A Design Scheme of Energy Management, Control, Optimisation System for Hybrid Solar-Wind and Battery Energy Storages System

A Thesis Submitted for the Degree of Doctor of Philosophy

by

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ABSTRACT

Hybrid renewable energy system was introduced to improve the individual renewable energy power system’s productivity and operation-ability. This circumstance has led towards an extensive technological study and analysis on the hybrid renewable energy system. The extensive technological study is conducted using many different approaches, but in this research the linear programming, artificial intelligence and smart grid approaches are studied.

This thesis proposed a complete hardware system development, implementation and construction of real-time DC Hybrid Renewable Energy System for solar-wind-battery energy source integrated with grid network support. The proposed real-time DC HRES hardware system adopts the hybrid renewable energy system concept which is composed of solar photovoltaic, wind energy system, battery energy storage system and grid network support. The real-time DC HRES hardware system research work is divided into three stages. Stage 1 involves modelling and simulation of the proposed system using MATLAB Simulink/Stateflow software. During this stage, system’s methodological design and development is emphasised. The obtained results are considered as fundamental finding to design, develop, integrate, implement and construct the real-time DC HRES hardware system. Stage II is designing and developing the electronic circuits for the real-time DC HRES hardware system using PROTEUS software. Real time simulation is performed on the electronic circuits to study and analyse the circuit’s behaviour. This stage also involves embedded software application development for the microcontroller PIC16F877A. Thus, continuous dynamic decision-making algorithm is developed and incorporated into microcontroller PIC16F877A. Next, electronic circuits and continuous dynamic decision-making algorithm are integrated with the microcontroller PIC16F877A as a real-time DC HRES hardware system to perform real time simulation. The real-time DC HRES hardware system simulation results are studied, analysed and compared with the results obtained in Stage 1. Any indifference between the obtained results in Stage 1 and Stage 2 are analysed and necessary changes are made. Stage 3 involves integrating, implementation and construction of real-time DC HRES. The continuous dynamic decision-making algorithm is also incorporated into the real microcontroller PIC16F877A development board. Real-time DC HRES’s
experimental results have successfully demonstrated the system’s ability to perform supervision, coordination, management and control of all the available energy sources with lease dependency on the grid network. The obtained results demonstrated the energy management and optimisation of the available energy sources as primary power source deliver.
ACKNOWLEDGEMENTS

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ADC</td>
<td>Analogue to Digital Conversion</td>
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<td>ASEAN</td>
<td>The Association of Southeast Asian Nation</td>
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<td>BATT</td>
<td>Battery</td>
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<tr>
<td>BC</td>
<td>Boost Converter</td>
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<tr>
<td>BESS</td>
<td>Battery Energy Storage System</td>
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<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
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<tr>
<td>CSP</td>
<td>Concentrating Solar Power</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>DE</td>
<td>Differential Evolution</td>
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<td>DisCh</td>
<td>Discharging</td>
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<td>DL</td>
<td>Dump Load</td>
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<td>FC</td>
<td>Fuel Cells</td>
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<td>FF</td>
<td>Fill Factor</td>
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<td>FL</td>
<td>Fuzzy Logic</td>
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<td>GA</td>
<td>Genetic Algorithm</td>
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<tr>
<td>HCC</td>
<td>Hybrid Charge Controller</td>
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<td>HOMER</td>
<td>Hybrid Optimization of Multiple Energy Resources</td>
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<td>HRES</td>
<td>Hybrid Renewable Energy System</td>
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<tr>
<td>IC</td>
<td>Integrated Circuit</td>
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<td>HEP</td>
<td>Hydroelectric Power</td>
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<td>LCD</td>
<td>Liquid Crystal Display</td>
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<td>LED</td>
<td>Light Emitting Diodes</td>
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<td>MCLR</td>
<td>Master Clear Unit</td>
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<td>MGT</td>
<td>Micro Gas Turbine</td>
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<tr>
<td>MPPT</td>
<td>Maximum Power Point Tracker</td>
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<tr>
<td>NC</td>
<td>Normally Closed</td>
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<td>NN</td>
<td>Neural Network</td>
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<td>NO</td>
<td>Normally Open</td>
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<tr>
<td>OWC</td>
<td>Oscillating Water Column</td>
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<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
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<tr>
<td>PEMFC</td>
<td>Proton Exchange Membrane Fuel Cell</td>
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<tr>
<td>PSO</td>
<td>Particle Swarm Optimisation</td>
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<td>PV</td>
<td>Solar Photovoltaic</td>
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<td>PWM</td>
<td>Pulse Width Modulation</td>
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<tr>
<td>RESs</td>
<td>Renewable Energy Sources</td>
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<td>RETs</td>
<td>Renewable Energy Technologies</td>
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<td>RPM</td>
<td>Revolutions Per Minute</td>
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<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
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<td>SoC</td>
<td>State of Charge</td>
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<td>SVP</td>
<td>Solar Ventilation Preheating</td>
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<td>TSR</td>
<td>Tip Speed Ratio</td>
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<td>UK</td>
<td>United Kingdom</td>
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<td>VRs</td>
<td>Variable Resistors</td>
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<td>VSM</td>
<td>Virtual System Modelling</td>
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<td>WT</td>
<td>Wind Turbine</td>
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DECLARATION

This work was produced by the author unless otherwise stated and duly acknowledged.

Signed: ..............................

Date: ..............................
CHAPTER 1

INTRODUCTION

Renewable energy sources have been available since many years ago. Renewable energy sources usually come from the natural sources such as sunlight, wind, rain water, tides, waves, geothermal heat and much more. These renewable energy sources can be used as replenishment to the depleting fossil fuels for electricity generation. The concern of depleting fossil fuels has encouraged the industries to explore or to increase the electricity productivity using the available renewable energy sources. Also, recent concerns on the concentrations of greenhouse gasses because of fossil fuels combustion have also encouraged the industries to look into new alternative sources for electricity generation. Alternative sources such as solar and wind power have been looked as notable renewable energy sources to support the diminishing conventional fossil fuels for electricity generation. Over the past 10 years, solar and wind power energies made a significant rise. Ever since solar and wind power is seen able to promisingly take over on the fossil fuels for electricity generation, many countries and local governments invested a lot of money into renewable energy electricity generation and distribution systems.

As the solar and wind power systems are growing into large-scale, the energy researchers, scientists and practitioners are looking into continuity research to improve the overall system performances, operation and reducing the financial risks. First, renewable energy sources such as solar and wind is always dependent on the geographical area, periodic climate change and greater energy production probability may disperse from the load locations. Neither solar nor wind power systems have the capability to fully satisfy the load demand and consumption due to the geographical area and periodic climate changes. Hence, solar and wind energies are combined to complement each another as hybrid power system to increase the electricity power generation, production and reduce the greenhouse gas emission impact on the environment. With the development of complementary hybrid power system, the power intermittency issue which greatly reflects on the climate condition can be probably resolved or improved. Theoretically, solar and wind complementary hybrid power systems have got more...
advantages compare to any other single renewable energy source power system. Solar Wind Energy Tower article [1] mentioned about the latest development of solar and wind complementary hybrid power system, which is also known as Hybrid Renewable Energy System (HRES). This development has emphasised on the optimisation of the hybrid system design for reliable economy costing. In its comparison the designed and developed complementary or hybrid solar - wind power system have shown a significant reduction in the installation area and costing while increasing the lifetime of the overall system performances [2]. This indicates that the deployment of renewable energy sources as complementary or hybrid power system could economically increase many involved parameters for a better performance [3]. Looking at the design and development in [1], this research hypothesised that complementary or hybrid renewable energy sources presents the cost-effective electricity power generation scheme to accommodate the increasing power supply demand and optimised the system operation.

This research work is divided into three stages; 1) modelling and simulating the concept of solar-wind renewable energy sources using the self-intervention method to supervise, coordinate, manage and control the available sources for an optimal system operation and integrating charging and discharging process for the Battery Energy Storage System (BESS) using MATLAB Simulink/Stateflow Software. 2) Designing, developing and simulating electronic circuits for solar-wind renewable energy sources and BESS to perform the self intervention method for optimal system controllability and operation, incorporating microcontroller PIC16F877A to supervise, coordinate, manage and control the BESS charging and discharging process using PROTEUS Software. 3) Development, implementation, integration and construction of solar-wind renewable energy sources and BESS as a complete hardware system for real-time testing.

This research work is conducted in three stages are to fundamentally study the concept of supervising, coordinating, managing and controlling the solar-wind renewable energy sources and BESS for optimal operation with least dependency on the power source supply from the grid network. Each stage is presented with system performance analysis results, obtained results in stage one and two are categorised as preliminary results to validate the self intervention of solar-wind renewable energy sources and BESS for charging or discharging process. The obtained preliminary results in stage one demonstrated the supervision,
coordinating, managing and controlling of solar-wind renewable energy sources and BESS charging or discharging using the MATLAB Simulink/Stateflow software.

Once the obtained preliminary results in stage one are studied and analysed, then the research is proceed to second stage. In the second stage, the electronic circuits PROTEUS software is used to design, develop and simulate the modelled system in stage one. All the modelled subsystems in stage one are designed, developed and simulated based on the real-time condition. The PROTEUS software is used to design and develop the electronics circuit and integrate the electronic circuits with microcontroller PIC16F877A to perform supervision, coordinating, managing and controlling the solar-wind renewable energy sources and BESS charging or discharging process. Prior to that, the embedded software application is designed and developed for microcontroller PIC16F877A. The embedded software application is important to be incorporated into microcontroller PIC16F877A to perform mathematical calculation on the available voltages to allow the microcontroller PIC16F877A intelligently supervise, coordinate, manage and control the solar-wind renewable energy sources and BESS charging or discharging process. This also will assist the system to optimise the solar-wind renewable energy sources and BESS utilisation for the connected Alternating Current (AC) load with least dependency on the grid network. The obtained results during the system simulation using the electronic circuits PROTEUS software is compared, analysed and validated with the obtained preliminary results in stage one. After these results are satisfied, then the hardware development, implementation, integration and construction is carried out. For a good hardware performance, it is necessary to realize a good preliminary work, clear feasible study which will be an indication for optimal technical solution for hardware development, implementation, integration and construction.

1.1 POWER ELECTRONICS ADVANCEMENT

Among the DC HRES, solar and wind energies are utilised broadly due to the extensive research in the system and technology development. Power electronics engineering research field have impacted in smoothing the overall performances of DC HRES for a continuous reliability of power generation, overall system operational optimisation and energy delivery/transfer between available sources/loads. Although many large HRES have been and are still under construction all around the globe, small scale HRES have seen increasing in
numbers and getting more focus in the recent years. Small scale HRES such as DC based are getting attention due to their lower impact on the landscape, avoid synchronisation process such as in AC based system, their ability to operate separately from the grid (islanded) and also able to operate with the grid network (non-islanded). In general, there is huge potential of usage for small scale DC HRES with strategic supervision, coordination, management and control of the available power from renewable energy sources and BESS for optimum power delivery, each subsystem to operate together and efficient self intervention performance between renewable energy sources and switching between BESS for charging or discharging process. All of these advantages are not possible with all the advancements in the power electronics engineering field.

1.2 MOTIVATIONS

Solar and wind energies are being utilized broadly as source to electricity generation due to the advance development in the renewable energy sector and technology, their freely available energy characteristics at no extra cost, independency from fossil fuels and cost reduction in the individual system development have gained interest from many sectors. The work to develop indigenous Direct Current (DC) HRES using solar and wind to harvest the available energies from the sun and wind to generate electricity requires proper technologies integration. Even though the solar and wind DC HRES have improved significantly in terms of design and development, there are still challenges involved in many subareas of the HRES. One of the challenges or constraints exist in the HRES are the power management control strategy, to harness the DC energies as maximum as possible to optimise the freely available power source as primary supply for the connected AC load. Therefore, a strategic power supervision, coordination, management and control from the input sources to the connected load and BESS for charging or discharging are necessary. In addition, these challenges and constraints need to be address due to HRES dependency on the weather that would cause the intermittency of power delivery and operation optimisation. The increase research and advancement in power electronics engineering have provided the flexibility to address the challenges and constraints of smoothing the power delivery via an effective supervision, coordination, management and control at the DC HRES.
1.3 PROBLEM STATEMENT

At this point, the integration of solar and wind renewable energy sources as a system is gaining popularity due to their limitation to perform satisfactorily as an individual source. Due to the intermittent climate nature, individual solar or wind energy power systems are unable to perform and satisfactorily meet the load demand. Hence, integrating solar and wind renewable energy sources can improve the system complementary operation for maximum power delivery. With additional of some sources and sinks, counter balance the system intermittency could be achieved. The rapid development in the renewable energy and power electronics technology, reduced costing of the energy storages and broad microgrid system applications, various different system control strategies for optimum operation of power delivery and management has managed to achieved an effective energy distribution from the sources to the load of a HRES [4].

The concept of having two renewable energy sources is no longer new and have gained popularity in recent years such as been discussed in [5 - 10]. HRES is aimed to increase the system power delivery efficiency, optimise system operation and increase the power utilisation mainly from HRES. In general, HRES have huge potential for utilising the renewable energy sources to maximize the electricity power generation and distribution for increasing electricity demand around the globe. However, HRES encounter several technical challenges which are mainly associated to the intermittent climate and nature of the renewable energy sources. Thus, the technical challenges associated with HRES require an extensive research in several areas. The areas that have been identified are:

Proper sources self-intervention to achieve system operational optimisation for power management strategy and utilisation – It is to ensure that the power produced by solar-wind renewable energy sources can be optimised as much as possible without switching to the grid network. Also, to assist the HRES to operate at minimum production level but still would be able to perform at optimum performance when intermittent nature condition occurs.

Proper supervision, coordination, management and control of each subsystem that is connected via the control system – The HRES requires a proper supervision, coordination, management and control among each of the subsystem during a complete system operational. Therefore, the control system has to supervise, coordinate, manage and control different task