ENERGY STORAGE EVALUATION UNDER SURGE LOAD IN AN OFF-GRID PHOTOVOLTAIC SYSTEM

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ABSTRACT

This study analyses the performances battery energy storages under surge load condition in an off-grid photovoltaic (PV) system whereby the surge load condition refers to the high start-up current being drawn by the motor load. The main contribution of this paper is determining the performances in terms of voltage, current and state-of-charge of the three energy storages: lead acid battery, lithium-ion battery, and supercapacitor under surge load condition when connected to an off-grid PV system. The modelling circuit consists of a solar PV array, maximum power point tracking charge controller, energy storage, DC-DC converter, inverter and AC load and the circuit is constructed based on the previous literatures regarding off-grid PV system. This is achieved by modelling the off-grid PV system using MATLAB/Simulink software and the surge load is modelled by using single-phase induction motor which is available in Simulink Simscape library. Important parameters data are retrieved from the available journals to be applied in the Simulink simulation. The performance of the battery energy storage is then evaluated and compared among each other.

ABSTRAK

Kajian ini dijalankan untuk mengkaji prestasi bateri dalam sistem tenaga solar fotovoltaik (PV) terasing apabila berlakunya lonjakan yang disebabkan oleh kejadian permulaan motor. Semasa kejadian permulaan motor, arus permulaan yang tingi akan ditarik oleh motor. Penyumbang utama kajian ini adalah mengenal pasti prestasi bateri dalam bentuk voltan, arus dan keadaan caj untuk bateri seperti lead acid, lithium-ion dan supercapacitor dalam sistem tenaga solar PV terasing, terutamanya pada ketika berlakunya kejadian permulaan motor. Litar pemodelan ini terdiri daripada panel PV solar, pengawal cas bateri, bateri, penukar DC, penyongsang dan beban AC. Litar ini dibina berdasarkan kajian terdahulu yang berkatitan dengan sistem tenaga solar terasing. Sistem ini akan dibina dengan menggunakan perisian MATLAB/Simulink dan beban lonjakan akan disimulasikan dengan menggunakan motor induksi fasa tunggal yang terdapat dalam perisian Simulink. Parameter yang penting ambil daripada jurnal yang sedia ada untuk digunakan dalam litar Simulink. Prestasi setiap bateri adalah dinilai dan dibandingkan antara satu sama lain. Objektif bagi projek ini hanya dicapai sebahagian di atas sebab prestasi supercapacitor yang tidak sebanding dengan kajian orang lain.

TABLE OF CONTENTS

TITLE | **PAGE**

DECLARATION		**ii**
ACKNOWLEDGEMENT		**iii**
ABSTRACT		**iv**
ABSTRAK		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**ix**
LIST OF FIGURES		**x**
LIST OF APPENDICES		**xii**
CHAPTER 1	**INTRODUCTION**	**1**
1.1	Background of Study	1
1.2	Problem Statement	3
1.3	Objectives	3
1.4	Scope of Study	4
CHAPTER 2	**LITERATURE REVIEW**	**5**
2.1	Introduction	5
2.2	Electrical Load Surge	5
2.3	Voltage Sag	5
2.4	Battery Energy Storage	7
	2.4.1 Lead-Acid Battery	9
	2.4.2 Lithium-ion Battery	9
	2.4.3 Nickel-Cadmium Battery	11
	2.4.4 Sodium-Sulphur Battery	11

	2.4.5	Supercapacitor	12
2.5		Off-Grid PV System	13
2.6		Battery in an Off-Grid PV System and with Surge Load Simulation	14
2.7		Selection of Energy Storage	22
CHAPTER 3		**RESEARCH METHODOLOGY**	**25**
3.1		Introduction	25
3.2		Project Methodology	25
	3.2.1	Solar PV Array	26
	3.2.2	MPPT Algorithm	27
	3.2.3	Battery Charge Controller	28
	3.2.4	DC-DC Buck Converter	30
	3.2.5	Energy Storage	34
	3.2.6	DC-DC Boost Converter	35
	3.2.7	Inverter	37
	3.2.8	AC Load	38
3.3		Overall Simulink Circuit	39
CHAPTER 4		**RESULTS AND DISCUSSION**	**41**
4.1		Introduction	41
4.2		Simulation Results	41
	4.2.1	SOC Comparison	42
	4.2.2	Current Comparison	44
	4.2.3	Voltage Comparison	45
CHAPTER 5		**CONCLUSION AND RECOMMENDATIONS**	**46**
5.1		Conclusion	46
5.2		Recommendation and Future Works	46

REFERENCES **48**

APPENDIX **51**

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Technical characteristics of lead-acid battery	9
Table 2.2	Technical characteristics of lithium-ion battery	10
Table 2.3	Technical characteristics of nickel-cadmium battery	11
Table 2.4	Technical characteristics of sodium-sulphur battery	12
Table 2.5	Technical characteristics of supercapacitor	13
Table 2.6	Performance metrics of energy storages	23
Table 3.1	Electrical parameters of solar PV module	26
Table 3.2	Parameters used in buck converter	33
Table 3.3	Parameters of lead acid battery	34
Table 3.4	Parameters of lithium-ion battery	34
Table 3.5	Parameters of supercapacitor	35
Table 3.6	Parameters used in boost converter	36

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Voltage and current waveform captured during the SLG fault	6
Figure 2.2	Voltage waveform caused by motor starting	7
Figure 2.3	Battery storage classification based on energy type	8
Figure 2.4	Development of specific energy and energy density with respect costs per watt-hour for lithium-ion battery between 1991 and 2005	10
Figure 2.5	Basic off-grid PV system block diagram	13
Figure 2.6	The effect on lithium-ion battery voltage of a cellphone supplying a transient load	15
Figure 2.7	MATLAB/Simulink model for battery control topology 1	16
Figure 2.8	SOC, V_{batt} and I_{batt} results for topology 1	16
Figure 2.9	MATLAB/Simulink model for battery control topology 2	17
Figure 2.10	SOC, V_{batt} and I_{batt} results for topology 2	17
Figure 2.11	MATLAB/Simulink modelling for the proposed hybrid power system	18
Figure 2.12	MATLAB/Simulink model for an off-grid PV system with a battery storage system	19
Figure 2.13	Current results for (a) PV and (b) load	19
Figure 2.14	Voltage waveforms for (a) PV, (b) DC and (c) load	20
Figure 2.15	Induction motor torques	21
Figure 2.16	DC link voltage	21
Figure 2.17	DC link voltage	22
Figure 3.1	Block diagram of an off-grid PV system	25
Figure 3.2	Flowchart of P&O MPPT algorithm	27
Figure 3.3	Simulink modelling of P&O MPPT algorithm	28
Figure 3.4	Flowchart of three-stage charging method	29
Figure 3.5	Simulink modelling of battery charge controller	30
Figure 3.6	Simulink modelling of buck converter circuit	34

Figure 3.7	Circuit overview of closed-loop boost converter in Simulink	36
Figure 3.8	Simulink modelling of boost converter circuit	37
Figure 3.9	Simulink modelling of inverter circuit	37
Figure 3.10	Parameters of single-phase split phase asynchronous machine	38
Figure 3.11	Overall Simulink circuit of off-grid PV system	39
Figure 4.1	Motor current during the simulation	42
Figure 4.2	SOC performance of three energy storages	43
Figure 4.3	Enlarged version of SOC performance of three energy storages	43
Figure 4.4	Current performance of three energy storages	44
Figure 4.5	Voltage performance of three energy storages	45

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	BMOD0165 48 V Supercapacitor Datasheet	51

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, renewable energy-based power system is gaining its popularity worldwide due to several reasons. The world currently has an urgent need in reducing the greenhouse gases (GHG) emissions, especially carbon dioxide (CO_2). Thus, a transition of resource usage from fossil fuels to low-carbon solutions is very much encouraged [1]. In [2], by using Long-range Energy Alternative Planning (LEAP) model in analysing future electricity demand, fuel consumption and CO_2 emissions reduction from 2010 till 2050 in Thailand, it is calculated that with penetration of renewable energy as high as 66%, approximately 70% of CO_2 emission reduction can be achieved. Besides, from the study, it predicts that Thailand will reach its peak emission 2036, which is very severe. Hence, it confirms that via reduction of CO_2 emission, it can contribute partial effort in limiting average global surface temperature increase below 2˚C.

Solar energy is one of the most notable energy sources as compared to other renewable energy sources, such as wind energy, biomass, tidal energy etc. due to its clean nature, high abundance, and totally free feature. Theoretically, about four million exajoules of solar energy reaching the Earth is said to be capable in fulfilling the energy demand of the Earth with advance technologies [3], [4]. Via strength, weakness, opportunities, and threats (SWOT) analysis, solar energy is limitless, since it originates from the Sun; environmentally friendly as it produces no harmful substances from the solar energy extraction process; ease of installation, if lacking suitable terrain, rooftop solar panels can be another decent alternative; and lastly, despite the high initial investment cost, the low maintenance cost of solar PV panel cuts down the overall cost of solar PV power system [3]. There are basically two major types of solar PV system: on-grid PV system and off-grid PV system. The difference between on-grid PV system and off-grid PV system is on-grid is connected to utility grid, but off-grid PV system is not connected to utility grid.

Talking about remote areas, it seems to be a common phenomenon for remote areas to suffer from lacking access to modern energy services, electricity, clean water source and so on [5]. In Sarawak, the rural electrification rate recorded in 2018 is 92% under the effort of Sarawak Government in initiating the Sarawak Alternative Rural Electrification Scheme (SARES). Despite the geographical factors and dispersed population in Sarawak, Sarawak rural electrification rate is said to be a great achievement. Electricity is assumed to be one of the pre-requisites for one community to fulfill their basic human needs and to conduct economic activities [6]. Besides, as stated by United Nations (UN) in Sustainable Development Goal (SDG) 7, ensure access to affordable, reliable, sustainable, and modern energy for all is another key in moving towards Sustainable Development [1]. Considering the distant location of remote areas from the electrical points, the conventional way of providing electricity access to remote areas, grid electrification is said to be an extreme challenge as it is often excessively costly [7]. On the other hand, off-grid solar PV system comes as an optimum alternative to be implemented in remote areas considering the solar energy availability at that particular remote area.

A reliable off-grid PV power system, which can meet the daily power demand requirement of the dwellers of the remote areas, is necessary. As this off-grid PV system depends fully on the clean solar energy, a well-performing energy storage component, shall be built into the system to ensure the continuity of power supply in case of uncontrolled event, or specifically, the occurrence of load surge in the power system. In this scenario, this sudden surge is caused by high starting current of some electrical loads which can be six times the rated current [8]. This load surge will cause the phenomenon of voltage sag to occur in the power system.

Hence, in this project, it aims to study the performances of battery energy storage under surge load in an off-grid PV system. In this study, energy storage performance in an off-grid PV system under surge load condition is simulated using

MATLAB/Simulink software, later the performances are analysed and finally compared among each other.

1.2 Problem Statement

Previous studies [9], [10] state that the occurrence of sudden load surge can cause voltage sag in the power system without the presence of battery energy storage. This sudden load surge is caused by motor-like load, which withdraws high starting current during its starting event. These start-up current usually can be six times the rated current of the motor load [8]. This sudden drop in voltage may damage sensitive machines connected in the off-grid power system and thus requires a well-performing energy storage devices or other distributed generators [10]. However, different battery energy storages have different response time towards fast transient power quality needs.

Thus, there is a need to learn how different battery energy storages performs under surge load condition in an off-grid PV system. Later, the performances of each energy storage can be analysed and compared with each other to determine which performs the best during the occurrence of sudden load surge in power system.

1.3 Objectives

The main objectives of this research are:

a) To simulate energy storage performance in an off-grid PV system under surge load condition.
b) To analyse three energy storages in an off-grid PV system under surge load condition.
c) To compare the performance of the three involved energy storages in an off-grid PV system.

1.4 Scope of Study

The scopes of this project are:

a) The performances in terms of voltage, current and SOC of three energy storages; lead-acid battery, lithium-ion battery and supercapacitor under surge load condition are studied.

b) The studied circuit is limited to single phase off-grid solar PV system, which consists of PV array, charge controller, energy storage, inverter, and surge load.

c) To study is only conducted through MATLAB/Simulink software.

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