DESIGNING AND SIMULATION OF ENERGY STORAGE SYSTEM FOR AN INSTITUTIONAL BUILDING

IBRAHIM KHALEEL BURHAN ALNAJI

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Faculty of Electrical Engineering
Universiti Teknologi Malaysia

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DEDICATION

This project report is dedicated to my father and my mother who supported me throughout my journey of education

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ABSTRACT

The purpose of this project is to compare between Energy Storage System(ESS, battery only) and Hybrid Energy Storage System(HESS, battery and supercapacitor) for a stand-alone PV system, followed by designing and simulation of an ESS for institutional building by considering the load demand, temperature and solar irradiance. The advantage of this project is to prolong lifespan of ESS and reduce the fluctuation of the output power and battery current. Parallel-active topology converter are used with underline control circuit using PI controller to maintain the ESS and PV output voltage at constant value even if there is a small reduction in irradiance. By using MATLAB/Simulation a stand-alone PV system with ESS (battery only) and HESS(battery with supercapacitor) are designed and simulated. The comparison results shows that with HESS (battery with supercapacitor), the SOC of battery little improves by 0.0005%, the peak current reduced by 69% and the fluctuations of output power and battery current are reduced compare to ESS(battery alone).

ABSTRAK

Tujuan projek ini adalah untuk membandingkan di antara Sistem Penyimpanan Tenaga (ESS, bateri sahaja) dan Sistem Penyimpanan Tenaga Hibrid (HESS, bateri dan supercapacitor) untuk sistem PV Terasing, diikuti dengan merekabentuk dan mensimulasi ESS untuk bangunan institusi dengan mempertimbangkan permintaan beban, suhu dan pancaran solar. Kelebihan projek ini adalah memanjangkan jangka hayat ESS dan mengurangkan perubahan keluaran kuasa dan arus bateri. Penukar topologi aktif selari digunakan dengan litar kawalan garis yang berpandukan pengawal PI untuk mengekalkan ESS dan voltan keluaran PV pada nilai malar walaupun terdapat sedikit pengurangan cahaya. Dengan menggunakan MATLAB / Simulasi sistem PV Terasing dengan ESS (bateri sahaja) dan HESS (bateri dengan supercapacitor) direkabentuk dan disimulasikan. Hasil perbandingan menunjukkan bahawa dengan HESS (bateri dengan supercapacitor), SOC bateri meningkat sebanyak 0.0005%, arus puncak berkurang sebanyak 69% dan perubahan keluaran kuasa dan arus bateri berkurang dibandingkan dengan ESS (bateri sahaja).

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LIST OF ABBREVIATIONS

TPES	-	Total Primary Energy Supply
GCC	-	Global Climate Change
RES	-	Renewable Energy Source
ESS	-	Energy Storage System
HESS	-	Hybrid Energy Storage System
HPS	-	High Power Storage
HES	-	High Energy Storage
BES	-	Battery Energy Storage
SCES	-	Supercapacitor Energy Storage
FC	-	Fuel Cell
MG	-	Micro Grid
SFES	-	Superconductor Flywheel Energy Storage
SC	-	Super Capacitor
SMES	-	Superconducting Magnetic Energy Storage
RBC	-	Rules Based Controller
DBC	-	Droop Based Controller
FBC	-	Filtration Based Controller

LIST OF SYMBOLS

I	-	Current
q	-	Charge of electron
V	-	Voltage
K	-	Boltzmann constant
C	-	Capacitance
L	-	Inductance
T	-	Temperature
R	-	Resistance
P	-	Power
K1,K2	-	Ratio
N	-	Number of parameters
SOC	-	State of charge
f	-	Frequency
℃	-	Celsius

CHAPTER 1

INTRODUCTION

1.1 Background of study

The global annual production of electrical energy grows and exceeds the growth rate of the Total Primary Energy Supply (TPES). The growth of the annual rate of TPES has been 1.9% since 1980, while for the electric energy production is 4.9%. That's means that many of the international TPES growth depend on the increasing in production of electrical energy. Recently, all indications shows that the global electricity demand will keep increasing in the near future as it doubles now every 14.5 years[1]. The major load that contribute to energy increment are the air conditioning system especially during the sunny and hot days.

The coal contributes 39% of the productid electrical energy in global range while the natural gas contributes of 23% of the productid electrical energy. Large amount of CO2 will be emitted to the air by utilizing these sources of energy which leads to increasing in earth temperature and the Global Climate Change (GCC).

Due to the environmental damaging outcomes and to sustain the growing energy demand, many countries try to minimize the usage of fossil fuel, such as coal and replace with Renewable Energy Sources (RES)[1].

Some of renewable energy power sources depend on the environment and weather condition to produce their energy such as solar cells and wind turbines. A lot of problems comes from these fluctuations of power supply such as variations in frequency of voltages supplied to the grid in the case of renewable sources in grid-connected mode. Another critical problem is the lack of other sources which is lead to blackouts when renewable sources not able to obtain and that's in case of standalone power supplies. The solution for these problems is the energy-storage system (ESS)

which is able to balance the power demand and the power source and make the system stable all the time. Therefore, it is one of the keys for large-scale introduction of renewable energy sources[2].

Moreover, Hybrid energy storage systems (HESSs) appeared as a solution to maintain good performance of the system, which is defined by connecting more than one of the different energy storage technologies. A single (ESS) technology not able to sustain the desired system operation because of its limited ability and capability in terms of power density, energy, cost, lifespan and dynamic response. In recent years a lot of researches have been published to show and illustrate the advantageous impact of HESS on RESs systems. Different ESS can be used as an HESS depends on the reason of the hybridization. Generally, the HESS combining of two types of storage which are high-power storage (HPS) responsible of absorbing and deliver the transient and peak power, and high-energy storage (HES) responsible to meets the long-term energy demand[3].

1.2 Problem Statement

Since the solar energy is not available all the time, a storage devices is required to fulfill the building demand. The most common energy storage technology used to balance the power demand and power source for standalone PV system is batteries. However, the battery has it is own disadvantages, where it has shorter lifespan, slow response for changing in load or solar irradiance, fluctuations and fast current transient and voltage transients in the battery. Therefore, an analysis on HESS and simulation will be carry out to conform reliability of the system.

1.3 Objectives of the project

- To compare ESS with HESS considering solar irradiance and load demand.
- To improve the energy storage system performance by using hybrid ESS technologies.
- To simulate the HESS with the standalone solar system design using MATLAB/Simulink Program.

1.4 Scope of study

A standalone PV system is considered in this study. A temperature data and the solar irradiance data for one month is obtained from meteorological department. The load profile data for the building is obtained from previous study[4]. Two energy storage devices which are battery and supercapacitor will simulate as an HESS. Two case study will be done in this project, which are a small DC load circuit for proving the advantages of HESS compared to ESS and complete AC load circuit of the Faculty of Electrical Engineering (FKE) , University Teknologi Malaysia (UTM) , Johor, Malaysia.

1.5 Report Organization

Chapter 1 describes the ESS and HESS and provides general information about the study objectives, the problem statement, as well as the scope of the research.

Chapter 2 reviewed the past works done on the designing of the ESS using different energy storage devices. This chapter includes the literature review about different HESS devices and control techniques, as well as the modeling of different circuits of PV system with ESS in MATLAB software.

Chapter 3 discusses the methods used in this project for designing stand-alone PV system with HESS using MATLAB/Simulink.

Chapter 4 analyzed the result obtained from MATLAB/Simulink software. The output waveforms of the circuits will be discussed in this chapter.

Chapter 5 concludes the results of stand-alone PV system with HESS or with ESS also the suggestion for the future works.

REFERENCES

[1] M. D. Leonard, E. E. Michaelides, and D. N. Michaelides, "Energy storage needs for the substitution of fossil fuel power plants with renewables," *Renewable Energy,* vol. 145, pp. 951-962, 2020.

[2] D. Yamashita, K. Tsuno, K. Koike, K. Fujii, S. Wada, and M. Sugiyama, "Distributed control of a user-on-demand renewable-energy power-source system using battery and hydrogen hybrid energy-storage devices," *International Journal of Hydrogen Energy,* 2019.

[3] S. Hajiaghasi, A. Salemnia, and M. Hamzeh, "Hybrid energy storage system for microgrids applications: A review," *Journal of Energy Storage,* vol. 21, pp. 543-570, 2019.

[4] R. Ayop, "Sizing of Energy Storage Based on Loss of Load Probability of Standalone Photovoltaic Systems," Universiti Teknologi Malaysia, 2015.

[5] J. Liu, X. Chen, S. Cao, and H. Yang, "Overview on hybrid solar photovoltaic-electrical energy storage technologies for power supply to buildings," *Energy conversion and management,* vol. 187, pp. 103-121, 2019.

[6] K. A. Reddy, K. Srinivas, and G. Ayyappan, "Simulation of power management circuit in a standalone solar photovoltaic-fuel cell-battery hybrid power system," in *2015 IEEE IAS Joint Industrial and Commercial Power Systems/Petroleum and Chemical Industry Conference (ICPSPCIC)*, 2015, pp. 168-173: IEEE.

[7] O. Saadeh, R. Rabady, and M. B. Melhem, "New effective PV battery charging algorithms," *Solar Energy,* vol. 166, pp. 509-518, 2018.

[8] N. Rai and B. Rai, "Control of fuzzy logic based PV-battery hybrid system for stand-alone DC applications," *Journal of Electrical Systems and Information Technology,* vol. 5, no. 2, pp. 135-143, 2018.

[9] J. Hu, Y. Xu, K. W. Cheng, and J. M. Guerrero, "A model predictive control strategy of PV-Battery microgrid under variable power generations and load conditions," *Applied Energy,* vol. 221, pp. 195-203, 2018.

[10] T. Kousksou, P. Bruel, A. Jamil, T. El Rhafiki, and Y. Zeraouli, "Energy storage: Applications and challenges," *Solar Energy Materials and Solar Cells,* vol. 120, pp. 59-80, 2014.

[11] L. W. Chong, Y. W. Wong, R. K. Rajkumar, and D. Isa, "An adaptive learning control strategy for standalone PV system with battery-supercapacitor hybrid energy storage system," *Journal of Power Sources,* vol. 394, pp. 35-49, 2018.

[12] Q. Jiang and H. Hong, "Wavelet-based capacity configuration and coordinated control of hybrid energy storage system for smoothing out wind power fluctuations," *IEEE Transactions on Power Systems,* vol. 28, no. 2, pp. 1363-1372, 2012.

[13] H. Lee, B. Y. Shin, S. Han, S. Jung, B. Park, and G. Jang, "Compensation for the power fluctuation of the large scale wind farm using hybrid energy storage applications," *IEEE Transactions on Applied Superconductivity,* vol. 22, no. 3, pp. 5701904-5701904, 2011.

[14] S. Mane, M. Mejari, F. Kazi, and N. Singh, "Improving lifetime of fuel cell in hybrid energy management system by lure–Lyapunov-based control formulation," *IEEE Transactions on Industrial Electronics,* vol. 64, no. 8, pp. 6671-6679, 2017.

[15] M. Momayyezan, D. B. W. Abeywardana, B. Hredzak, and V. G. Agelidis, "Integrated reconfigurable configuration for battery/ultracapacitor hybrid energy storage systems," *IEEE Transactions on Energy Conversion,* vol. 31, no. 4, pp. 1583-1590, 2016.

[16] R. Mo and H. Li, "Hybrid energy storage system with active filter function for shipboard MVDC system applications based on isolated modular multilevel DC/DC converter," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 5, no. 1, pp. 79-87, 2016.

[17] K. Shreelekha and S. Arulmozhi, "Multiport isolated bidirectional DC-DC converter interfacing battery and supercapacitor for hybrid energy storage application," in *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, 2016, pp. 2763-2768: IEEE.

[18] L. W. Chong, Y. W. Wong, R. K. Rajkumar, and D. Isa, "Modelling and simulation of standalone PV systems with battery-supercapacitor hybrid energy storage system for a rural household," *Energy Procedia,* vol. 107, pp. 232-236, 2017.

[19] A. Etxeberria, I. Vechiu, H. Camblong, and J.-M. Vinassa, "Comparison of sliding mode and PI control of a hybrid energy storage system in a microgrid application," *Energy Procedia,* vol. 12, pp. 966-974, 2011.

[20] (). *NASA Surface meteorology and Solar Energy, Atmospheric Science Data Center.* https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov.