



# **DESIGN AND OPTIMIZATION OF HYBRID ENERGY SYSTEM OF A REMOTE AREA OF BANGLADESH**

**Md Rosaidul Mawla**  
**B.ScEngg (EEE), BUET**  
**Roll No: 2016160023 (P)**

A THESIS SUBMITTED FOR THE PARTIAL FULFILLMENT  
OF  
MASTER OF SCIENCE  
IN  
ELECTRICAL, ELECTRONIC AND COMMUNICATION  
ENGINEERING

**DEPARTMENT OF ELECTRICAL, ELECTRONIC AND COMMUNICATION  
ENGINEERING**

**MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY  
MIRPUR CANTONMENT, DHAKA-1216**

November 2020

## **BOARD OF APPROVAL**

The thesis entitled “**DESIGN AND OPTIMIZATION OF HYBRID ENERGY SYSTEM OF A REMOTE AREA OF BANGLADESH**” submitted by MdRosaidulMawla, Roll No: 2016160023 (P), Session: April-2016 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Electrical, Electronic and Communication Engineering on 30 November 2020.

## **BOARD OF EXAMINERS**

1. \_\_\_\_\_  
Dr. Md. ZiaurRahman Khan  
Professor  
Department of EEE, BUET, Dhaka-1205  
Chairman  
(Supervisor)
  
2. \_\_\_\_\_  
Maj Md. Ali AzamKhan  
Instructor Class-B  
Department of EEE, MIST, Dhaka-1216  
Member  
(Co-Supervisor)
  
3. \_\_\_\_\_  
Brig Gen A K M Nazrul Islam, PhD  
Head of the Department  
Department of EECE, MIST, Dhaka-1216  
Member  
(Ex-officio)
  
4. \_\_\_\_\_  
Dr. MdGolamMostafa  
Professor  
Department of EECE, MIST, Dhaka-1216  
Member  
(Internal)
  
5. \_\_\_\_\_  
Dr. Abdul HasibChowdhury  
Professor  
Department of EEE, BUET, Dhaka-1205  
Member  
(External)
  
6. \_\_\_\_\_  
Dr. Tareq Aziz  
Professor  
Department of EEE, AUST, Dhaka-1208  
Member  
(External)

## **CANDIDATE'S DECLARATION**

“I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.”

---

MD ROSAIDULMAWLA

November2020

## **DEDICATION**

To my mother and my beloved family

## ACKNOWLEDGMENTS

I am thankful to Almighty Allah for giving me strength, integrity and patience for the successful completion of the thesis work. I am greatly indebted and respectful to my supervisor Professor Dr. ZiaurRahman Khan for his great support, guidance and encouragement. His valuable suggestions greatly helped in understanding the intricate problem involved in completion of the work. He has guided with his remarkable expertise in this sector during the entire progress of the work. I would like to thank Professor Dr. ZiaurRahman Khan, Professor, Department of Electrical and Electronic Engineering, BUET, a brilliant motivator and human being who enlighten the path through the course of postgraduate research work. His enthusiasm, broad knowledge and sharp thinking gained the sincerest admiration of mine. His caring and understanding touched deeply. Finally, I bow to my supervisor for his contribution and inspiration.

I also want to extend my thanks and gratitude to the Head of Dept. and all senior faculty members and my colleagues of EECE department, MIST who helped time to time to carry out the research work smoothly.

I firmly believe that this thesis would not be implemented without the assistance of SREDA and some other organizations.

Last but not least, I want to thank my parents and beloved wife for the continual inspiration and motivation to pursue my utmost goals.

## ABSTRACT

Mitigation of power demand of a remote area of Bangladesh has been studied here. SwarnaDweep, an island in the Bay of Bengal, is considered for the work. Due to its geographical location, it is not economically feasible to connect SwarnaDweep with grid connection. People of this island need to depend on diesel generator which is not environment friendly. To obtain the environment friendly power, a detail survey is conducted to assess the renewable resources available in SwarnaDweep and to estimate the component cost. In the study, optimum configuration of a solar-wind-biogas-diesel-battery hybrid energy system is determined for the uninterrupted power supply system for the SwarnaDweep using Hybrid Optimization Model for Electric Renewables software developed by National Renewable Energy Laboratory. Besides that by economic modeling, the economic viability is tested. Moreover, an effort is taken to validate the result of HOMER by intelligent system and functional test is conducted on the proposed hybrid design. Payback period and internal rate of return are calculated and compared with the hybrid energy systems reported in the literature. A combination of 100 kW PV array, 25 Wind turbine (10 kW each), a diesel generator with a rated power of 40 kW, 30 kW biomass generator, 2000 piece of storage battery and 650 kW converter is the most commercially reliable in terms of Cost of Energy (21.655 Tk/kWh), Net Present Cost (171,171,120 Tk) and initial cost (40,451,200Tk). The proposed hybrid energy system has the electricity generation mix of 29 % from PV, 56% from the wind turbine, 5% from diesel generator and 10% from biogas resources. The proposed hybrid system was able to produce 1957 kWh/day against the 1694 kWh/day required for lighting and power loads. Considering 25 taka per kilowatt hour, the payback period is only 9 years and considering 30 taka, the payback period is 8 years. After calculation of internal rate of return becomes 9.33% which is beneficial as the interest rate is considered 8% for the project. The sensitivity analysis is undertaken to assess the effect solar, wind, biogas resource and diesel costs, on the net present cost and CO<sub>2</sub> emissions. The results indicate that available solar, wind and biogas resource can be utilized economically using hybrid energy systems for decentralized applications in remote areas of Bangladesh.

***MD ROSAIDULMAWLA***

***Dhaka, Bangladesh***

***November, 2020***

## TABLE OF CONTENTS

	<b>Page Number</b>
<b>BOARD OF APPROVAL</b>	<b>ii</b>
<b>CANDIDATE'S DECLARATION</b>	<b>iii</b>
<b>DEDICATION</b>	<b>iv</b>
<b>ACKNOWLEDGEMENTS</b>	<b>v</b>
<b>ABSTRACT</b>	<b>vi</b>
<b>TABLE OF CONTENTS</b>	<b>vii</b>
<b>LIST OF TABLES</b>	<b>xi</b>
<b>LIST OF FIGURES</b>	<b>xiii</b>
<b>LIST OF ACRONYMS &amp; ABBREVIATIONS</b>	<b>xvi</b>
<b>CHAPTER 1: INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Motivation of the Study	5
1.3 Literature Review	6
1.4 Objectives	9
1.5 Thesis Structure	10
<b>CHAPTER 2: DESIGN METHODOLOGY</b>	
2.1 Introduction	12
2.2 Methodology	12
2.2.1 Flow Chart of the Methodology	13
2.2.2 Site Selection	14
2.2.3 Data Collection for Load Assessment	14
2.2.4 Resources Assessment	14
2.2.5 Selection of Parameters	15
2.2.6 Implementation	15
2.3 Conclusion	16
<b>CHAPTER 3: SYSTEM MODELING</b>	<b>17</b>
3.1 Introduction	17
3.2 Survey Area	17
3.2.1 Load Assessment	19
3.2.2 Estimation of Electrical Load of the Studied Area	20
3.3 Renewable Resources at SwarnaDweep	22
3.3.1 Solar Resources	22

3.3.2	Wind Resources	23
3.3.3	Biomass Resources	26
3.4	Technical Specifications and Cost Assessment	28
3.4.1	System Components Assessment	28
3.4.2	Solar Photovoltaic	29
3.4.3	Wind Turbine	30
3.4.4	Biogas Generator	32
3.4.5	Diesel Generator	32
3.4.6	Battery Model	33
3.4.7	Power Converter	34
3.5	System Modeling	35
3.5.1	Introduction	35
3.5.2	System Components Modeling	35
3.6	Hybrid System Configurations	44
3.6.1	Different Scenarios of the Proposed of Hybrid System	44
3.6.2	Modeling of Renewable Hybrid Systems Components	44
3.7	Modeling Validation by Fuzzy Expert System	46
3.8	Functionality Test of the Design by ETAP Software	47
3.9	Summary	48
<b>CHAPTER 4: RESULTS AND ANALYSIS</b>		49
4.1	Introduction	49
4.2	HOMER Modeling	49
4.3	Different Scenarios of Various Parameters of Hybrid Scenarios	51
4.4	Scenario C -Solar PV-Wind-Diesel Generator	52
4.4.1	Introduction	52
4.4.2	Cash Flow Summary Cash Flows	52
4.4.3	Generation of Electricity of the Scenario C	53
4.4.4	PV Array	55
4.4.5	Wind Turbine	56
4.4.6	Diesel Generator	57
4.4.7	Battery	58
4.4.8	Converter	59
4.4.9	Emissions	60
4.5	Scenario B -Solar PV- Wind-Biogas Generator	61
4.5.1	Introduction	61



4.5.2	Cash Flow Summary	62
4.5.3	Generation of Electricity of the Scenario B	62
4.5.4	PV Array	64
4.5.5	Wind Turbine	66
4.5.6	Biogas Generator	67
4.5.7	Battery	67
4.5.8	Converter	69
4.5.9	Emissions	70
4.6	Scenario C-Solar PV-Wind-Biogas Generator-Diesel Generator	70
4.6.1	Introduction	70
4.6.2	Cash Flow Summary	71
4.6.3	Generation of Electricity of the Scenario A	72
4.6.4	PV Array	73
4.6.5	Biogas Generator	75
4.6.6	Wind Turbine	76
4.6.7	Diesel Generator	77
4.6.8	Battery	78
4.6.9	Converter	79
4.6.10	Emissions	80
4.7	Analysis of the Homer Results	81
4.8	Simulation Model	81
4.9	Analysis of Different Scenarios of the Hybrid Configurations	82
4.10	Analysis of the Best Configurations of hybrid system	90
4.11	Electrical Demand and Supply	92
4.12	Overall Energy Performance	92
4.13	Pay Back Period	93
4.14	Internal Rate of Return (IRR)	94
4.15	Comparing COE and NPC with Previous Literature of other Countries	95
4.16	Socio-economic Benefits	97
4.17	Conclusion	98

<b>CHAPTER 5: SENSITIVITY ANALYSIS</b>	99
5.1 Introduction	99
5.2 Sensitivity Analysis Results	102
5.3 Conclusion	109
<b>CHAPTER 6: VALIDATION BY INTELLIGENT SYSTEM AND FUNCTIONALITY TEST</b>	110
6.1 Structure of Fuzzy Expert System	110
6.2 Implementation of Fuzzy Expert System	111
6.3 Operation of the Fuzzy Expert System Model	113
6.4 Fuzzy Control Surfaces	114
6.5 Comparison between HOMER and Fuzzy Expert System	115
6.6 ETAP Functional Test Analysis	115
6.7 Summary	123
<b>CHAPTER 7: CONCLUSION</b>	124
7.1 Conclusion	124
7.2 Future Work	126
<b>LIST OF PUBLICATIONS</b>	128
<b>BIBLIOGRAPHY</b>	131

## LIST OF TABLES

Table 3.1	Daily Load Consumption of Selected Area	20
Table 3.2	Primary load input into HOMER for Summer	21
Table 3.3	Monthly Solar Radiation	22
Table 3.4	Wind speed of Different Locations of SwanaDweep at 60 meters	23
Table 3.5	Monthly Wind Speed	24
Table 3.6	Livestock's Statistics at survey area	27
Table 3.7	Month wise cattle dung recovered from survey area	27
Table 3.8	Calculation of Amount of Dung to be received from survey area	28
Table 3.9	Solar PV Module Specification	30
Table 3.10	Parameters and costs considered for Solar Photovoltaic	30
Table 3.11	AeolosWind Turbine 10 KW Specifications	31
Table 3.12	Cost Analysis for Wind Turbine	31
Table 3.13	Specifications for Puxin Biogas Generator	32
Table 3.14	Costs considered for biomass generator	32
Table 3.15	Parameters and costs considered for diesel generator	33
Table 3.16	Parameters and costs considered for Hoppecke 16 OPzS storage batteries	34
Table 3.17	Cost Analysis for Battery	34
Table 3.18	Parameters and costs considered for power converter	35
Table 3.19	Cost Analysis for Converter	35
Table 4.1	PV scheme simulation result	55
Table 4.2	Wind turbine simulation result of scenario C	57
Table 4.3	Diesel Generator simulation result of scenario C	58
Table 4.4	Battery simulation result of scenario C	58
Table 4.5	Converter simulation result of scenario C	59
Table 4.6	Pollutant released per year of scenario C	61
Table 4.7	PV scheme simulation result	65
Table 4.8	Wind turbine simulation result of scenario B	66
Table 4.9	Diesel Generator simulation result of scenario B	67
Table 4.10	Battery simulation result of scenario B	68
Table 4.11	Converter simulation result of scenario B	69
Table 4.12	Pollutant released per year of scenario B	70
Table 4.13	PV scheme simulation result	74

Table 4.14	Biogas generator simulation result	75
Table 4.15	Wind turbine simulation result of scenario A	76
Table 4.16	Diesel Generator simulation result of scenario A	77
Table 4.17	Battery simulation result of scenario A	78
Table 4.18	Converter simulation result of scenario A	79
Table 4.19	Pollutant released per year of scenario A	80
Table 4.20	Optimized system architectures for the hybrid system	84
Table 4.21	CO <sub>2</sub> Emissions related to each system configuration	85
Table 4.22	Electrical Productions for Proposed Three Scenarios of Hybrid Energy System	86
Table 4.23	Electrical Consumption for Proposed three Scenarios of HybridEnergy System	86
Table 4.24	Electrical Quantity for Proposed three Scenarios of Hybrid Energy System	87
Table 4.25	Cost analysis of three-hybrid renewable energy system	88
Table 4.26	Summary of performance parameters of three different system configurations	89
Table 4.27	Summary of Cost of the Components	91
Table 4.28	Electricity production of hybrid system components for best Option	96
Table 6.1	Comparison of Results	115

## LIST OF FIGURES

Fig.2.1	Flow Chart of Methodology	13
Fig. 3.1	Survey area map	17
Fig. 3.2	Survey area map showing the neighboring islands	18
Fig. 3.3	Seasonal Profile of SwarnaDweep	21
Fig. 3.4	Snapshot of Primary load	21
Fig. 3.5	Monthly Temperature Distribution over the Year	25
Fig. 3.6	Probability Distribution Function	26
Fig. 3.7	Architecture of System Components	29
Fig. 3.8	Hybrid system configuration of solar PV, wind, diesel generator	45
Fig. 3.9	Hybrid system configuration of solar PV, wind, biogas generator	45
Fig. 3.10	Hybrid system configuration of solar PV, wind, Biogas and diesel generator	46
Fig. 3.11	Block diagram of fuzzy interface	47
Fig. 4.1	Conceptual relationship between simulation, optimization and sensitivity analysis	50
Fig. 4.2	Block diagram of Scenario A of the hybrid configuration system	52
Fig. 4.3	Snapshot of Cash flow summary by components of scenario A	53
Fig. 4.4	Monthly average Electricity production of scenario A	53
Fig. 4.5	Energy generation percentage share from each component of scenario A	54
Fig. 4.6	Snapshot of generation and consumption of electricity for Scenario A	54
Fig. 4.7	PV array power output monthly averages of scenario A	55
Fig. 4.8	Yearly PV output of scenario A	56
Fig. 4.9	Wind turbine output of scenario A	56
Fig. 4.10	Generator output of scenario A	57
Fig. 4.11	Frequency histogram and monthly statistics of battery of scenario A	59
Fig. 4.12	Snapshot of battery bank state of charge of scenario A	59
Fig. 4.13	Snapshot of inverter output of scenario A	60
Fig. 4.14	Snapshot of rectifier output of scenario A	60
Fig. 4.15	Block diagram of Scenario B of the hybrid configuration system	61
Fig. 4.16	Snapshot of Cash flow summary of scenario B	62
Fig. 4.17	Monthly average Electricity production of scenario B	63
Fig. 4.18	Energy generation percentage share from each component of scenario B	62
Fig. 4.19	Snapshot of generation and consumption of electricity for Scenario B	64
Fig. 4.20	PV array power output monthly averages of scenario B	64

Fig. 4.21	Daily Map for Solar PV of scenario B	65
Fig. 4.22	Daily Map for wind turbine of scenario B	66
Fig. 4.23	Yearly biogas generator output of scenario B	67
Fig. 4.24	Snapshot of Frequency histogram and state of charge of scenario B	68
Fig. 4.25	Snapshot of battery bank state of charge of scenario B	68
Fig. 4.26	Snapshot of inverter output of scenario B	69
Fig. 4.27	Snapshot of rectifier output of scenario B	69
Fig. 4.28	Block diagram of Scenario C of the hybrid configuration system	71
Fig. 4.29	Snapshot of Cash flow summary by components of scenario C	72
Fig. 4.30	Monthly average Electricity production of scenario B	72
Fig. 4.31	Energy generation percentage share from each component of scenario C	73
Fig. 4.32	Snapshot of generation and consumption of electricity for Scenario	73
Fig. 4.33	PV array power output monthly averages	74
Fig. 4.34	Yearly PV output of scenario C	75
Fig. 4.35	Yearly biogas generator output	75
Fig. 4.36	Wind turbine output of scenario C	76
Fig. 4.37	Diesel Generator output of scenario C	77
Fig. 4.38	Snapshot of Frequency histogram and monthly statistics of battery of scenario C	78
Fig. 4.39	Snapshot of battery bank state of charge of scenario C	79
Fig. 4.40	Snapshot of inverter output of scenario A	80
Fig. 4.41	Snapshot of rectifier output of scenario A	80
Fig. 4.42	Architecture of the hybrid power system design using HOMER	82
Fig. 4.43	Screenshot of Simulation results of the hybrid configuration system from HOMER	82
Fig. 4.44	Comparison of scenarios based on replacement cost and operation and maintenance cost	84
Fig. 4.45	Capital cost percentage by components for best option	90
Fig. 4.46	Cash flow summary in terms of NPC by component type	91
Fig. 4.47	IRR of the Project	95
Fig.5.1	Sensitivity analysis (variation of wind speed with respect to solar radiation)	100
Fig.5.2	Sensitivity analysis (variation of biomass resource with respect to solar radiation)	100
Fig.5.3	Sensitivity analysis (variation of diesel price with respect to solar radiation)	101
Fig.5.4	Sensitivity analysis (variation of biomass resource with respect to wind speed)	101
Fig.5.5	Sensitivity analysis (variation of diesel price with respect to wind speed)	101

Fig.5.6	Sensitivity analysis (variation of diesel price with respect to biomass resource)	102
Fig. 5.7	COE-When diesel price is 65Tk/Litre	103
Fig.5.8	COE-when diesel price is 70 Tk/litre	103
Fig. 5.9	COE-When diesel price is 75Tk/Litre	103
Fig.5.10	NPC-when diesel price is 65 Tk/litre	104
Fig. 5.11	NPC-When diesel price is 70Tk/Litre	104
Fig.5.12	COE-when diesel price is 75 Tk/litre	104
Fig. 5.13	Diesel price and global solar radiation variations on NPC and COE	105
Fig.5.14	Effect of Wind Speed and global solar radiation keeping biomass resources and diesel price fixed	106
Fig. 5.15	Wind Speed and global solar radiation by varying the biomass resources and diesel price	106
Fig. 5.16	Effect of total COE and NPC by varying few key parameters	107
Fig.5.17	Effect of total COE and NPC by varying few key parameters	107
Fig. 5.18	The graph illustrates the effect of variations in four key sensitivity variables.	108
Fig.5.19	The graph illustrates the best estimate considering key variables	108
Fig. 5.20	The graph illustrates best estimate varying key variables	109
Fig. 6.1	General structure of Fuzzy expert system	111
Fig.6.2	Membership function plot for photovoltaic (PV)	112
Fig. 6.3	FES rule editor	112
Fig.6.4	Rule viewer of the fuzzy inferring system	113
Fig. 6.5	Control surfaces of the fuzzy inferring system	114
Fig. 6.6	Single Line Diagram of Proposed Hybrid System	118
Fig.6.7	Single Line Diagram of Hybrid System - When Solar PV and Battery is Open	119
Fig. 6.8	Single Line Diagram of Hybrid System - When Biogas Generator is Open	120
Fig.6.9	Single Line Diagram of Hybrid System - When Diesel Generator is Open	121
Fig. 6.10	Single Line Diagram of Hybrid System - When Wind Turbine is Open	122

## LIST OF ACRONYMS & ABBREVIATIONS

AC	Alternating Current
BPDB	Bangladesh Power Development Board
COE	Cost of Energy
ETAP	Electrical Transient Analyzer Program
GDP	Gross Domestic Product
GHGs	Greenhouse gases
GoB	Government of Bangladesh
HOMER	Hybrid Optimization Model for Electric Renewable
IEA	Internal Energy Association
EPCD	Environment Pollution Control Department
IDCOL	Infrastructure Development Company Limited
IPPs	Independent Power Producers
IRR	Internal Rate of Return
MATLAB	Matrix Laboratory
NASA	National Aeronautics and Space Administration
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
PSMP	Power System Master Plan
PV	Photo Voltaic
RE	Renewable Energy
SDG	Sustainable Development Goal
SHS	Solar Home System
SREDA	Sustainable & Renewable Energy Development Authority
UNDP	United Nations Development Programme