengan itu, reka bentuk pengawal urutan berulang untuk pelbagai input dengan, sistem kuasa output tunggal diperkenal dan dicadangkan. Tenaga elektrik dari sistem hidro mikro, sistem solar, sistem kincir angin dan grid utiliti disediakan sebagai sumber siap sedia alternatif, manakala pemilihannya ditentukan keutamaannya dari konsep yang diperkenalkan, supaya ianya lebih mesra pengguna dari sudut interaktif, fleksibel disertai dengan analisis visual untuk pengatur stesen tenaga boleh diperbaharui hibrid secara mandiri. Reka bentuk model yqng dicadangkan menerapkan algoritma model mesin berorientasikan objek yang dibina dari*

*Simulink untuk mendapatkan profil output tunggal berbilang input. Lengkung model yang dihasilkan dari kontur lintasan peralihan berurutan, jadual kebenaran logik, dan lain-lain dalam pemilihan praktikal untuk kerja projek, dikaji secara terperinci. Reka bentuk pengawal hibrid ini meningkatkan kesinambungan sistem tenaga boleh diperbaharui secara mandiri dan mengurangkan kos operasi secara keseluruhan.*

**Kata kunci:** *Sumber tenaga boleh diperbaharui hibrid, reka bentuk berasaskan simulasi berulang, kelestarian, pemodelan dan mesin finite-state*

**TABLE OF CONTENTS**

**Page**

## LIST OF TABLES

**LIST OF FIGURES**

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | Alternating Current |
| BESS | Battery Storage System |
| CAES | Compressed Air Energy Storage |
| CdTe | Cadmium Telluride |
| CECS | Central Energy Controller System |
| CIGS | Copper-Indium-Gallium-Dieseline |
| ESS | Energy Storage System |
| EUI | Energy Unsustainability Index |
| EV | Electric Vehicle |
| FSM | Finite State Machines |
| GA | Generic Algorithm |
| GaAs | Gallium Arsenide |
| GHG | Green House Gas |
| GMPP | Global Maximum Power Point |
| GUI | Graphical User Interface |
| HDI | Human Development Index |
| HCI | Human Computer Interaction |
| HEC | Hybrid Energy Control |
| HECS | Hybrid Energy Control System |
| HES | Hybrid Energy System |
| HESS | Hybrid Energy Storage System |
| HMI | Human Machine Interface |

| | |
|---|---|
| MPPT | Maximum Power Point Tracking |
| ODE | Ordinary Differential Equation |
| PAC | Programmable Auto. Controller |
| PEMFC | Proton Exchange Membrane Fuel Cell |
| PH | Pump Hydro |
| PD | Proportional Derivative |
| PI | Proportional Integral |
| PID | Proportional Integral Derivative |
| PH | Pump Hydro |
| PHES | Pump Hydro Energy Storage |
| PHSS | Pumped Hydro Storage System |
| PLC | Programmable Logic Controller |
| P&O | Perturb & Observe |
| PSCAD | Power System Computer Aided Design |
| PSO | Particle Swam Optimization |
| PWM | Pulse Width Modulation |
| PV | Photovoltaic |
| RE | Renewable Energy |
| RER | Renewable Energy Resource |
| RLC | Resistive Inductive and Capacitive |
| RTD | Resistance Temperature Detector |
| RTU | Remote Terminal Unit |
| SCADA | Supervisory Control and Data Acquisition |
| SCORE | Sarawak Corridor of Renewable Energy |

| | |
|---|---|
| SDG | Sustainable Development Goals |
| SDEG | Standalone Distributed Energy Generation |
| SEB | Sarawak Electricity Berhad |
| SFC | Sequential Function Chart |
| SISO | Single Input Single Output |
| SPV | Solar Photovoltaic |
| SREPP | Small Renewable Energy Power Program |
| SSS | Standalone Single Source |
| TC | Thermocouple |
| TCT | Total Cross-Tie |
| TNB | Tenaga Nasional Bernhard |
| TOC | Theory of Constraint |
| UI | User Interface |
| UNIMAS | Universiti Malaysia Sarawak |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Different countries have diverse energy challenges like remote rural distance; erratic energy addressed using Standalone Distributed Energy Generation (SDEG) from Dispersing Renewable Resources (DRR). A strategic approach tailored by individual countries depend on regional situations to meet the energy irregularity and shortage. Various nations or situations have different energy demands that present varied energy encounters, and related solutions. Diverse and disperse remote rural populations of the world mostly rely on standalone single source lack sustainable and adequate electricity supply. SDEG is a priority requirement for the socioeconomic and entrepreneurial development of remote rural communities like in Malaysia. Remote settlers use various fossil fuels for daily energy requirements despite the trend of increasing fuel costs, and carbon emission health hazards due to environmental impacts (Alam et al., 2013; Kaygusuz, 2012).

Standalone power supply with a single source is the common electrical structure in rural remote locations so the loss of energy probability becomes a common phenomenon. Commercial and industrial activities anywhere require sustainable energy therefore alternative power systems such as Hybrid Renewable Energy Resources (HRER) and its components have energy sustainability impacts (Alam et al., 2013). HRER components like the electric energy resources, Proton Exchange Membrane Fuel Cell (PEMFC) and energy automation hybrid controller or hybrid switch eventually increase power consistency at less cost (optimized).

Solar Photovoltaic (SPV) is one of the Renewable Energy (RE) sources that are truly intermittent, and not stockpiled like the conventional fossil system. Integrating Micro Hydro (MH) with complementary SPV, energy storage and other energy components as a hybrid could improve energy sustainability. The daily maximum energy demand usually lasts for several hours of every day. Whereas, solar energy is intermittent and the backup or storage service lasts for shorter duration or the MH flow rate is periodically dynamic. HRER power supply sequential transition (Borges, 2012) can extend supply sustainability, all the same, the standalone hydro last as long as run-of-the-river water flow, it is said to be intermittent.

The simulation -based design of Hybrid Renewable Energy System (HRES) use multiport-switch logic patterns of crossbreed energy sources. The SPV and MH primary meteorological data, energy storage and utility grid become the inputs to the hybrid controller or multiport-switch as output. The hybrid solar photovoltaic and micro-hydro supply disperse communities using hybrid standalone infrastructure. Residential, industrial and commercial consumers of electricity supplied with energy for socioeconomic activities require optimal cost and supply standby (Amer et al., 2013).

The electricity delivery becomes sustainable when the subsystems have alternative backups in the form of hybrid structure. Development of HRER for power sustainability involves sites, resource data feasibility analysis to determine Renewable Energy System (RES) availability level. The design, modelling, and simulation of subsystems like hybrid energy resources, Hybrid Energy Storage Systems (HESS) or Hybrid Renewable Controller (HRC) become important (Amer et al., 2013). The proposition of hybrid energy control for hybrid MH, SPV with PEMFC as ESS, and utility grid or other RE using HRC controller or hybrid switch platform enhance energy sustainability. The plan of simulation-based design