



FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

FINAL YEAR PROJECT REPORT

**DESIGN AND PROTOTYPE OF A SOLAR POWERED VACCINE KIT FOR OFF-GRID
COMMUNITIES FOCUS: POWER SYSTEM**

BY

KAGoola ADRONA JULIET

BU/UP/2021/1334

SUPERVISED BY:

DR. MIRONDO.G. KIBALYA

MR. MBABAALI FRANK

*A final year project report submitted to the Department of Electrical Engineering in partial
fulfillment of the requirements for the award of a Bachelor of Science in Electrical
Engineering.*

MAY 2025

ABSTRACT

This project aimed to design and prototype a solar-powered vaccine kit to address the critical challenge of maintaining the cold chain for vaccines in remote and off-grid communities. Access to reliable vaccine storage and transportation remains a critical challenge in remote and underserved communities, where electricity shortages hinder proper cold chain management. This project developed a self-contained kit incorporating a solar panel, battery, and a temperature-controlled vaccine storage unit. The kit was designed to maintain the required cold chain temperature for vaccines even in remote locations with limited access to electricity. Through a combination of design, simulation, and field testing, this project evaluated the performance and reliability of the solar-powered vaccine kit, which developed a cost-effective and sustainable solution for enhancing immunization coverage in underserved communities. The kit was designed for portability, durability, and ease of use, making it suitable for healthcare workers operating in off-grid locations. The objectives included creating a functional prototype of a solar powered vaccine kit, to design the power system, to construct the power system and to test the power system of the vaccine carrier kit. The Solar-Powered Vaccine Kit effectively maintains a 2°C – 8°C temperature range for vaccine storage, achieving 94.5% system efficiency with an 88% solar fraction. Powered by a 330W solar panel and 24Ah Li-ion battery, it provides 7+ hours of autonomy, recharges in ~5 hours under optimal sunlight, and exhibits minimal battery degradation (11.4% capacity loss after one year). While it performs reliably in moderate climates, peak summer conditions (June–August) result in an 11.95% energy shortfall, suggesting potential improvements such as a larger battery or enhanced insulation for extreme environments. Overall, the kit is a viable, efficient solution for off-grid vaccine storage, with minor optimizations needed for hotter regions. The project aligned with Sustainable Development Goals 3 and 7 of Good Health and Well-Being and Affordable and Clean Energy respectively.

DECLARATION

I KAGOOOLA ADRONA JULIET (BU/UP/2021/1334), declare that this project report titled “Design and Prototype of a Solar Powered Vaccine Kit for Off-Grid Communities Focus: Power System” is my original work except where due acknowledgement has been made. I declare that this work has never been submitted to this university or any other institute for funding or for partial fulfillment for any award.

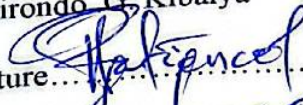
Signature..........

Date.....20th|05|2025.....

APPROVAL

This report is submitted in partial fulfilment for the award of Bachelor's degree in Electrical Engineering at Busitema University, with an approval from my project supervisors.

Dr. Mirondo G. Kibalya

Signature.....

Date.....18/11/2025.....

Mr. Mbabaali Frank

Signature.....

Date.....29th/05/2025.....

DEDICATION

This work is wholeheartedly dedicated to my family, whose unwavering love, sacrifice and encouragement have been the backbone of my academic journey. Their strength, prayers and belief in my potential have been a constant source of motivation and inspiration throughout my life.

ACKNOWLEDGEMENT

First and foremost, I thank the Almighty God for his guidance, protection and knowledge. I also want to thank my parents and siblings for their encouragement and support both spiritually, mentally and financially. My sincere gratitude goes to my final year project Supervisors, Dr. Mirondo .G. Kibalya for his guidance, commitment and financial support, Mr. Mbabaali Frank and the projects coordinator Miss. Tusiimire Patience and all other lecturers for their combined efforts towards my success with this project.

TABLE OF CONTENTS

ABSTRACT.....	i
DECLARATION.....	ii
APPROVAL	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
TABLE OF FIGURES	ix
LIST OF TABLES	x
LIST OF ABBREVIATIONS	xi
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background of Study	1
1.2 Problem Statement.....	3
1.3 Objectives	3
1.3.1 Main Objective	3
1.3.2 Specific Objectives	3
1.4 Justification for the study.....	3
1.5 Significance.....	4
1.6 Scope of Study	4
1.6.1 Design Scope	4
1.6.2 Geographical Scope.....	5
1.6.3 Time Scope	5
1.7 Conceptual framework.....	5
CHAPTER TWO: LITERATURE REVIEW	6
2.1 Introduction.....	6
2.2 Previous Work.....	8

2.2.1 Peltier-Based Refrigerators.....	8
2.3 Integrated Cold Storage Solutions	9
2.4 DC Refrigerators	9
2.4.1 Solar-Assisted DC Refrigerators	9
2.4.2 Miniature DC Compressors	9
2.5 Efficiency Improvements.....	10
2.6 Solar-Powered Refrigeration Systems	11
2.7 Comparative Study.....	11
CHAPTER THREE: METHODOLOGY	13
3.1 Introduction.....	13
3.2 Data Collection Methods	13
3.2.1 Initial data gathering.....	13
3.2.2 Manual logging.....	13
3.3 System Design	14
3.4 Objective one: To Design the Power System of a Solar-Powered Vaccine Kit.	14
3.4.1 System Requirements Analysis	14
3.4.2 Component Selection.....	18
3.5 Objective two: To Construct the Power System of the Solar-Powered Vaccine Kit.....	27
3.5.1 Component selection	27
3.5.2 Constructions method, tools and equipment.....	27
3.6 Objective three: To Test the Power System of the Solar-Powered Vaccine Kit.....	28
3.6.1 Test 1: Solar Charging test.....	28
3.6.2 Test 2: Battery Discharge Test	29
3.6.3 Test 3: Cooling Unit Temperature Stability	30
3.7 Data Analysis	31

CHAPTER FOUR: RESULTS AND DISCUSSIONS	32
4.1 Objective 1: To determine the power requirements for various components of the system	32
4.1.1 System Requirements Analysis	32
4.1.2 Sizing the Vapor Compression Refrigeration Components	35
4.1.3. Battery Sizing	38
4.1.4 Solar Panel sizing	40
4.1.5 PVSyst Simulation.....	43
4.1.5.1 Simulation Results	43
4.2 Objective 2: To Construct the Power System of the Solar-Powered Vaccine Kit.....	45
4.3 Objective 3: To Test the Power System of the Solar-Powered Vaccine Kit.....	48
4.3.1 Test 1: Solar Charging test.....	48
4.3.2 Test 2: Battery Discharge Test	49
4.3.3 Test 3: Cooling Unit Temperature Stability	50
CHAPTER FIVE: CONCLUSION, CHALLENGES AND RECOMMENDATIONS	54
5.1 Conclusion	54
5.2 Challenges.....	54
5.3 Recommendations.....	54
REFERENCES	56
APPENDICES	59
Appendix A: Additional figures.....	59
Appendix B: Proteus Simulation	60
Appendix C: PVSyst Simulation Report	62

TABLE OF FIGURES

Figure 1 Conceptual design	5
Figure 2 System design.....	14
Figure 3 A figure showing meteorological data for Busitema	23
Figure 4 A figure showing orientation of the system.....	24
Figure 5 A figure showing estimated daily energy requirement for the vaccine kit	25
Figure 6 Figure showing the selected PV Module.....	26
Figure 7 Figure showing the Battery set	27
Figure 8 Figure showing the summary of the system	27
Figure 9 Figure showing the constructed kit in different views	48
Figure 10 A graph of battery charging (voltage) against time	49
Figure 12 A graph showing the discharge time on different days.....	50
Figure 13 Graph showing Temperature against time (7am to 7pm) in a cool room	51
Figure 14 Graph showing Temperature against time (7am to 7pm) in an outdoor setting	52

LIST OF TABLES

Table 1 A table showing pros and cons of different software tools	22
Table 2 A table showing component selection criteria for different components	27
Table 3 A table showing the methods & tools used during the fabrication process.....	28
Table 4 A Table showing electronic system sensors and their power consumption	34
Table 5A table showing different criteria used to select a battery	39
Table 6 A Table showing the different criteria used to choose a solar panel	42
Table 7 Table showing main results for systems energy balance over a year	43
Table 8 A table showing how the construction of the kit was achieved	46
Table 9A table showing charging results	48
Table 10 Showing battery discharging times on different days	49
Table 11 A table showing ambient and internal temperature in a cool room.....	50
Table 12 A table showing ambient and internal temperature in an outdoor setting.....	51

LIST OF ABBREVIATIONS

CFD	Contract for Difference
COP	Coefficient of Performance
DC	Direct Current
GIZ	German Agency for International Cooperation
HDPE	high-density polyethylene
Hr	Hour
LCD	Liquid Crystal Display
LMICs	Low- or middle-income countries
MPPT	Maximum Power Point Tracking
PCM	Phase Changing Material
PQS	Performance, Quality and Safety
PV	Photovoltaic
SDG	Sustainable Development Goals
TB	Tuberculosis
TE	Thermoelectric
UNICEF	United Nations International Children's Emergency Fund
VVM	Vaccine Vial Monitors
Wh	Watt Hour
WHO	World Health Organization

REFERENCES

- (WHO). (1994). *Requirements for Measles, Mumps, and Rubella Vaccines and Combined Vaccines*. Geneva: World Health Organization.
- (WHO), W. H. (2014). *WHO Expert Committee on Biological Standardization: Sixty-Third Report*. Geneva: World Health Organization (WHO).
- Abet, T. (2024.). Uganda turns to solar refrigerators to keep vaccines cool.
- AH Sabry, P. K. (2021). Improvement on energy consumption of a refrigerator within PV system including battery storage. *Elsevier*, Pages 430-438.
- Atwiine Flavia, B. F. (2023). Gaps in vaccine management practices during vaccination outreach sessions in rural settings in southwestern Uganda. *BMC Infectious Diseases*, 5.
- AY Faraji, H. G. (2014). Experimental study of a thermoelectrically-driven liquid chiller in terms of COP and cooling down period. *Energy conversion* .
- Bank, W. (2012). Access to energy infrastructure. *World Bank*.
- Dipika M. Matthias a, C. N. (2007). Freezing temperatures in the vaccine cold chain: A systematic literature review. *Vaccine*, 3980-3986.
- H Ammari, A. A. (2015). Economic comparison between PV powered vapor compression refrigeration system and solar thermal powered absorption refrigeration system. *Proceedings of the 5th Jordanian IIR Int Conference*. researchgate.net.
- IEA, O. (2012). Measuring progress towards energy for all: power to the people? *World Energy Outlook 2012*, 529–547, 668.
- James Riffat, C. K.-B. (2021). Development and testing of a PCM enhanced domestic refrigerator with use of miniature DC compressor for weak/off grid locations. *International Journal of Green Energy* , 1118-1131.

- Jun Luo, L. C. (2003). Optimum allocation of heat transfer surface area for cooling load and COP optimization of a thermoelectric refrigerator. *Energy Conversion and Management*, 3197–3206.
- Kemigisha, R. M. (2024). Assessment of vaccine wastage and associated factors in Rukungiri District, South western uganda,2018-2019:a mixed methods study. *Research square*, 3.
- Miriah Kemigisha, R. M. (2024). Assessment of vaccine wastage and associated factors in Rukungiri District, South western uganda,2018-2019:a mixed methods study. *Research square*, 3.
- Murat Gökçek, F. Ş. (2017). Experimental performance investigation of minichannel water cooled-thermoelectric refrigerator. *ELSEVIER*, 54-62.
- ND Shikalgar, S. S. (2021). *Intelligent Electrical Systems*. taylorfrancis.com.
- Ninsiima, M. M. (2024). Vaccine wastage rates and attributed factors in rural and urban areas in uganda:case of mukono nad kalungu district. 2-6.
- Organisation, W. H. (2016). PQS devices catalogue: pre-qualified equipment for the Expanded Programme on Immunization (EPI).
- Organization, W. H. (2005). *Monitoring Vaccine Wastage at Country Level: Guidelines for Program Managers*. 1–63: WHO.
- Organization, W. H. (2015). Managing an immunization session. *Who*, 37–7.
- Organization, W. H. (2016). PQS devices catalogue: pre-qualified equipment for the Expanded Programme on Immunization (EPI) .
- Parmar D, B. E. (2010). Impact of wastage on single and multi-dose vaccine vials: implications for introducing pneumococcal vaccines in developing countries. *Hum Vaccines*, 6.
- Partapuri T, S. R. (2012). Integrated delivery of health services during outreach visits: a literature review of program experience through a routine immunization lens. *Journal of Infectious Diseases*, 20–7.

- R Kumar, V. S. (2022). Thermostable vaccines: an innovative concept in vaccine development. *Expert Review of Vaccines*, 15.
- S Zipursky, L. B.-C. (2011). Assessing the potency of oral polio vaccine kept outside of the cold chain during a national immunization campaign in Chad. *Vaccine*.
- Sabeena Setia a, H. M. (2002). Frequency and causes of vaccine wastage. *Vaccine*, 1148-1156.
- U Kartoglu, S. G. (2009). Use of cool water packs to prevent freezing during vaccine transportation at the country level. *PDA Journal of Pharmaceutical Science and Technology*.
- W, B. (2010). Addressing the electricity access gap. *World Bank*.
- Weir, E., & Hatch, K. C. (2004). Preventing cold chain failure: vaccine storage and handling. *Scholarly Journal*, 1050.
- WHO. (2005). Monitoring Vaccine Wastage at Country Level: Guidelines for Programme managers. *WHO*, 34.
- WHO. (1998). *Requirements for Yellow Fever Vaccine*. Geneva: World Health Organization.
- Yakum MN, A. J. (2015). Vaccine storage and cold chain monitoring in the North West region of Cameroon: a cross sectional study. *BMC Research Notes*, 145–5.