# DESIGN AND ANALYSIS OF GRID – CONNECTED PV RENEWABLE SOLAR ENERGY SYSTEM FOR IGBINEDION UNIVERSITY OKADA CROWN ESTATE OKADA

**BY**

**UMEOZOR SOPURUCHUKWU STANLEY PG/19/023343/ENG**

**DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING GEN. ABDULSALAMI A. ABUBAKAR**

**COLLEGE OF ENGINEERING IGBINEDION UNIVERSITY, OKADA EDO STATE, NIGERIA**

**2021**

# DESIGN AND ANALYSIS OF GRID – CONNECTED PV RENEWABLE SOLAR ENERGY SYSTEM FOR IUO CROWN ESTATE OKADA

**BY**

**UMEOZOR SOPURUCHUKWU STANLEY PG/19/023343/ENG**

**SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER**

# ENGINEERING, COLLEGE OF ENGINEERING

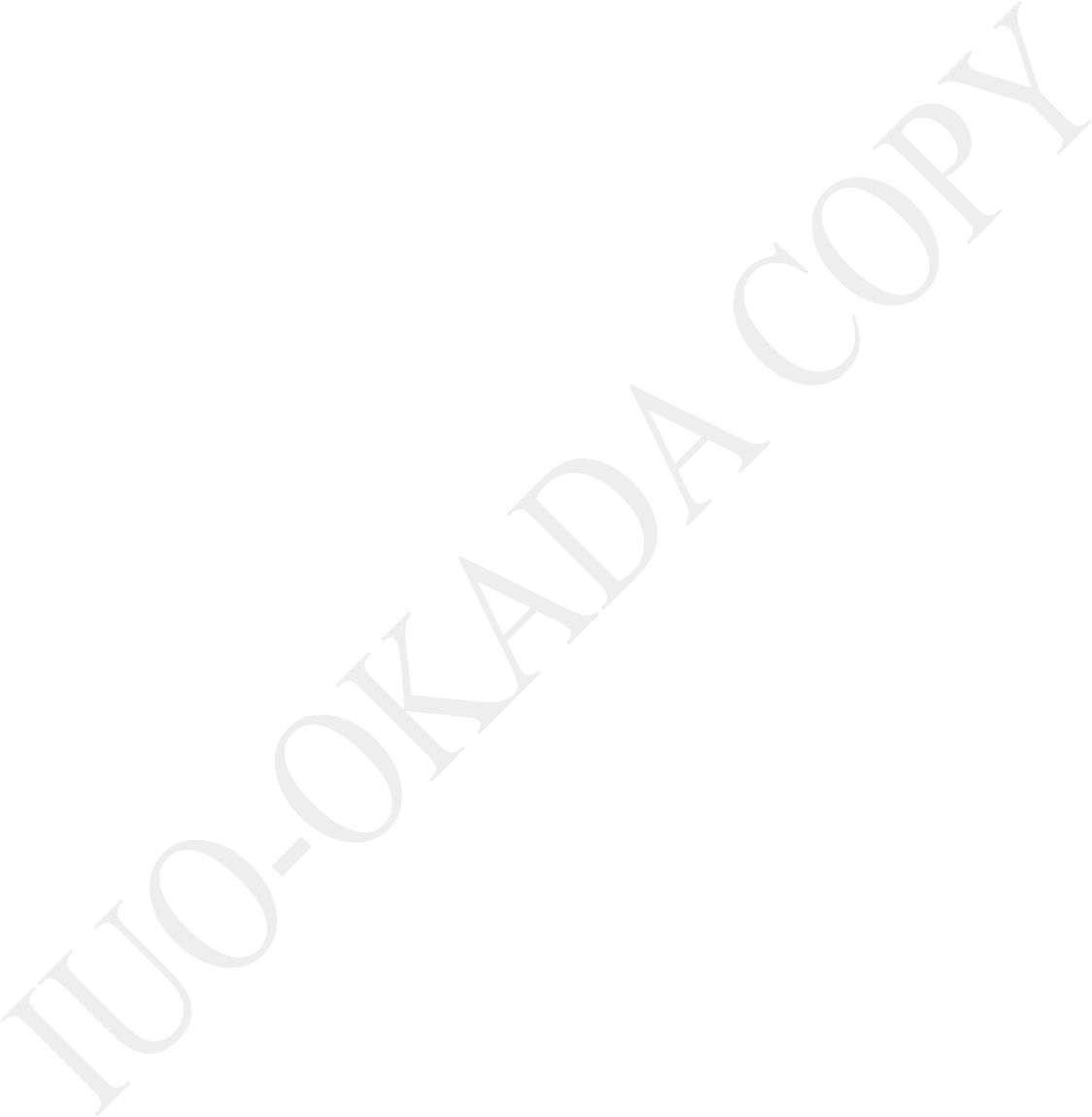
**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF**

# MASTER OF ENGINEERING (M.ENG) IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

**ABDULSALAMI A. ABUBAKAR COLLEGE OF ENGINEERING IGBINEDION UNIVERSITY, OKADA**

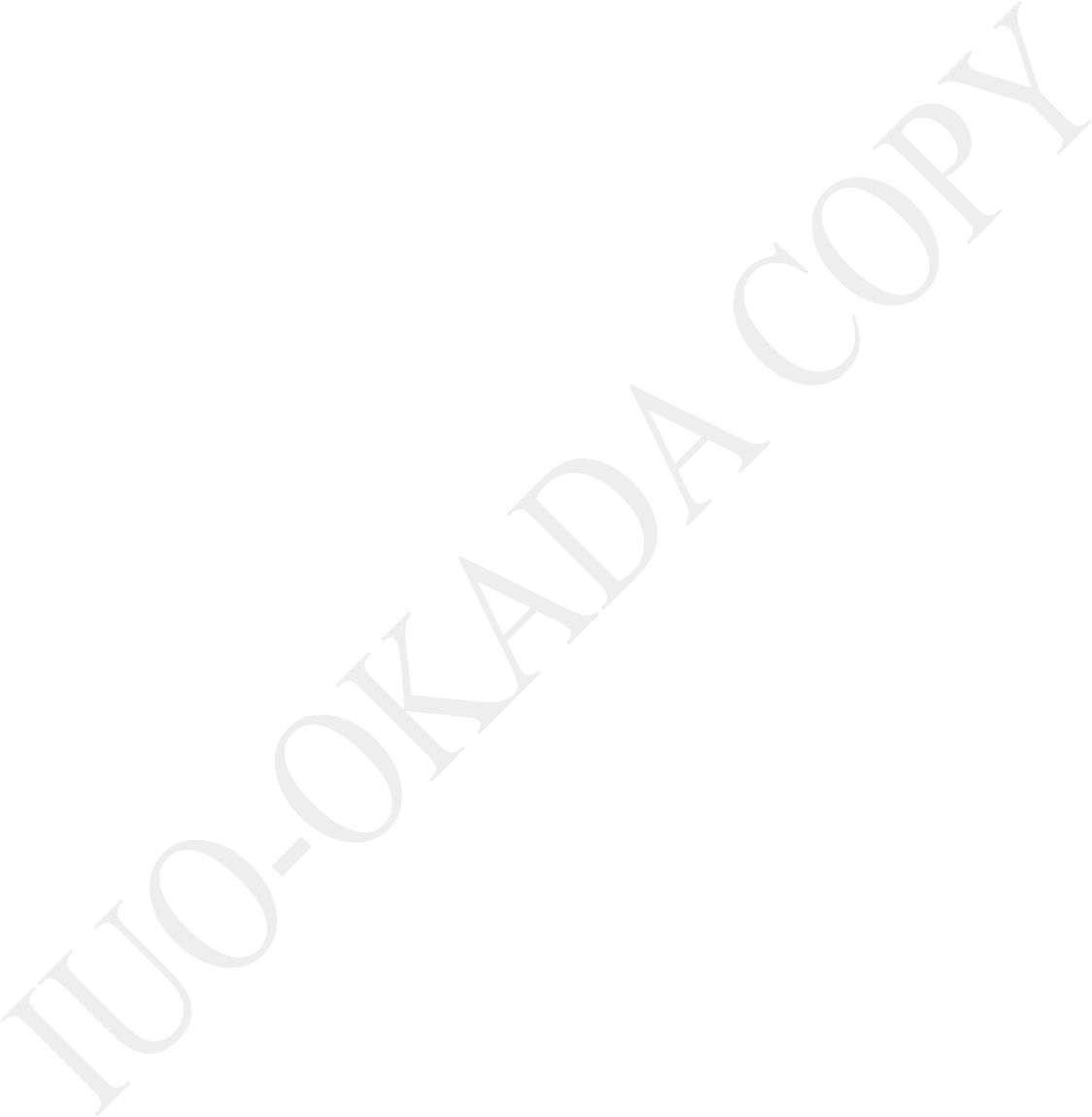
# 2021

# DECLARATION

This is to declare that **Umeozor Sopuruchukwu Stanley**, with Matriculation Number: **PG/19/023343/ENG** carried out this research work in partial fulfillment for the award of a Master of Engineering in Electrical and Computer Engineering, Igbinedion University Okada.

# UMEOZOR SOPURUCHUKWU STANLEY DATE

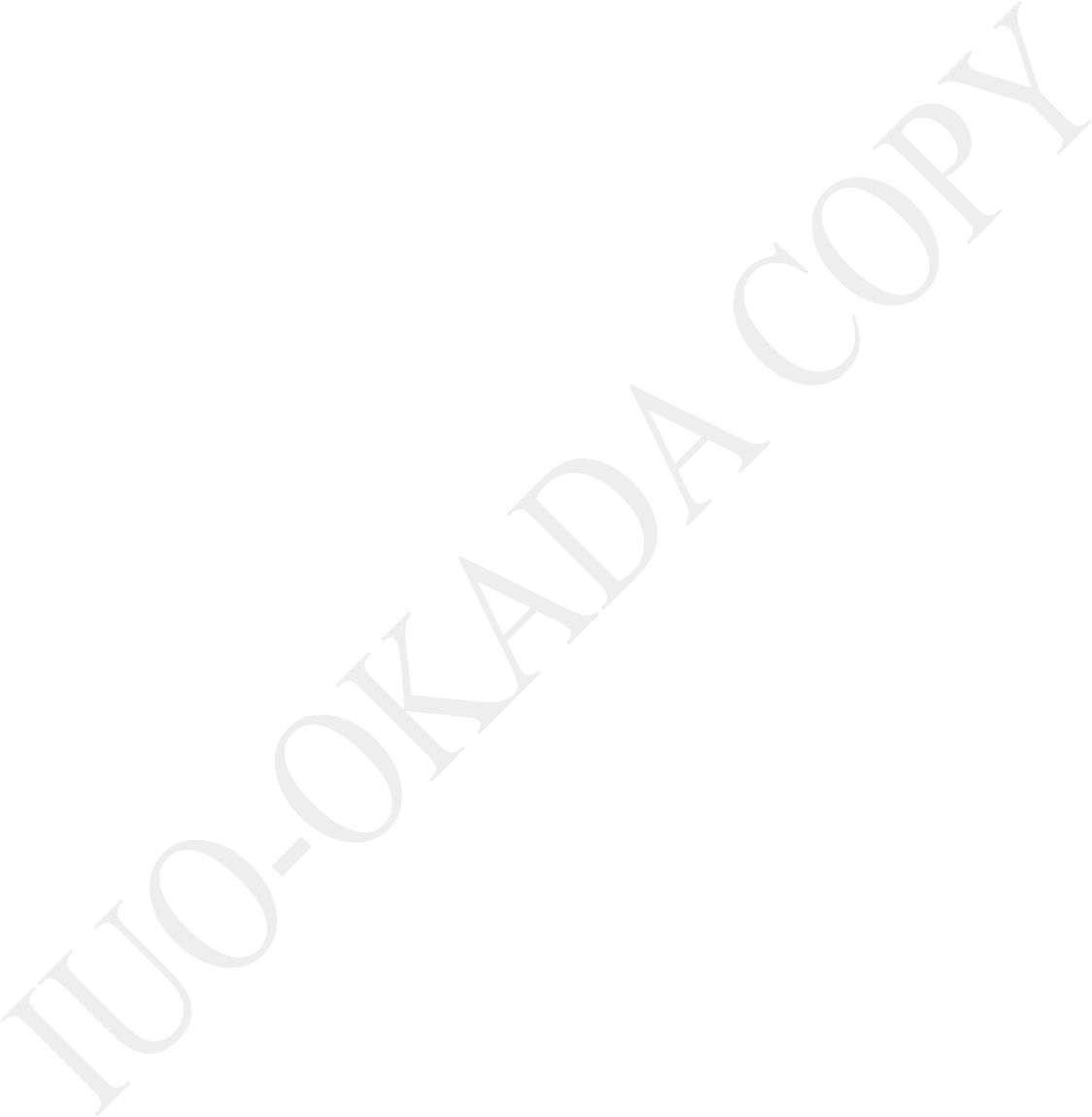
# DEDICATION

I dedicate this dissertation work to God Almighty who has kept me moving in the field of academics.

# CERTIFICATION

This is to certify that, this research and written dissertation entitled; **Design and Analysis of Grid – Connected PV Renewable Solar Energy System for Igbinedion University Crown**

**Estate Okada** was carried out by **UMEOZOR SOPURUCHUKWU STANLEY** with

Matriculation Number: **PG/19/023343/ENG**. In partial fulfillment of the requirement for the

award of Master Degree (M.ENG) in Electrical and Computer Engineering Department of

Igbinedion University Okada, Nigeria under my supervision and guidance.

# Dr. (Mrs.) Guiawa Mathurine Date

Project Supervisor

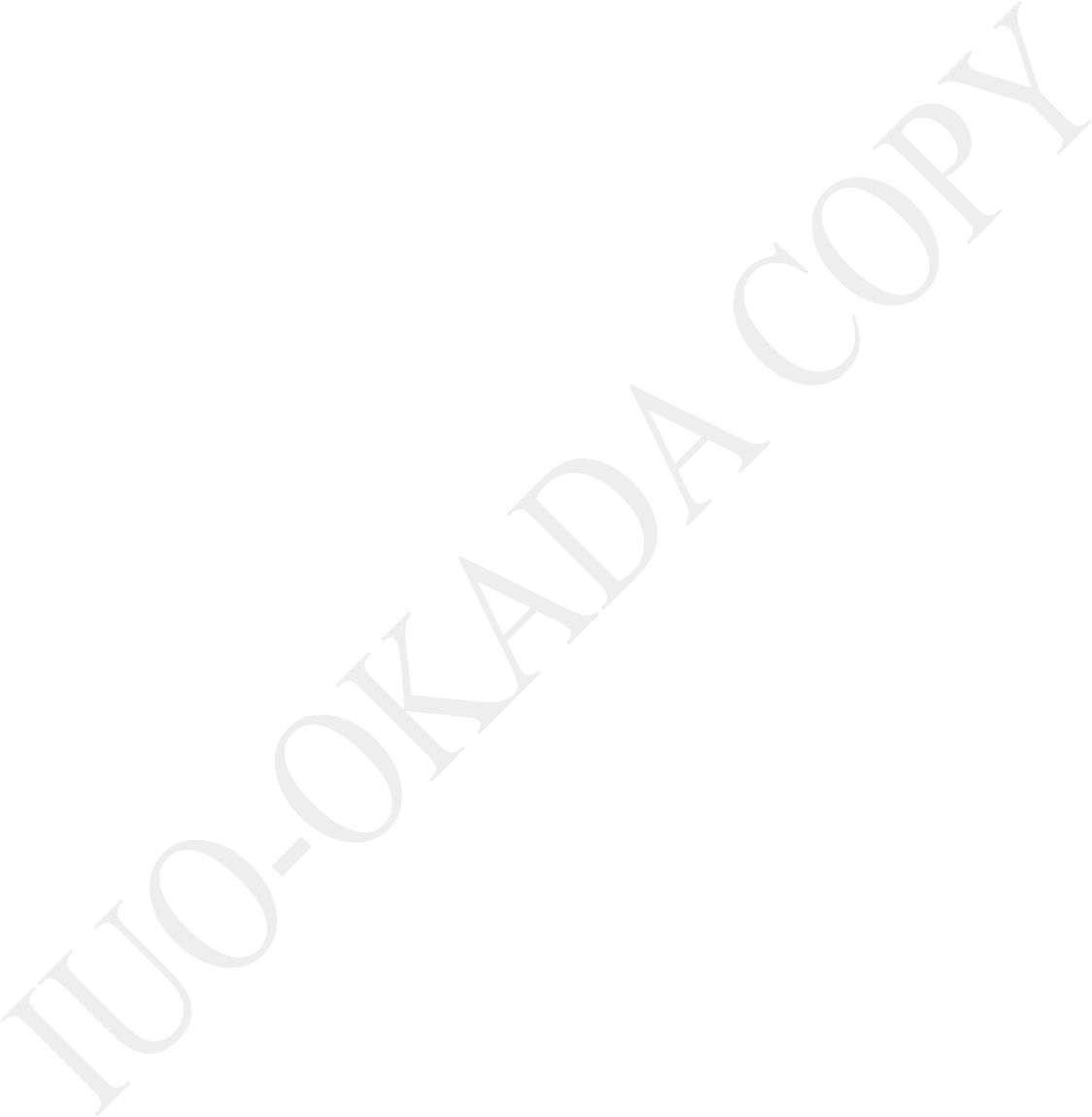
# Dr. (Mrs.) Guiawa Mathurine Date

**Head of Department**

# Dr. C.E. Ochem Date

**Ag. Dean, School of Postgraduate Studies & Research**

# ACKNOWLEDGEMENTS

Firstly, I give all praise, honor and glory to the Almighty God, creator of heaven and earth for his wisdom, direction, protection and provision throughout the period of this course and project work.

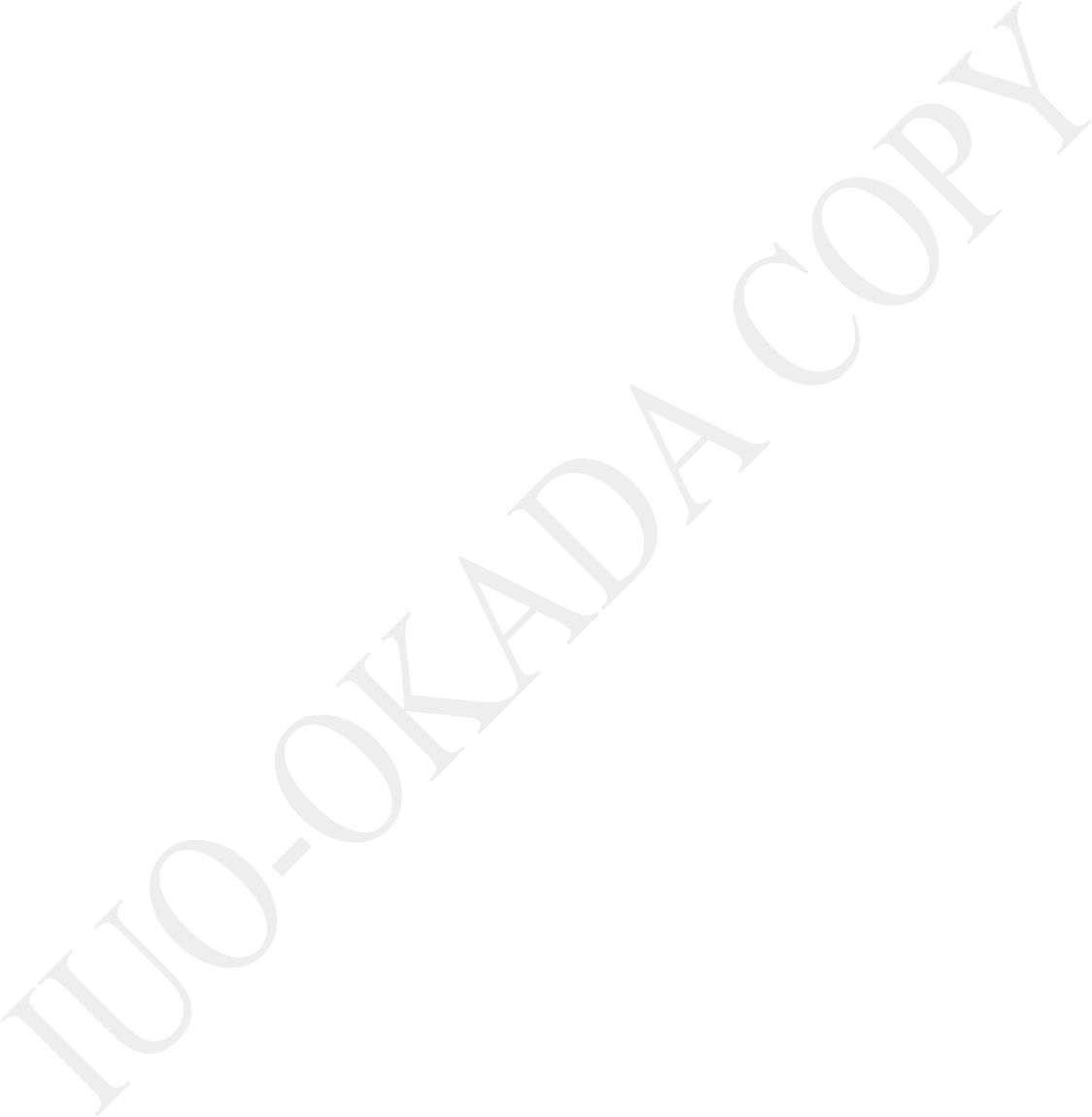
I want to use this medium to acknowledge my dearest wife Mrs. Happiness Chinaza Umeozor for her love, prayers and support during the course of this program. My acknowledgement also goes to my mother Mrs. Edith Umeozor for her encouragement and support which I enjoyed in full during the course of the program. My sincere thanks also goes to my supervisor and the Head of Department of Electrical/Electronic Engineering Dr. (Mrs.) Mathurine Guiawa and all the departmental Lecturers.

I say thank you and God bless you all.

# ABSTRACT

Renewable energy has given institutions and individuals the opportunity to generate and manage their own energy consumption without much interference from power utility

companies. This dissertation focused on design and analysis of Grid – connected PV Renewable

Solar energy system for Igbinedion Crown estate Okada. Nigeria Solar Market study was

carried out to know the available grid PV components in Nigeria, their qualities, suitability,

capacities, and environmental adaptability. Several Capacities of bifacial and mono – facial

systems were designed and analyzed using PVsyst simulation software with the solar data about

Igbinedion University, Okada (IUO) obtained from meteonorm 7.1. The final result revealed

via the Performance ratios and the generated energy from each design that Igbinedion

University Okada Crown estate has vast potential in generating its own energy via solar system.

Finally, bifacial system with trackers proved to be the best system for the institution in

comparison with fixed bifacial system, mono – facial system with trackers and fixed mono –

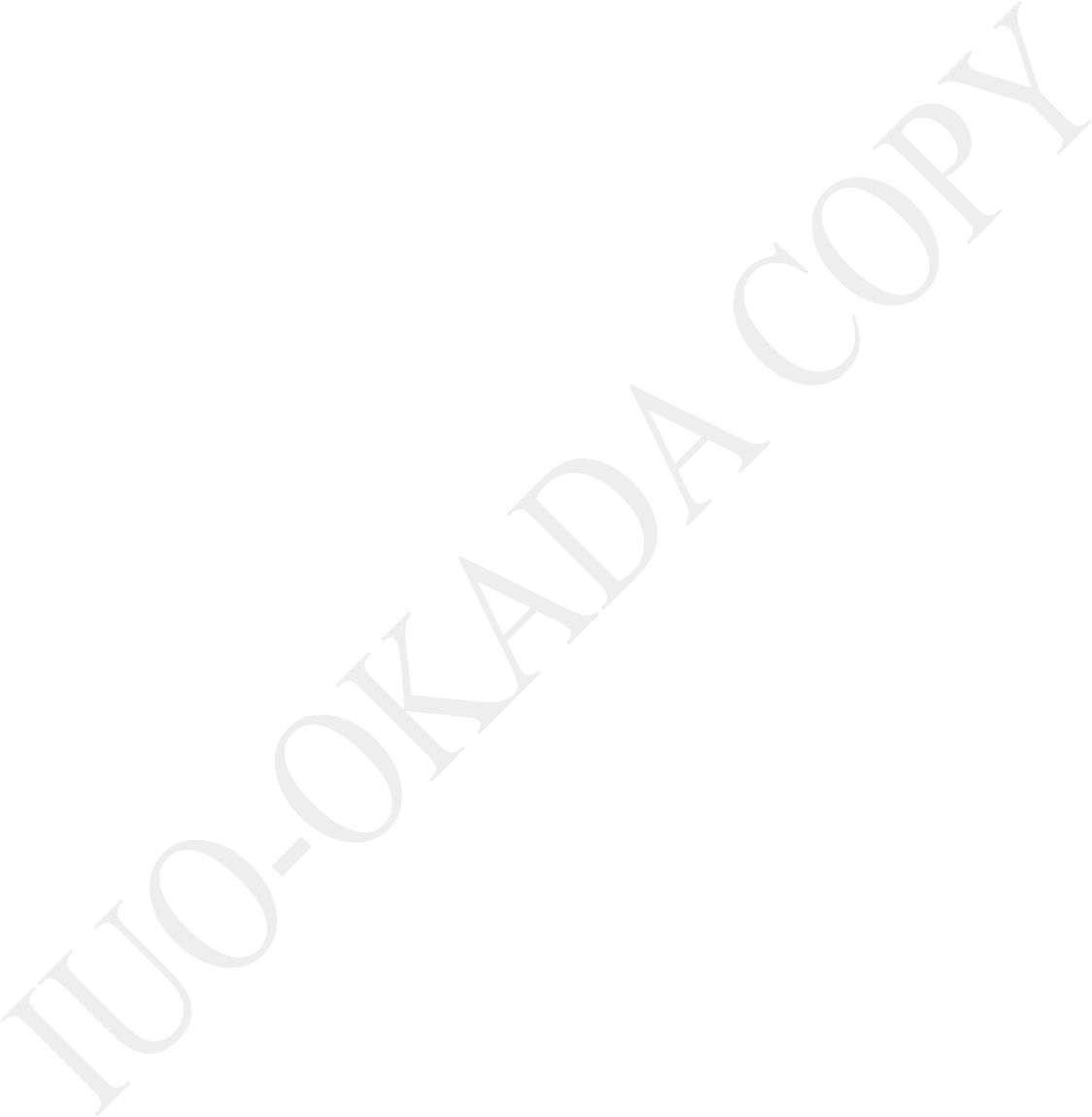
facial system.

# TABLE OF CONTENTS

**CONTENTS PAGE**

Title Page i

[Declaration ii](#_TOC_250005)

[Dedication iii](#_TOC_250004)

[Certification iv](#_TOC_250003)

Acknowledgements v

[Abstract vi](#_TOC_250002)

[Table of Contents vii](#_TOC_250001)

List of Tables x

[List of Figures xi](#_TOC_250000)

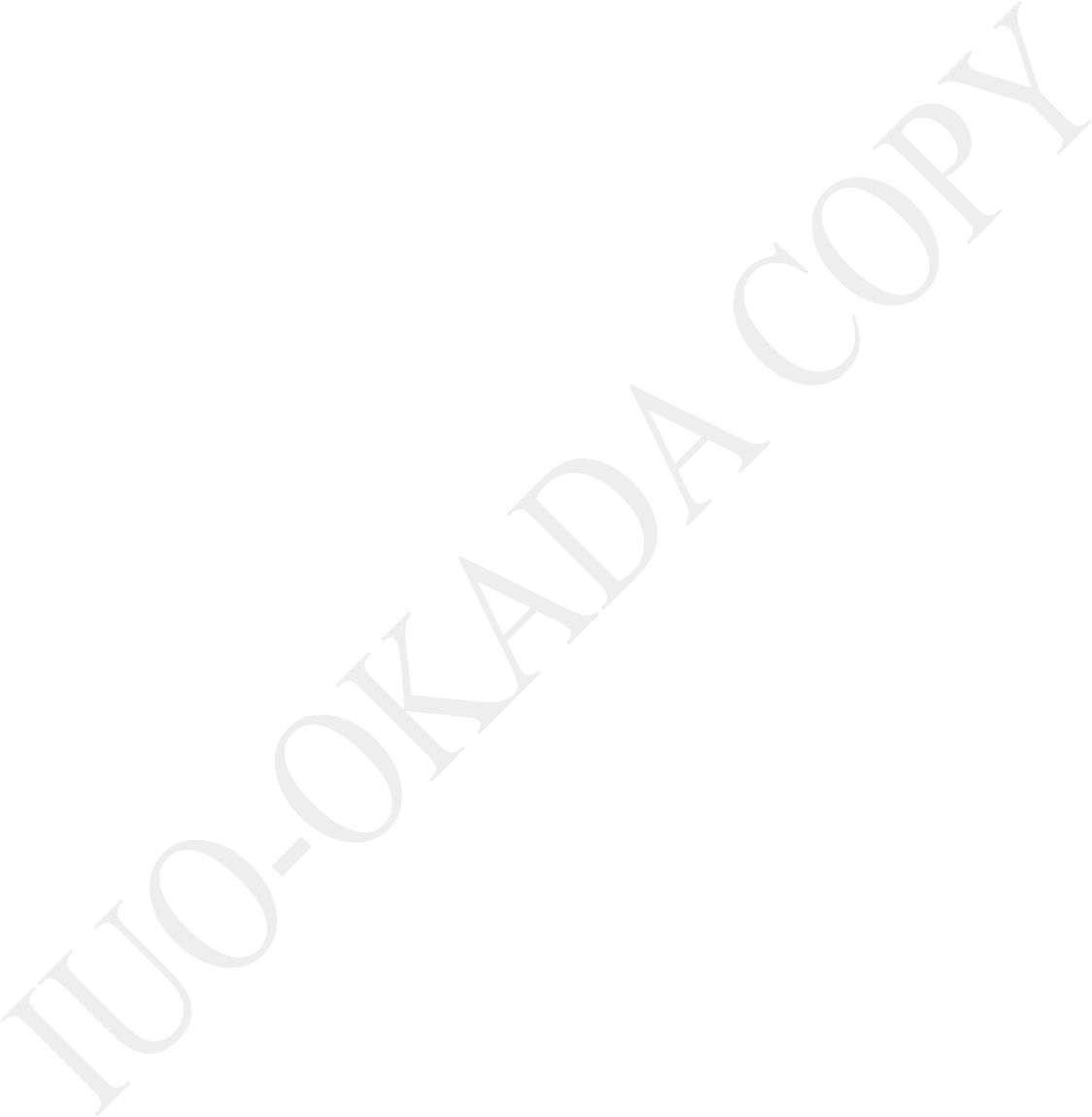
List of Abbreviation xiii

CHAPTER ONE

INTRODUCTION

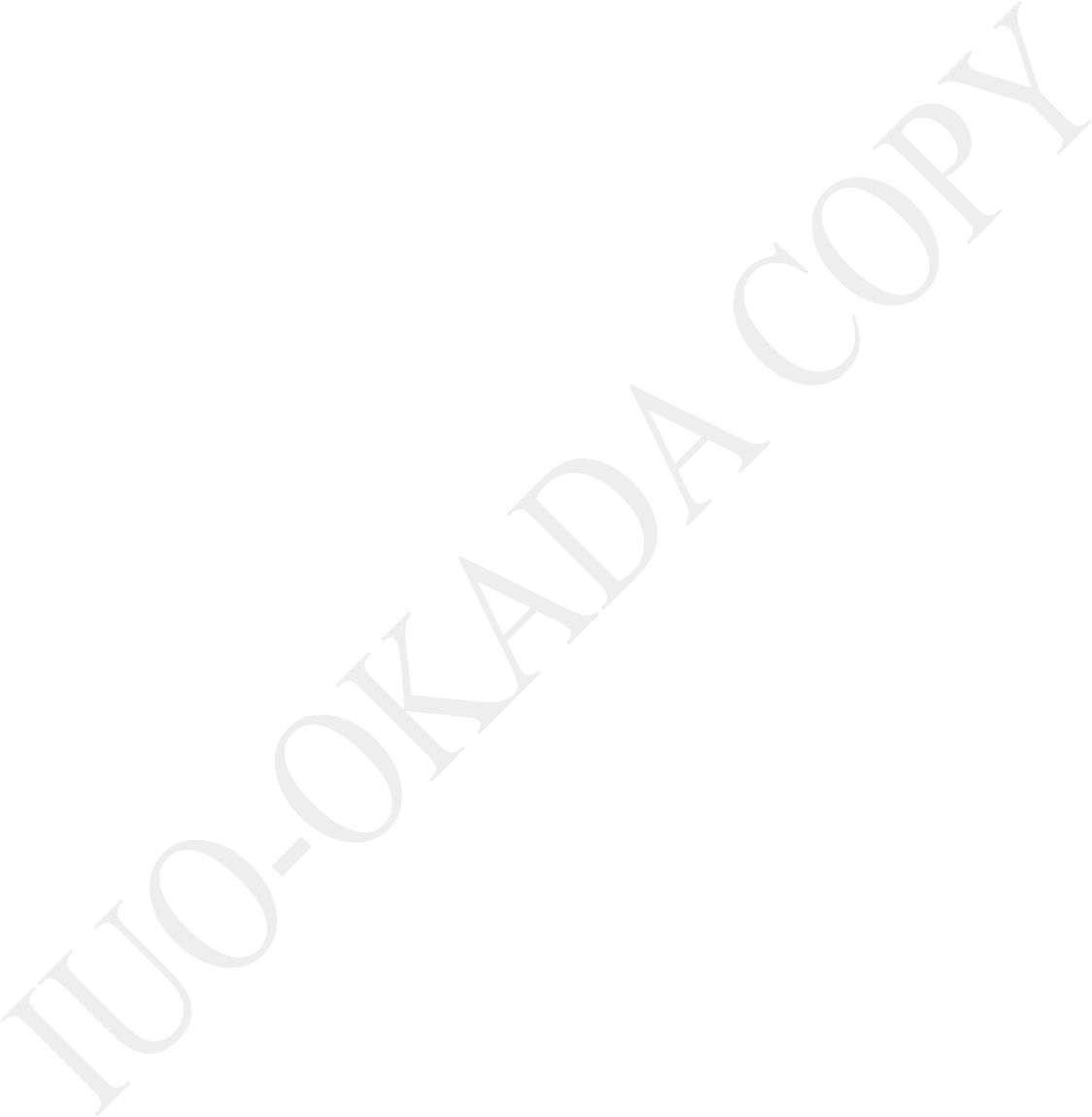
* 1. Background of the Study 1
  2. Statement of Problems 3
  3. Significance of the Research 3
  4. Aim of the Research 4
  5. Research Objectives 4
  6. Scope of the Research 4

CHAPTER TWO LITERATURE REVIEW

* 1. Preamble 6
  2. Solar Photovoltaic (PV) Energy generation System 6
     1. Grid – connected PV energy generation system 7
  3. Important Terms used in solar PV systems 8
     1. Solar Radiation 8
     2. Irradiance 8
     3. Terrestrial solar Output (radiation) 9
     4. Seasonal, Daily and Latitudinal Variations 9
     5. Position of the Sun and PV module 11
     6. Solar Irradiance on a Tilted PV Module 15
  4. Module Orientation and Inter-Row Spacing 16
     1. Inter-Row Spacing 18
  5. Islanding 19
  6. Components of Grid – Connected System 20
     1. The PV Module 20
        1. Module Structure and Materials 22
        2. Shading on PV Modules 24
        3. The Photovoltaic Cell 25
        4. Crystalline Silicon and Doping 26
        5. Working principle of the solar cell 27
        6. Performance of a Solar Cell 30
  7. Solar Cell One – Diode Model 32

2.7.1. Electrical Properties of a Solar Cell 32

2.7.2 Effect of temperature and irradiance level 34

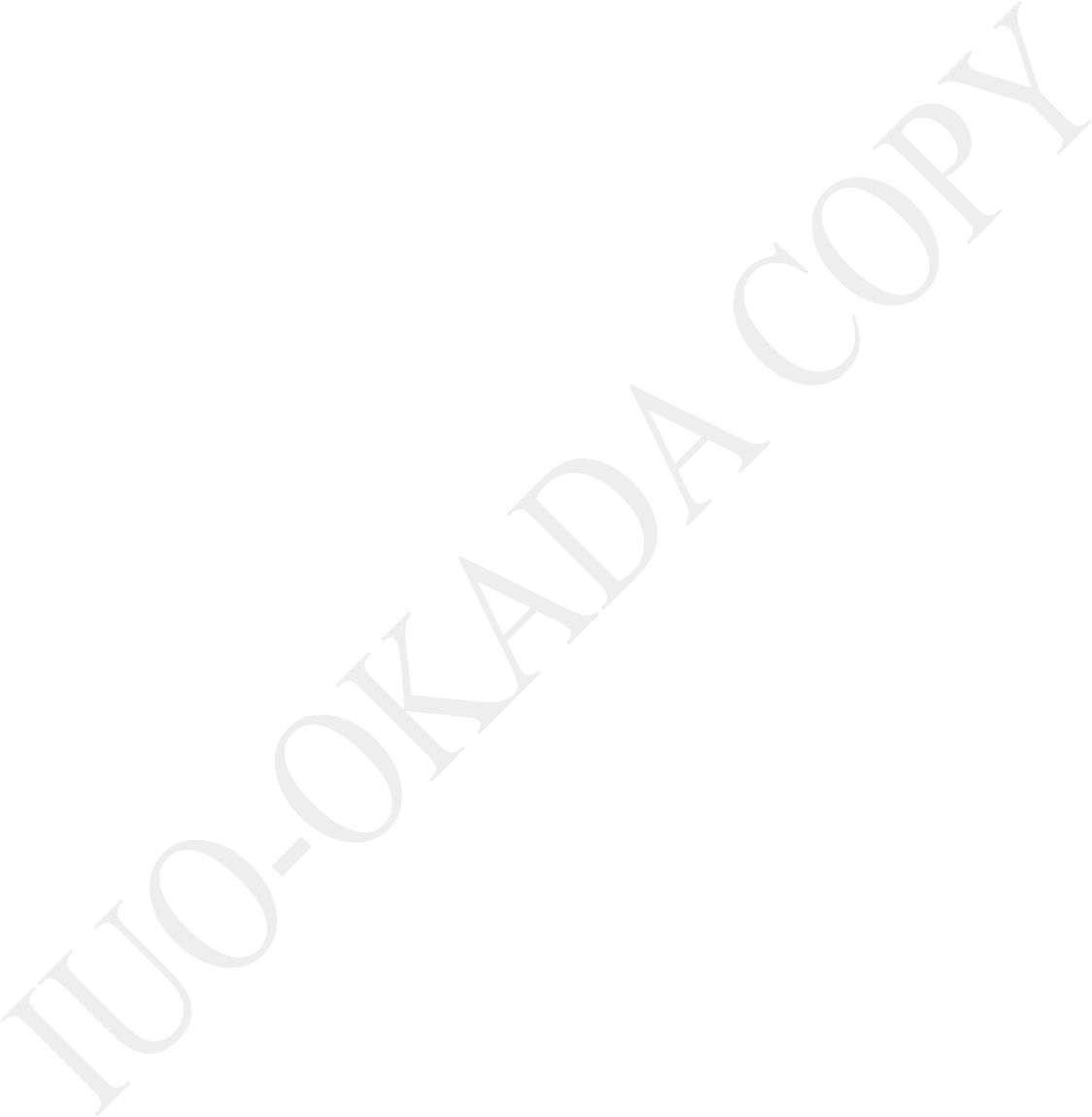
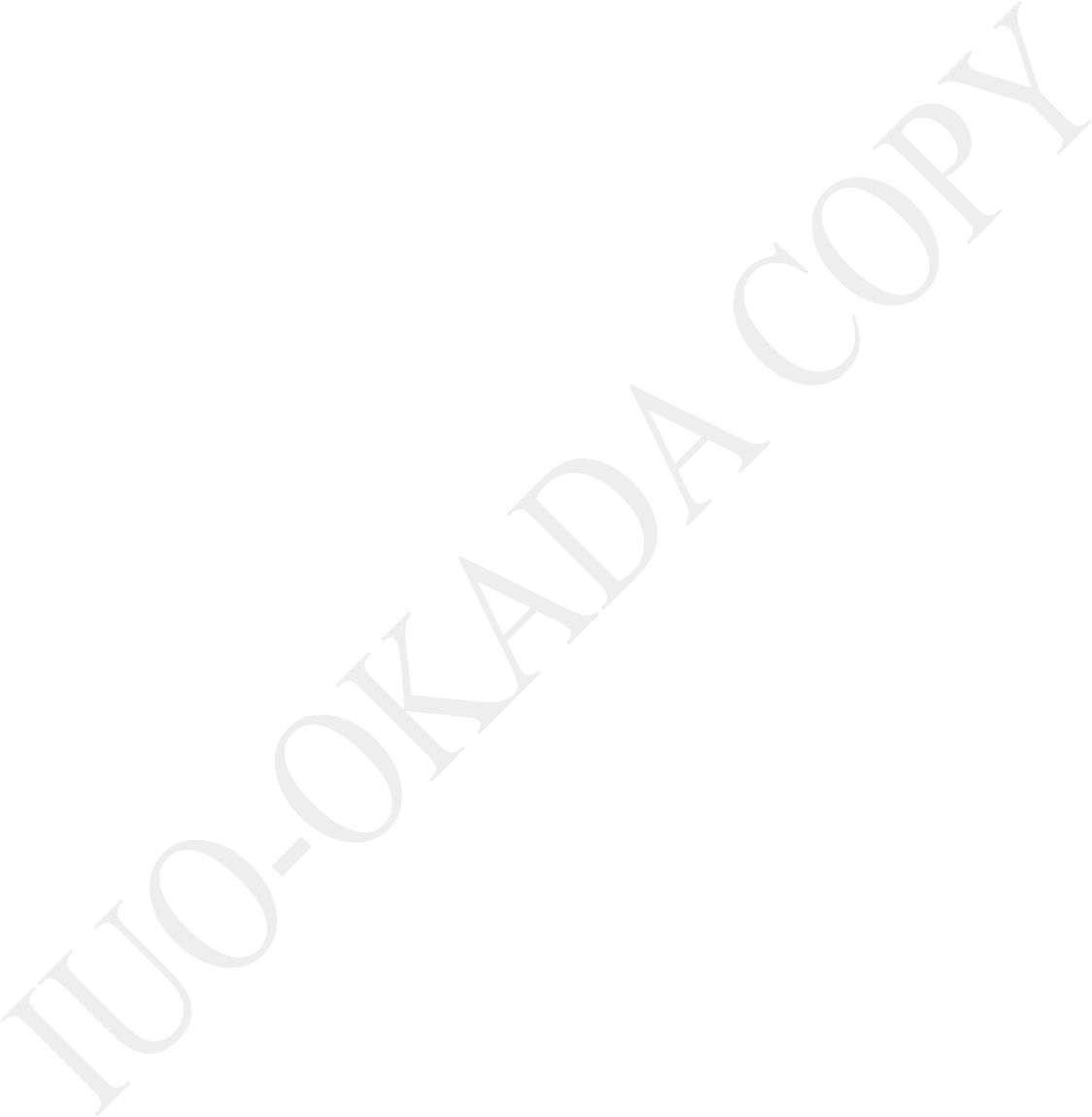
* 1. Inverters 36
     1. PV Inverter Configurations 37
        1. Central Inverter 38
        2. String Inverter 39
        3. Module Inverter 39
        4. Power Optimizer 40
  2. Mounting System 40
  3. Other BoS Components 42
     1. AC and DC cabling 42
     2. Monitoring System 43
     3. Protection, Disconnection and Metering 43
  4. Review of related Works 44

CHAPTER THREE

RESEARCH METHODOLOGY

* 1. Research Methodology 53
  2. Preliminary Design 53
     1. I U O Crown estate Power Requirement Estimate 53
  3. Preliminary Specifications for IUO Crown Estate Grid

Connected PV System 54

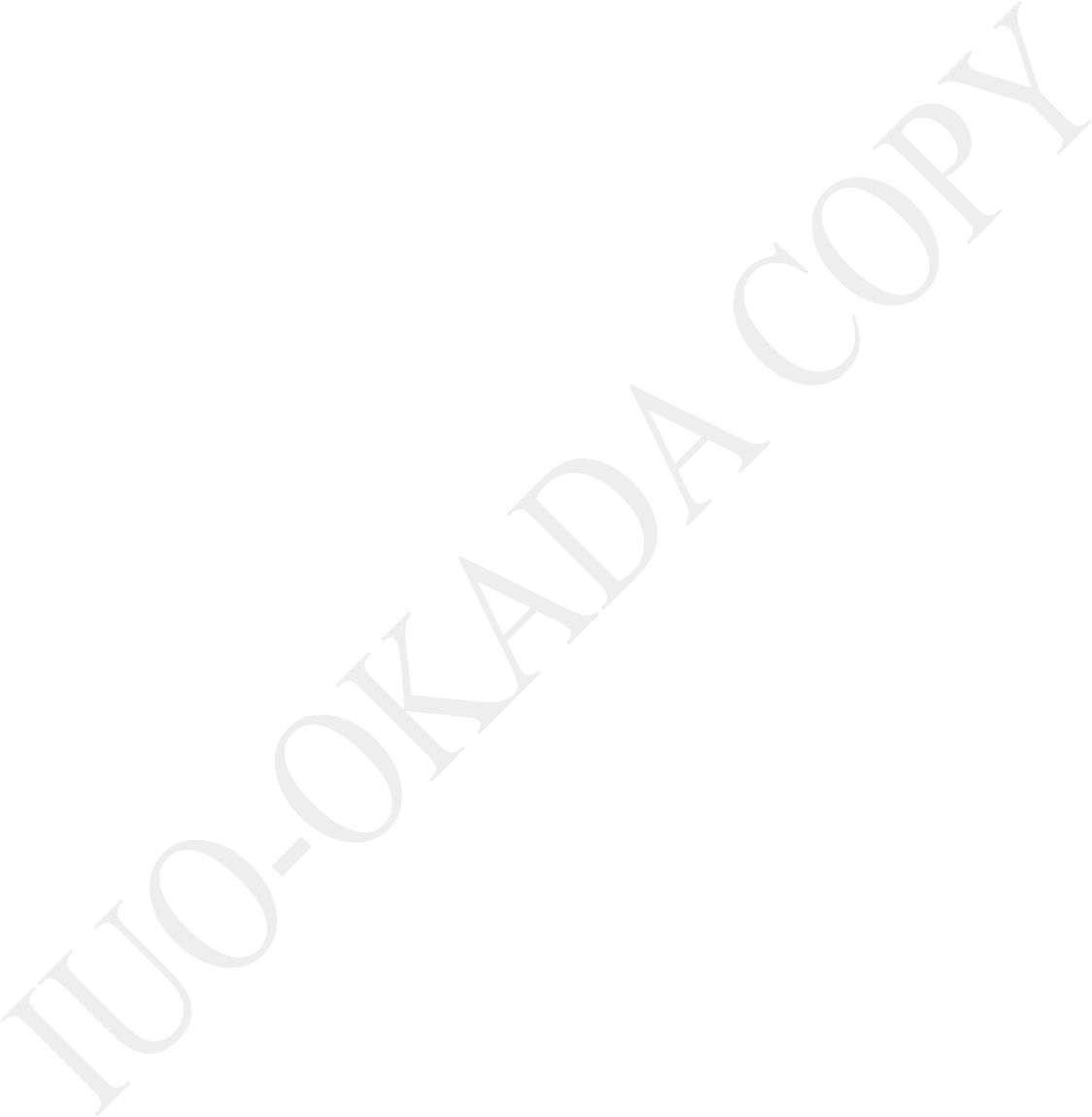
* 1. Verification of Voltage Fluctuation with Installed Panel at the Site 55
  2. Preliminary Manual Sizing Calculations 57
     1. Matching Inverter and Array 60
     2. Number of Modules in a String 60
     3. Maximum and minimum effective voltage of the module 61
     4. Maximum number of string (to match with the inverter input) 62
     5. Matching power rating 63
  3. Main design with PVsyst Simulation Software: 64
     1. Opening the PVsyst Software: 65
     2. Preliminary Design 65
     3. Selecting the Type of PV System Structure 67
     4. Project Design 68
     5. Creating a Project: 69
     6. Project Specification 69
        1. Site Coordinate 69
        2. Site Selection: 70
        3. Input Data and new site creation 72
     7. Save the Project 76
     8. Project Settings 77
     9. Mandatory Parameters 78
        1. System Variant Management 78
     10. Orientation 79
         1. Fixed Plane Field Type 79
         2. Tilt Angle and Azimuth Angle 80
         3. Orientation of the String Modules in Relation to Inverter 81
     11. System under Variant 81
     12. Array to Inverter Matching 82
     13. Detailed Losses under Variant or Derating factors 83
         1. Dc Ohmic Wiring 84
         2. AC Ohmic Loss: 85
         3. Module Quality Loss: 85
         4. Soiling Loss: 85
         5. Module Array Mismatch Loss: 85
         6. Auxiliary Loss: 86
         7. Ageing Loss: 86
         8. System Unavailability: 86

CHAPTER FOUR

RESULT AND DISCUSSIONS

* 1. Result and Discussion 88
  2. Result on the Energy need for IUO Crown Estate Okada 88
  3. Result on the PV Output Voltage Fluctuation carried out on the

Field with Installed Solar panels 89

* 1. PVsyst Simulation Results 92
     1. PVsyst Report Sections 92
        1. Project Summary 92
        2. System Summary 93
        3. Result Summary 93
        4. General Summary 93
        5. Array Losses 93
        6. Near Shading 93
  2. PVsyst Results on different scenarios of simulations, 94
     1. Scenario A simulation 94
        1. Shaded 500kWp PV Plant 94
        2. Non Shaded 500kWp 99
        3. Discussion on 500kWp shaded and non – shaded system 102
     2. Scenario B simulation 104
        1. Mono- facial PV plant on 100 by 50 plot of land 104
        2. Bifacial PV plant on 100 by 50 plot of land 108
        3. Discussion on Mono Facial and Bifacial PV system on 100 by

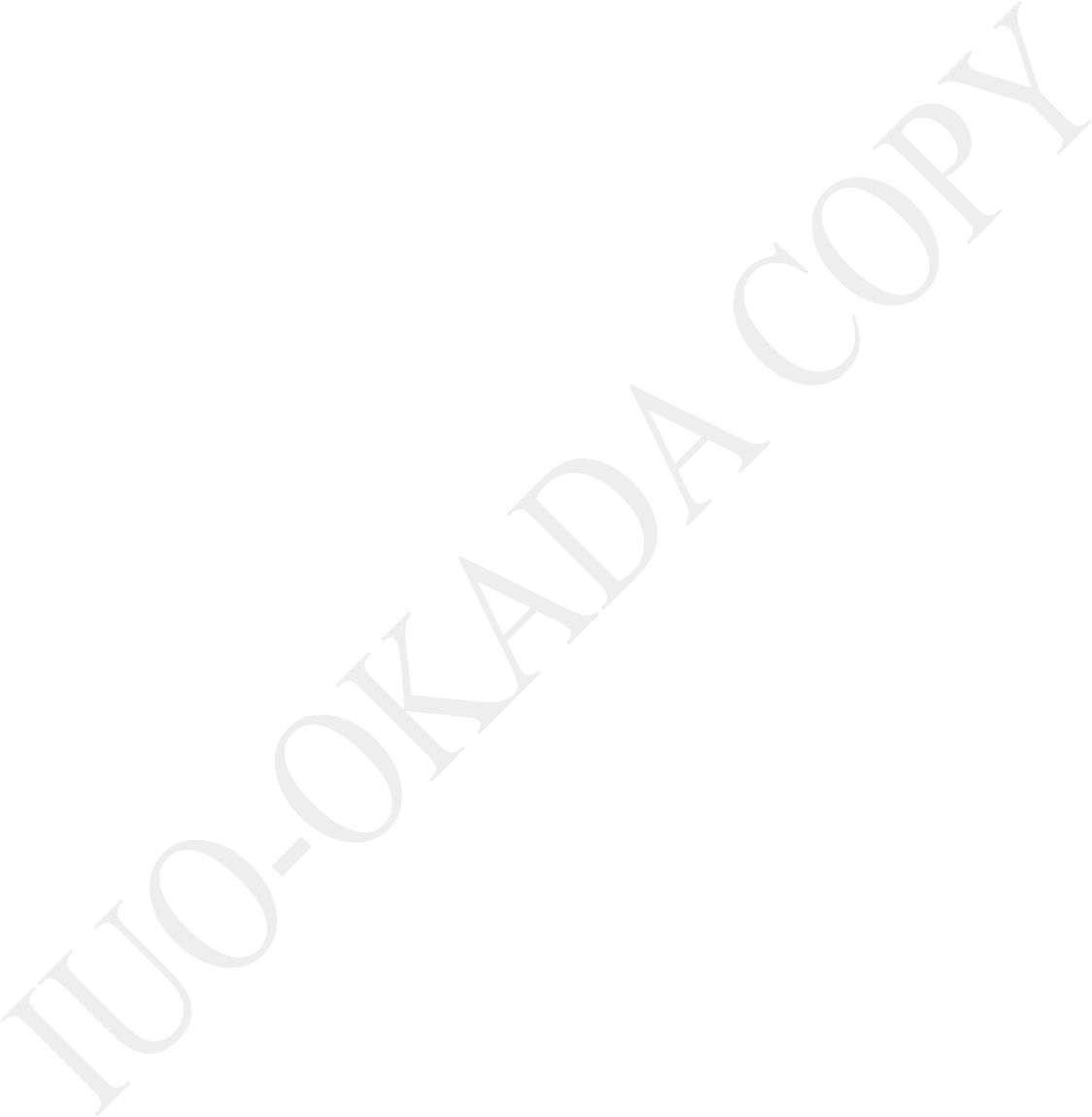
50 plot of land (Scenario B) 111

* + 1. Scenario C simulations 112
       1. 998kWp Bifacial without tracker 112
       2. 998kWp bifacial system with tracker 115
       3. Discussion on Scenario C 117
  1. Normalized Energy Production 118
  2. Energy Injected to the Grid 119
  3. Performance Ratio 119

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

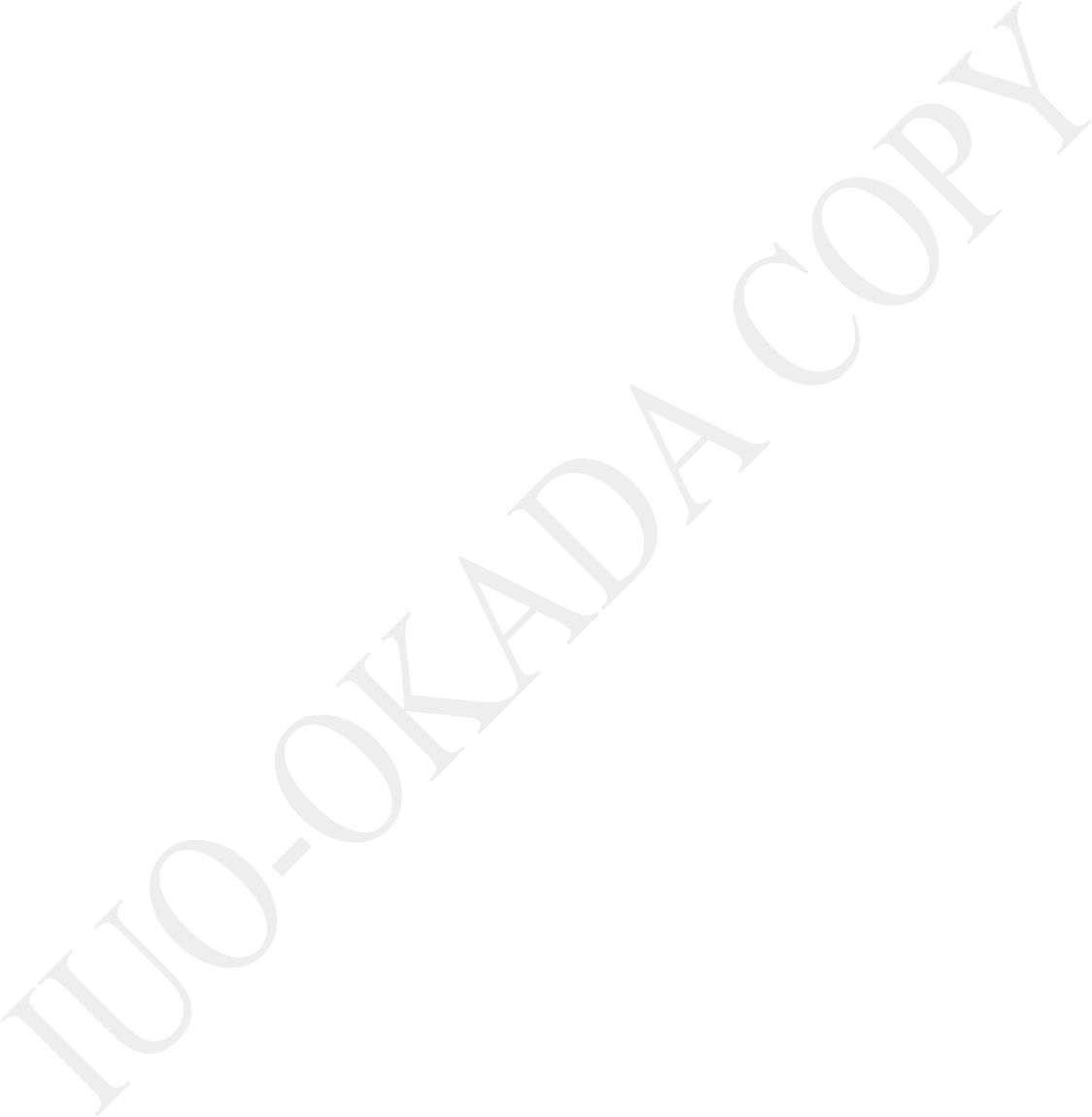
* 1. Conclusion 120
  2. Recommendations 121

REFERENCES 122

# LIST OF TABLES

|  |  |  |
| --- | --- | --- |
| Table 3.1: | 2020 Approximated power capacity of IUO Crown Estate from BEDC (Benin electricity Distribution Company ) | 53 |
| Table 3.2: | Ratings of panels installed at IUO Crown estate | 55 |
| Table 3.3: | Voltage values of the panels installed at IUO Crown estate measured at different time intervals | 56 |
| Table 3.4: | Technical specifications of the solar module chosen for the design | 58 |
| Table 3.5: | Module coefficient factors | 58 |
| Table 3.6: | Chosen Grid Inverter specification Input data DC | 59 |
| Table 3.7: | Chosen Grid Inverter specification output data AC | 59 |
| Table 3.8: | Different possible of arrangement of module array | 63 |
| Table 3.9: | Different scenarios of simulations | 65 |
| Table 3.10: | PVsyst built in database | 71 |
| Table 3.11: | Igbinedion Crown estate Meteonorm data | 75 |
| Table 4.1: | 2020 Approximated power capacity of IUO Crown Estate from BEDC (Benin electricity Distribution Company ) | 88 |
| Table 4.2: | Installed PV panel nameplate ratings | 90 |
| Table 4.3: | Open circuit output voltage measurement result | 91 |
| Table 4.4 | Important parameters on shaded system | 94 |
| Table 4.5 | Balances ad main result for Shaded 500kWp I U O PV plant | 97 |
| Table 4.6 | Important parameters on Non-shaded 500kW system | 99 |
| Table 4.7 | Balance of result for non shaded 500Kwp system | 101 |
| Table 4.8 | Important parameters Mono- facial PV plant on 100 by 50 plot of land | 104 |
| Table 4.9 | Balance of result for Mono- facial PV plant on 100 by 50 plot of land | 106 |

|  |  |  |
| --- | --- | --- |
| Table 4.10 | Important parameters on Bifacial PV plant on 100 by 50 |  |
|  | plot of land | 108 |
| Table 4.11 | Balance for Bifacial system on 100 by 50 plot of land | 109 |
| Table4.12 | Important parameters on 998kWp Bifacial without tracker | 112 |
| Table 4.13 | Balance of result for 998kWp bifacial system without tracker | 113 |
| Table 4.14 | Important parameters on 998kWp bifacial system with tracker | 115 |
| Table 4.15 | Balance of result for 998kWp Bifacial system with tracker | 116 |



# LIST OF FIGURES

Figure 2.1: Block diagram of PV system connected to

the grid (Mansour et al, 2016) 7

Figure 2.2: The tilt of the Earth and its path around the Sun. (Marie, 2018) 10

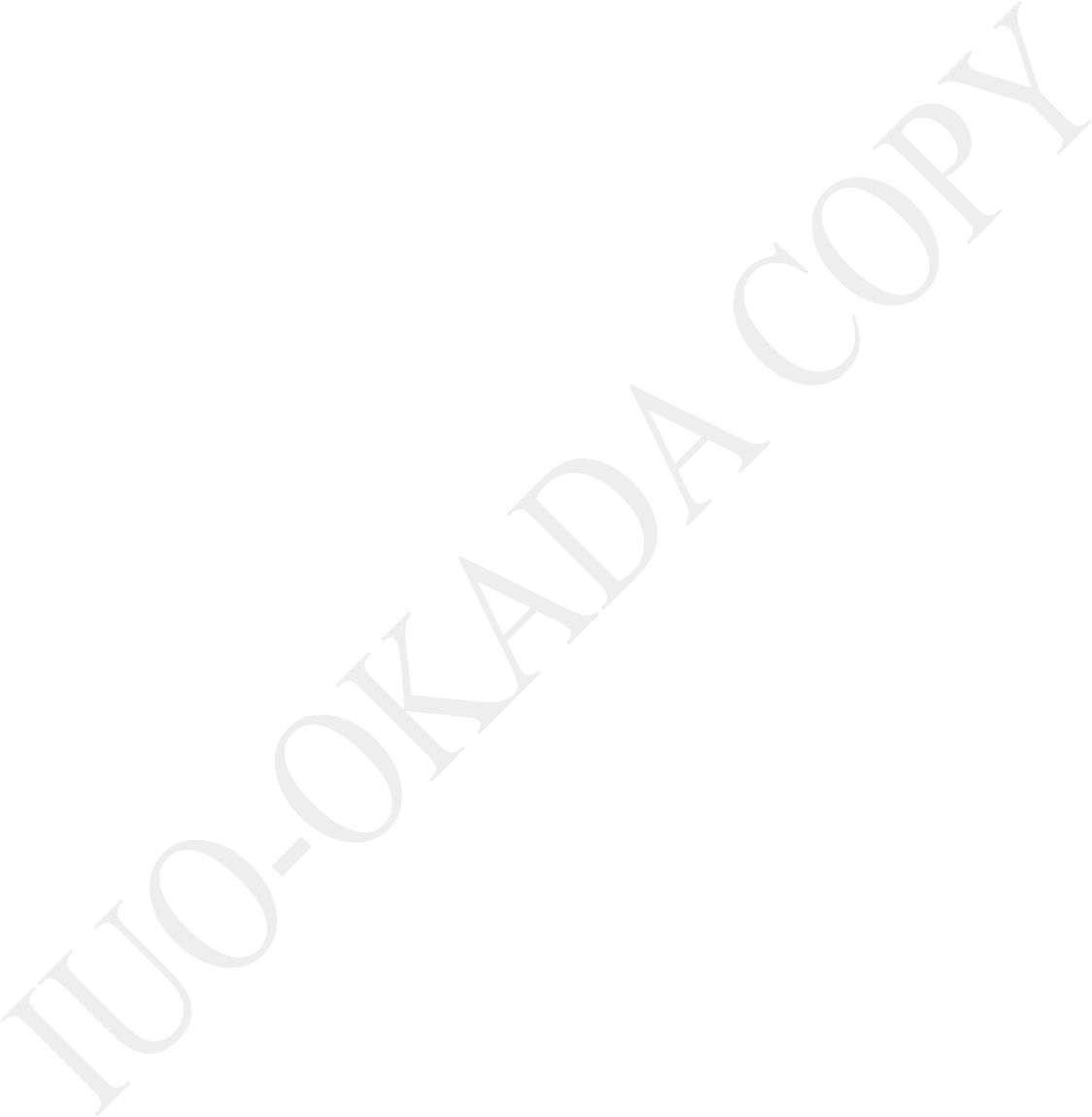
Figure 2.3 (a): Sun and PV module position angles. (Arno et al.,, 2016) 11

Figure 2.3(c): Sun and PV module position angles. (Marie, 2018) 12

Figure 2.3 (d): Incidence angle. (Marie, 2018) 12

Figure 2.4: Illustration of a sun path diagram for the location -34.46◦S,

19.53◦E. (Anton Fedorov, 2015) 14

Figure 2.5: Solar radiation is reflected, absorbed and scattered when

it travels through the atmosphere. (Anton Fedorov, 2015) 15

Figure 2.6: Inter-row spacing for a ground mounted PV

system. (Paller et al., 2018) 19

Figure 2.7: Circuit Diagram Of Grid connected system (Paller et al., 2018) 20

Figure 2.8: Typical structure of (a) a crystalline module. (Marie, 2018) 21

Figure 2.9: Typical structure of (b) a thin-film module. (Marie, 2018) 22

Figure 2.10: Structure of a crystalline silicon PV module. Illustration

inspired by (Arno et al.,, 2016). 24

Figure 2.11(a): Bonding model illustrating (a) silicon above 0 K 26

Figure 2.11(b): Bonding model illustrating (b) p-doping 27

Figure 2.11(c): Bonding model illustrating (c) n-doping 27

Figure 2.12: Illustrates the working principle of a solar cell. (López, 2020) 29

Figure 2.13: The band gap model for a semiconductor with the

excitation of an electron by absorption of light. (López, 2020) 29

Figure 2.14: I-V curve and power curve for a solar cell. (Marie, 2018) 30

Figure 2.15: One-diode model for a solar cell. (Jawairia , 2017) 32

Figure 2.16a: Effect of series resistance on the IV curve of a

solar cell (Adeyemi et al, 2019) 33

Figure 2.16b: Effect of shunt resistance on the IV curve of a

solar cell. (Adeyemi et al, 2019) 33

Figure 2.17a: Effect of cell temperature on power output of a

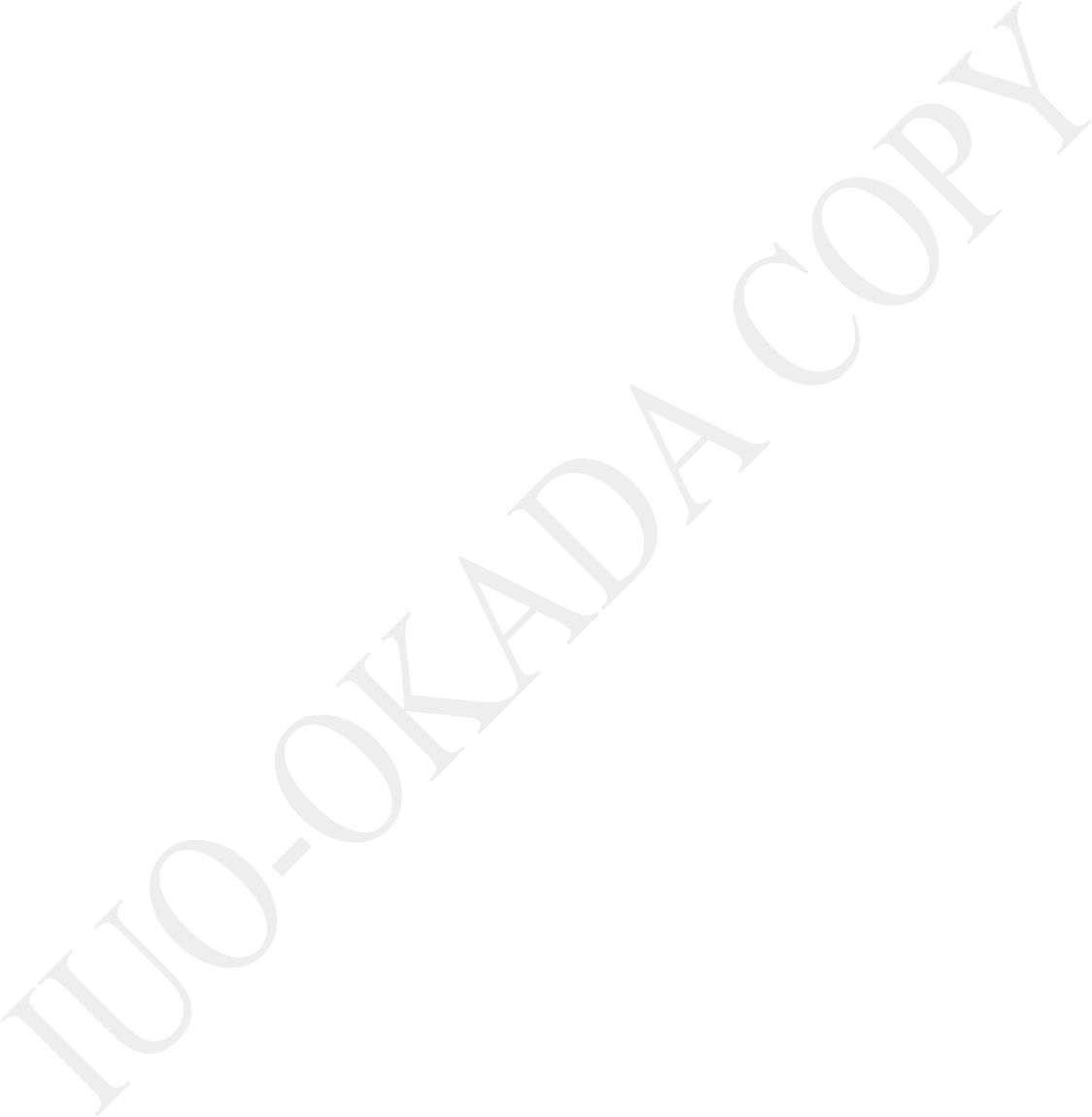
PV module (Marie, 2018) 34

Figure 2.17b: Effect of cell irradiance on power output of a

PV module (Marie, 2018) 35

Figure 2.18a: Central inverter configuration Uploaded by (Adefarati, 2015) 37

Figure 2.18b: String Inverter Configuration Uploaded by (Adefarati, 2015) 37

Figure 2.18c: Module Inverter Configuration (Marie, 2018) 38

Figure 2.18d: Multi - string Optimizer Configuration (Marie, 2018) 38

Fig 2.19(a): Tilted roof mounted from (Marie, 2018) 41

Fig 2.19 (b): Ground mounted from (Marie, 2018) 41

Figure 3.1: PVsyst preliminary design interface 66

Figure 3.2: PVsyst page that shows three PV structure type grid

connected, stand alone and pumping structures. 67

Figure 3.3: Project design step in PVsyst (Paller et al., 2018) 68

Fig 3.4: Interface for geographical or site coordinate in PVsyst. 70

Figure 3.5: I U O Crown estate on Google map with the latitude

and longitude 73

Figure 3.6: I U O Crown estate on google map 74

Fig 3.7: Igbinedion Crown estate created in PVsyst database 76

Figure 3.8: Orientation interface under fixed plane field type 79

Fig 3.9: Orientation interface under unlimited shed 80

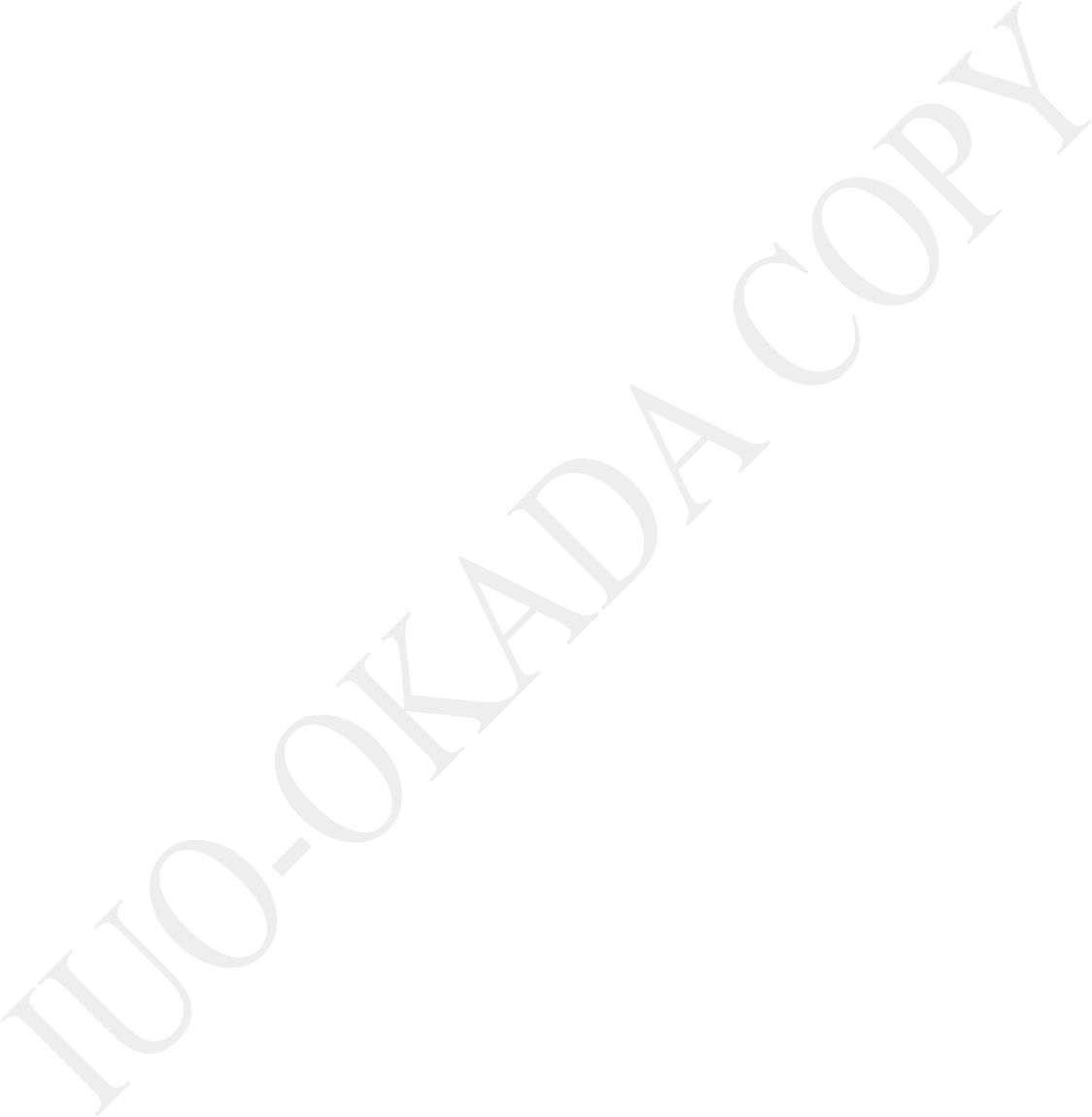
Figure 3.10: Detailed losses page of pvsyst 83

Figure 4.1 Shaded 500kWp system 95

Figure 4.2: Horizon definition for IUO Crown Estate Okada 95

Figure 4.3: Bar chart representation of Normalized energy for

shaded 500kWp PV plant 96

Figure 4.4: Bar representation of Performance Ration for 500kWp

shaded PV plant 96

Figure 4.5 Shaded 500kWp I U O PV plant Loss diagram 98

Figure 4.6 Non- shaded 500kWp array 99

Figure 4.7 Horizon definitions for non shaded 500kWp plant 100

Figure 4.8 Bar chart representation of non shaded 500kWp plant 100

Figure 4.9 Bar chart representation of Performance for non

shaded 500kWp PV Plant 101

Figure 4.10 Loss diagram for non shaded 500kWp system 102

Figure 4.11 Bar chart representing Normalized Energy for Mono- facial

PV plant on 100 by 50 plot of land 105

Figure 4.12. Bar chart representing performance Ratio for Mono- facial PV

plant on 100 by 50 plot of land 105

Figure 4.13: Loss diagram for Mono- facial PV plant on 100 by 50 plot of land 107

Figure 4.14: Bar chart representing Normalized energy for

Bifacial system on 100 by 50 plot of land 108

Figure 4.15: Bar chart representing performance for Bifacial system on

100 by 50 plot of land 109

Figure 4.16: Loss diagram for Bifacial system on 100 by 50 plot of land 110

Figure 4.17: Bar chart representing normalized energy for 998kWp Bifacial

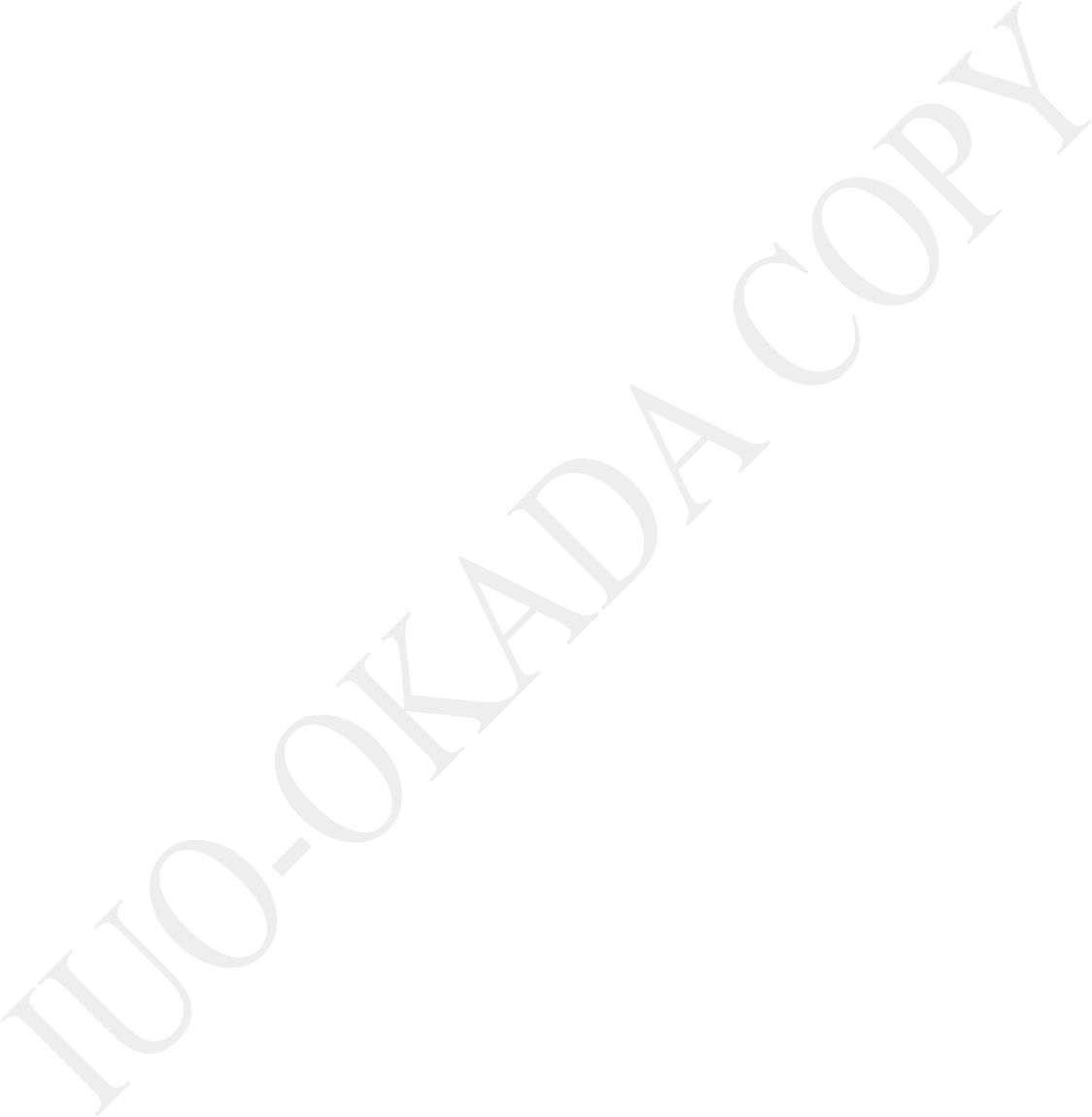
system without tracker (fixed bifacial) 112

Figure 4.18: Bar chart for performance ratio on 998kWp bifacial system

without tracker 113

Figure 4.19 Loss diagrams for 998kWp Bifacial system without tracker 114

|  |  |  |
| --- | --- | --- |
| Figure 4.20: | Bar chart representing normalized energy for 998kWp Bifacial system with tracker | 115 |
| Figure 4.21: | Bar chart for performance ratio on 998kWp Bifacial system without tracker | 116 |
| Figure 4.22 | Loss diagrams for 998kWp Bifacial system without tracker | 117 |



# List of Abbreviations

|  |  |
| --- | --- |
| a – Si | Amorphous Silicon |
| AC | Alternating Current |
| AM | Air Max |
| BDC | Benin Distribution Company |
| BoS | Balance of System |
| CdTe | Cadmium Telluride |
| CiGs | Copper Indium, Gallium Selenide |
| C-Si | Crystalline Silicon |
| DC | Direct Current |
| EC | Edge of the Conduction Band |
| EV | Edge of the Valence Band |
| EVA | Ethyl Vinyl Acetate |
| FF | Fill Factor |
| GHG | Greenhouse Gas |
| GTI | Global Tilted Irradiance |
| ISC | Short Circuit Current |
| IUO | Igbinedion University Okada |
| MPP | Maximum Power Point |
| NOCT | Nominal Operating Cell Temperature |
| PR | Performance Ratio |
| PV | Photovoltaic |
| STC | Standard Test Conditions |
| UV rays | Ultra Violet Rays |
| VMAX | Maximum Photovoltaic Module Output Voltage |
| VOC | Open Circuit Voltage |
| Ya | Array Yield |
| Yf | Specific Yield |
| Yr | Reference Yield |
| IUO | Igbinedion University Okada |