TECHNO-ECONOMIC ANALYSIS OF A STAND-ALONE PHOTOVOLTAIC-DIESEL-BATTERY SYSTEM: A CASE STUDY IN NOTHERN NIGERIA

ABUBAKAR MUSA

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical Power)

.
Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2016

This project is dedicated to my Family.

ACKNOWLEDGEMENT

Alhamdulillah, first of all I give thanks to almighty Allah (S.W.T), whose in his infinite mercy grant me the opportunity to complete this project successfully. I would like to dedicate my appreciation to my project supervisor Dr. Tan Chee Wei for his great ideas, encouragement, support and help in order to make this project possible. I am grateful to have such an amazing project supervisor whom had been guide me throughout my final year project My gratitude goes to my beloved father for his fatherly advice and prayers.

Alhamdulillah I give thanks to almighty Allah (S.W.T), whose in his infinite mercy grant me the opportunity to complete this project successfully. I also want to use this opportunity to extend my sincere appreciation to my supervisor Dr. Tan Chee Wei for her guidance, encouragement and advice throughout the period of this study. My gratitude goes to my beloved father for his fatherly advice and prayers.

Alhamdulillah I give thanks to almighty Allah (S.W.T), whose in his infinite mercy grant me the opportunity to complete this project successfully. I also want to use this opportunity to extend my sincere appreciation to my supervisor Dr. Tan Chee Wei for her guidance, encouragement and advice throughout the period of this study. My special gratitude goes to my family, friends and relatives fatherly advice and prayers.

ABSTRACT

For many years, the application of renewable energy systems have significantly increased due to the negative impact realised in using fossil fuel and how it seriously affect the environment. The renewable energy source are always available for free, this have contributed to the increased in its application every day. Photovoltaic system have been considered as one of the best source of energy due to many factors, these factors include clean environment, less noise, little maintenance and clean energy. This project work examine the configuration of photovoltaic and diesel stand-alone off-grid system where the PV system alternatively generate electrical energy during the day time while the battery supply electrical power to the load from the energy it reserved during night hours or when there is no enough energy from the PV modules. The generator set is acting on standby mode as it only supply the load essentially on priority bases or during maintenance services which require complete isolation of the entire PV system. The modelling is divided into two parts; technical analysis is perform using Matlab/Simulink where the behaviour and characteristics of the system is obtained. The second part is the economic and environmental analysis performed by Homer simulation software which compare different energy system configuration and focused on initial capital cost, Net present cost (NPC), operating cost, Cost of energy and reduction in carbon emission (CO2). The Homer select the overall winning sizes from different energy configuration, based on that sensitivity analysis was perform. Lastly, the hybrid system will served as an alternative solution that will supply electrical power to the healthcare centre in northern Nigeria which require little amount of electricity to improve their medical.

ABSTRAK

Selama bertahun-tahun, penggunaan sistem tenaga boleh diperbaharui telah meningkat dengan nyata disebabkan oleh kesedaran mengenai kesan negatif dalam penggunaan bahan api fosil dan bagaimana ia telah menjejaskan persekitaran dengan teruk sekali. Sumber tenaga boleh diperbaharui boleh didapati dengan percuma, ini telah menyumbang kepada peningkatan penggunaannya setiap hari. Sistem fotovoltaik telah dipertimbangkan sebagai salah satu sumber tenaga terbaik disebabkan oleh banyak faktor, faktor-faktor ini termasuk persekitaran bersih, kurang bunyi bising, kurang penyelenggaraan dan tenaga bersih. Projek ini memeriksa tatarajah fotovoltaik dan sistem diesel tunggal tanpa grid di mana sistem PV secara alternatif menghasilkan tenaga elektrik semasa siang manakala bateri membekalkan kuasa elektrik kepada beban dari tenaga yang disimpan semasa malam hari atau apabila tenaga tidak mencukupi dari modul PV. Set penjana bertindak sebagai mod menungu sedia kerana ia hanya membekalkan beban mengikut keutamaan atau semasa proses penyelenggaraan yang memerlukan pengasingan sepenuhnya seluruh sistem PV. Peragaan dibahagikan kepada dua bahagian; analisis teknikal yang dijalankan menggunakan Matlab / Simulink di mana kelakuan dan sifat sistem diperolehi. Bahagian kedua ialah analisis persekitaran dan ekonomi yang dijalankan oleh perisian simulasi Homer yang membandingkan tatarajah sistem tenaga yang berbeza dan fokus pada kos modal awal, kos bersih (NPC), kos operasi, kos tenaga dan pengurangan dalam pelepasan karbon(CO_2). Homer memilih saiz keseluruhan yang terbaik dari tatarajah tenaga lain, berdasarkan analisis kepekaan yang dijalankan. Akhir sekali, sistem kacukan akan digunakan sebagai satu penyelesaian alternatif yang akan membekalkan kuasa elektrik kepada pusat penjagaan kesihatan di utara Nigeria yang memerlukan jumlah elektrik kecil untuk meningkatkan perkhidmatan perubatan mereka.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

BIPV	-	Building Integrated Photovoltaic
COE	-	Cost of Energy
CO_2	-	Carbon Dioxide
DG	-	Diesel Generator
DE	-	Differential Evaluation
FiT	-	Fit-in-Tariff
ICC	-	Initial capital Cost
MPP	-	Maximum Power Point
O & M	-	Operation & Maintenance
PSC	-	Partial Shading Condition
PV	-	Photovoltaic
PWM	-	Pulse Width Modulation
RES	-	Renewable Energy System

LIST OF SYMBOLS

$\frac{d_{iL}}{dt}$	-	Derivative of inductor current to time
I_D	-	Diode current
I_{MPP}	-	Current at maximum power point
$I_{PV}.$	-	Photovoltaic current
I_{SC}	-	Short circuit current
I_{ph}	-	Current produced by PV array
$\dot{P}$	-	Derivative of power
R_s	-	Series resistance
R_{sh}	-	Shunt resistance
T_{Ref}	-	Reference temperature
$\dot{V}$	-	Derivative of voltage
V_D	-	Diode voltage
V_{MPP}	-	Voltage at maximum power point
V_{PV}	-	Photovoltaic voltage
V_T	-	Thermal voltage

V_g	-	Global voltage
V_i^k	-	Current particle velocity
V_i^{k+1}	-	Particle velocity update
V_o	-	Output voltage
V_{oc}	-	Open circuit voltage
V_s	-	Voltage source
c_1	-	Influence of individual learning rate
c_2	-	Influence of social learning rate
$\frac{dI}{dV}$	-	Derivative of current to voltage
$gbest_i$	-	The best solution found by the swarm
$pbest_i$	-	The best position found by the particle
r_1 and r_2	-	Uniform distributed random values to Add Randomness to particle movement
v_L	-	Inductor voltage
x_i^k	-	Current particle position
x_i^{k+1}	-	Particle position update
ΔI	-	Change of current
ΔP	-	Change of power
ΔE	-	Change of error
$\Delta I / \Delta V$	-	Change of current to change of voltage
A	-	Diode ideality factor

AC	-	Alternate current
B.C	-	Before century
C	-	Capacitor
D	-	Duty cycle
DC	-	Direct current
dP/ dV	-	derivative power to voltage
I-V	-	Current- Voltage
kHz	-	Kilo Hertz
KVL	-	Kirchhoff's Voltage Law
kW	-	Kilowatt
NB	-	Negative big
NM	-	Negative medium
NP	-	Number of particle
NS	-	Negative small
P- V	-	Power- Voltage
P(k)	-	Current power
P(k-1)	-	Previous power
PB	-	Positive big
PM	-	Positive medium
PS	-	Positive small

R	-	resistor
V	-	Voltage
Vpvcell	-	Photovoltaic cell voltage
W	-	Watt
W/m^2	-	Watt per meter square
Z	-	Zero
E	-	Error
$I\ (t)$	-	Instantaneous current
I	-	Current
I/V	-	Current to voltage ratio
L	-	Inductor
T	-	Temperature of p- n junction
V	-	Voltage
$V\ (t)$	-	Instantaneous voltage
Vin	-	Input voltage
k	-	Boltzman constant
q	-	Electron charge
w	-	Inertia weight
λ	-	Solar irradiance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Electricity supply has become a major constraint in many health care centres in Nigeria, where almost (~85%) of the health care centres are located in the rural areas in order to provide health care delivery system to the rural communities in health related issues as getting access to the general or specialized hospital use to be very difficult due to environmental and economic constraints. Thus, if those centres can have adequate electricity supply, only special cases can be brought to specialist hospital in the city[1]. Recent research conducted by the ministry of rural and community development in conjunction with T. H. E. W. Bank, "Nigeria Economic Report" reveals that only 15% of those health centres are active due to lack of electricity supply as most of them are far away from the national grid. Sometimes their remote location is also a contributing factor, therefore, to extend electricity supply to such areas become capital intensive[2]. It has been proven, confirm and tested that solar energy can adequately provide electrical power for small storage fridges and freezers where blood, vaccines and drugs can be safely stored for treatment and emergency services in the health care centres[3].

In view of the above circumstances, generating electricity from an unconventional energy sources has thus become a welcome development in Nigeria due to governmental support and encouragement from private sectors. Among these unconventional energy sources are (solar, wind, hydro, tidal power, Biomass etc.). Solar photovoltaic technology is among the most popular and is gearing, interest, especially in countries like Nigeria where there is abundant sunlight throughout the year[4].

Moreover, sourcing, generating or extracting energy from the renewable sources has exhibited higher reliability and lower cost of maintenance. A system of generation that combines many sources of energy is known as hybrid system while those system which are designed to only use one energy source is known as stand-alone system. The hybrid system of generating electrical energy is a combination of wind and diesel, PV and diesel or PV, diesel and wind. A storage facility can also be incorporated to the hybrid system such as batteries, ultra-capacitors, flywheel etc. in order to store the energy generated by the system [5].

Nowadays, solar panel manufactures are increasingly producing an efficient and affordable PV arrays. These result in the increase in power generation from the sun energy that helps to create a convenient life style that reduce environmental impacts such as noise, cost of diesel, pollution and save time and energy. Solar stand-alone off-grid system is encouraged to be used as an alternative in the health care centres that are located in the remote areas in order to replace the use of conventional energy sources which cannot be accessed or maintained easily [6].

1.1.1 Renewable Energy Resources in Nigeria

Nigeria is the mother and giant of Africa. It is well blessed with abundant energy resources. Some of the natural energy resources have been discovered long ago while some are yet be discovered. The most widely energy being exploited for decades has been the crude oil. Nigeria alongside other African countries like Libya and Algeria has the two-third of the crude oil reserved in Africa followed by Algeria in terms of natural gas reserved [7]. Bitumen and lignite (a low grade brownish-black coal) can be found in many parts of the country. Therefore in terms of natural energy reserve, Nigeria is ahead of any other country in the African continent. Out of many renewable energy sources such as solar, wind, tidal power and biomass [8]. Solar energy has been considered as the most reliable renewable energy source in Nigeria due to its availability, easy access and unlimited potentials which are environmentally friendly. During dusty and cold atmosphere which usually lasts from November to February every year still Northern part of Nigeria receives average of 6.25h of intensive sun radiation while south-south and south-west receive 3-4h respectively [9]. Northern states like Borno, Jigawa, Kano, Kaduna, Kebbi, Yobe and Zamfara receives an average of 2200Wh/m^2 of solar energy annually, while in the southern part of the country, state like Abia, Anambara, Cross river, Delta and Enugu, receives up to 600kWh/m^2 of energy annually.

Table 1.1 Solar irradiation according to zones in Nigeria [10].

S/N	States	Zones	KWh/m^2	h/d	KWh/m^2/yr
1	Borno, Bauchi, Gombe, Kano, Katsina, Kaduna, Plateau	1	5.7-6.5	6.0	2186
2	Abuja, Kebbi, Kwara, Nassarawa, Sokoto, Taraba	2	5.0-5.7	5.5	2006
3	Benue, Ekiti, Osun, Oyo, Rivers, Enugu, Lagos	3	<5	5.0	1880

1.2 Problem Statement

Most of the remote areas as earlier highlighted suffer the epileptic electricity supply from the national grid. Ironically, these remote or rural areas only require a small amount of electricity to improve their living standard. They require electrical power not only for social activities, but for their medical services. Against this background, there is a need for a reliable source of energy to power the healthcare centers as an alternative way of generating stable electricity supply in these areas. A stand alone solar PV system will be the practically viable solution to such problem[11]. For this project work, Ahmadu Bello University university health care center (Sick Bay) is chosen as a case study. The research work can also be applied to the other public or community health care centers across the country because of their importance in the environment. Most diseases cannot be cured or treated easily due to lack of electricity supply in those healthcare centers. Electricity is the driving force of so many medical equipment and facilities in the hospitals as Doctors, Nurses as well as the patient need it to perform so many healthcare delivery activities.

1.3 Objectives of the Project

The main objective of this project is to design a Photovoltaic stand-alone system that will guarantee the supply of an uninterrupted power to public or community based health care centres which is safe, environmentally friendly and economically viable.

More specifically, the main objectives are as follows:

- ✓ To perform the technical analysis of a Photovoltaic-diesel generator-battery system using Matlab/Simulink software.
- ✓ To carry out the economic and environmental analysis of the proposed energy system configuration using HOMER simulation software.
- ✓ To analyse the result of the feasible system focused on public or community based healthcare centers.

1.4 Scope of Study

These project work consists of four sections which can be fully implemented. The Literature review clearly shows similar work and results obtained from Journals, Text Books etc. on solar PV stand-alone system, the simulation analysis was perform using Matlab/Simulink software, where the economic analysis will be carried out using HOMER software. There is a tremendous increase on the use of diesel and unstable price fluctuations which became a major constrain in the activities of health care centers in Nigeria. Health care centers are always on the neglecting side because 70% of them are funded by the government while the rest are funded by either charitable organisations, Millennium Development Goal (MDG) or foreign aid. Despite the payback period in an off-grid solar system is always higher than on-grid system, but it is still better for the health care centers to be solemnly on alternative energy.

Figure 1.1 Installed solar power system at Idda village, Kogi state [12].

Figure 1.2 Installed solar power system at kwoi village, Benue state [12].

1.5 Methodology

The initial part is the literature review of the proposed stand-alone solar PV system that consists of photovoltaic and Battery as a storage facility which will generate better and clear understanding of the proposed stand-alone PV system. Therefore, all the references used were found from journals, e-books, internet, result and findings from related work to affirm the final result obtainable.

Secondly, the simulation analysis of the proposed solar stand-alone PV system will be performed using MATLAB/Simulink. The solar PV stand-alone off-grid system model will be specifically designed and simulated for the purpose of exploring output characteristics from each block. Lastly, the Solar PV stand-alone system specifically designed to power public and community health care centers, PV module, battery storage, and converters analysis are to be performed using HOMER software.

This research is aware of the need to involve a wider area of coverage in this kind of important project. However duty limited time and resources, the area of study is only limited to Ahmadu Bello University healthcare centre (sick-bay). Though the finding can be applied widely in other locations, especially in the northern part of Nigeria.

1.6 Project schedule

Chapter 1 presents the introduction of the PV-Diesel-Battery off-grid system. This chapter provides an overview on some related information of various types of energy system. The chapter also discussed on the study background, it scope of work, problem statement as well as the methodology involve in the study. Chapter 2 explains the PV system and Diesel generator system for better understanding. This chapter also explain detail information about the PV, MPPT and power converter that has been used in this modelling. Chapter 3 discusses an overview of the modelling and simulation using Matlab/Simulink software that examine the behaviour and characteristics of the entire system. Chapter 4 discusses an overview of the modelling and simulation using HOMER that examine the behaviour and characteristics of the entire system which focused on the economic and environmental analysis involved for the purpose of the study. Chapter 5 shows the conclusion for the PV-Diesel system and recommendation for future works.

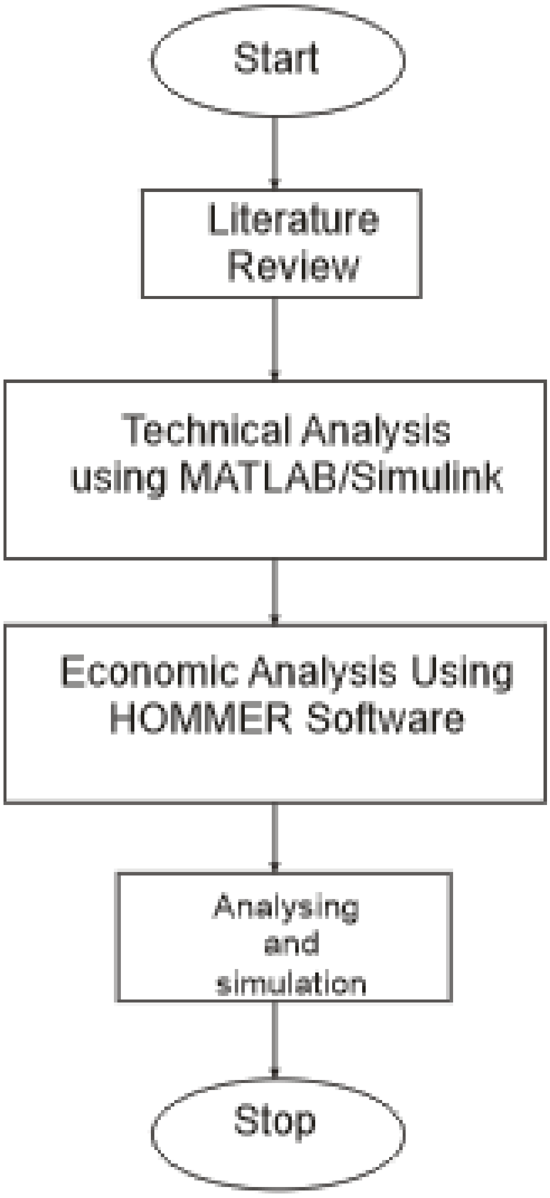

Figure 1.3 Project work flow

REFERENCES

[1] J. G. Castellanos, M. Walker, D. Poggio, M. Pourkashanian, and W. Nimmo, "Modelling an off-grid integrated renewable energy system for rural electrification in India using photovoltaics and anaerobic digestion," *Renew. Energy*, vol. 74, pp. 390–398, Feb. 2015.

[2] T. H. E. W. Bank, "Nigeria Economic Report," no. 1, 2013.

[3] K. Uduma and T. Arciszewski, "Sustainable Energy Development: The Key to a Stable Nigeria," *Sustainability*, vol. 2, no. 6, pp. 1558–1570, Jun. 2010.

[4] M. Shaaban and J. O. Petinrin, "Renewable energy potentials in Nigeria: Meeting rural energy needs," *Renew. Sustain. Energy Rev.*, vol. 29, pp. 72–84, Jan. 2014.

[5] O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, "Solar energy applications and development in Nigeria: Drivers and barriers," *Renew. Sustain. Energy Rev.*, vol. 32, pp. 294–301, Apr. 2014.

[6] M. Cloutier and P. Rowley, "The feasibility of renewable energy sources for pumping clean water in sub-Saharan Africa: A case study for Central Nigeria," *Renew. Energy*, vol. 36, no. 8, pp. 2220–2226, Aug. 2011.

[7] "BP-statistical-review-of-world-energy-2014-full-report." .

[8] L. Updated and P. E. Countries, "Nigeria," 2013.

[9] U. B. Akuru, "Renewable Energy Investment in Nigeria : A Review of the Renewable Energy Master Plan," 2008.

[10] M. S. Adaramola, S. S. Paul, and O. M. Oyewola, "Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria," *Energy for Sustainable Development*, Apr-2014. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0973082613001130. [Accessed: 18-Sep-2014].

[11] U. Muhammad, "Rural Solar Electrification In Nigeria : Renewable Energy Potentials and Distribution for Rural Development," pp. 1–8, 2009.

[12] S. Trasatti, “1799–1999: Alessandro Volta’s ‘Electric Pile,’” *J. Electroanal. Chem.*, vol. 460, no. July 1998, pp. 1–4, 1999.

[13] K. G. H??yer, “The history of alternative fuels in transportation: The case of electric and hybrid cars,” *Util. Policy*, vol. 16, pp. 63–71, 2008.

[1] J. G. Castellanos, M. Walker, D. Poggio, M. Pourkashanian, and W. Nimmo, “Modelling an off-grid integrated renewable energy system for rural electrification in India using photovoltaics and anaerobic digestion,” *Renew. Energy*, vol. 74, pp. 390–398, Feb. 2015.

[2] T. H. E. W. Bank, “Nigeria Economic Report,” no. 1, 2013.

[3] K. Uduma and T. Arciszewski, “Sustainable Energy Development: The Key to a Stable Nigeria,” *Sustainability*, vol. 2, no. 6, pp. 1558–1570, Jun. 2010.

[4] M. Shaaban and J. O. Petinrin, “Renewable energy potentials in Nigeria: Meeting rural energy needs,” *Renew. Sustain. Energy Rev.*, vol. 29, pp. 72–84, Jan. 2014.

[5] O. S. Ohunakin, M. S. Adaramola, O. M. Oyewola, and R. O. Fagbenle, “Solar energy applications and development in Nigeria: Drivers and barriers,” *Renew. Sustain. Energy Rev.*, vol. 32, pp. 294–301, Apr. 2014.

[6] M. Cloutier and P. Rowley, “The feasibility of renewable energy sources for pumping clean water in sub-Saharan Africa: A case study for Central Nigeria,” *Renew. Energy*, vol. 36, no. 8, pp. 2220–2226, Aug. 2011.

[7] “BP-statistical-review-of-world-energy-2014-full-report.” .

[8] L. Updated and P. E. Countries, “Nigeria,” 2013.

[9] U. B. Akuru, “Renewable Energy Investment in Nigeria : A Review of the Renewable Energy Master Plan,” 2008.

[10] M. S. Adaramola, S. S. Paul, and O. M. Oyewola, “Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria,” *Energy for Sustainable Development*, Apr-2014. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0973082613001130. [Accessed: 18-Sep-2014].

[11] U. Muhammad, “Rural Solar Electrification In Nigeria : Renewable Energy Potentials And Distribution For Rural Development,” pp. 1–8, 2009.

[12] S. Trasatti, “1799–1999: Alessandro Volta’s ‘Electric Pile,’” *J. Electroanal. Chem.*, vol. 460, no. July 1998, pp. 1–4, 1999.

[13] K. G. H??yer, “The history of alternative fuels in transportation: The case of electric and hybrid cars,” *Util. Policy*, vol. 16, pp. 63–71, 2008.

[14] A. Goetzberger, C. Hebling, and H.-W. Schock, “Photovoltaic materials, history, status and outlook,” *Mater. Sci. Eng. R Reports*, vol. 40, pp. 1–46, 2003.

[15] W. X. Shen, “Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia,” *Renew. Energy*, vol. 34, no. 1, pp. 348–352, Jan. 2009.

[16] H. Tsai, C. Tu, and Y. Su, “Development of Generalized Photovoltaic Model Using MATLAB / SIMULINK,” *Proc. World Congr. Eng. Comput. Sci. 2008 WCECS 2008, Oct. 22 - 24, 2008, San Fr. USA*, p. 6, 2008.

[17] K. Ishaque, Z. Salam, and H. Taheri, “Simple, fast and accurate two-diode model for photovoltaic modules,” *Sol. Energy Mater. Sol. Cells*, vol. 95, no. 2, pp. 586–594, 2011.

[18] D. S. H. Chan and J. C. H. Phang, “Analytical Methods for the Extraction of Solar-Cell Single- and Double-Diode Model Parameters From I-V Characteristics.,” *IEEE Trans. Electron Devices*, vol. ED-34, no. 2, pp. 286–293, 1987.

[19] H. N. Zainudin, “Comparison Study of Maximum Power Point Tracker Techniques for PV Systems,” no. 1, pp. 750–755, 2010.

[20] N. Onat, “Recent developments in maximum power point tracking technologies for photovoltaic systems,” *Int. J. Photoenergy*, vol. 2010, 2010.

[21] P. Conditions, E. Koutroulis, and F. Blaabjerg, “A New Technique for Tracking the Global Maximum Power Point of PV Arrays Operating Under,” vol. 2, no. 2, pp. 184–190, 2012.

[22] V. Phimmasone, T. Endo, Y. Kondo, and M. Miyatake, “Improvement of the maximum power point tracker for photovoltaic generators with particle swarm optimization technique by adding repulsive force among agents,” *Proc. - 12th Int. Conf. Electr. Mach. Syst. ICEMS 2009*, 2009.

[23] R. Baños, F. Manzano-Agugliaro, F. G. Montoya, C. Gil, A. Alcayde, and J. Gómez, “Optimization methods applied to renewable and sustainable energy:

A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1753–1766, May 2011.

[24] R. Gules, J. D. P. Pacheco, H. L. Hey, J. Imhoff, A. S. Cell, and O. Characteristic, "A Maximum Power Point Tracking System With Parallel Connection for PV Stand-Alone Applications," vol. 55, no. 7, pp. 2674–2683, 2008.

[25] D. P. Hohm, "Comparative Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed," 2000.

[26] S. Powermax, "Shell Solar Shell PowerMax TM Ultra SQ85-P / 80-P," no. category D, 2005.

[27] H. Ullah, "An Efficient Solar-Wind-Diesel-Battery Hybrid Power System for St . Martin Island of Bangladesh," vol. 3, no. 3, 2013.

[28] J. Lidenholm and U. Lundin, "Estimation of hydropower generator parameters through field simulations of standard tests," *IEEE Trans. Energy Convers.*, vol. 25, no. 4, pp. 931–939, 2010.

[29] Ž. Špoljarić, K. Miklošević, and V. Jerković, "Synchronous Generator Modeling Using Matlab," *SiP 2010 28th Int. …*, pp. 9–14, 2010.

[30] K. Kusakana and H. J. Vermaak, "Hybrid diesel generator/renewable energy system performance modeling," *Renew. Energy*, vol. 67, pp. 97–102, 2014.

[31] S. G. Malla and C. N. Bhende, "Enhanced operation of stand-alone 'photovoltaic-Diesel Generator-Battery' system," *Electr. Power Syst. Res.*, vol. 107, pp. 250–257, 2014.

[32] M. M. A. Salama, "Distributed generation technologies , definitions and benefits," vol. 71, no. August 2002, pp. 119–128, 2004