MONTE-CARLO BASED ROBUST ANALYTICAL METHOD FOR OPTIMAL SIZING AND RELIABILITY OF HYBRID RENEWABLE ENERGY SYSTEM

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

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FEBRUARY 2020

DEDICATION

I would like to dedicate this thesis to my beloved parents, dearest family, lovely children, and my good friends whom without their enthusiasm and encouragement; I would never have been able to complete this journey to fruition.

ACKNOWLEDGEMENT

Alhamdulillah, I am greatly thankful to Allah S.W.T. for His mercy and blessing for making this research a success.

I would like to acknowledge the advice, dedication and guidance of Prof. Ir. Dr. Mohd Wazir bin Mustafa as my supervisor. His dedications and constant scientific and technical input is worth mentioning. I sincerely thank him for being patient with me. My sincere thanks to all the staff and colleagues of power energy system Lab for their selfless, brotherly and research contributions. I would also like to express my gratitude to my parents for their love, support, courage and prayers without which I would never have been able to attain my goal. Also I would like to acknowledge my lovely family; dearest children and my loving brothers and sisters for their patient and support throughout the study period. The support of the Nigerian Airspace Management Agency (NAMA) is hereby acknowledged for the permission granted to undergo the full time PhD research program, I will forever be grateful to them. Worthy of mentioning here are my colleagues at Nigerian Airspace Management Agency, Kano Airport and most importantly the staff of the Navigational Aids Department for their sincere love and encouragement.

Finally, my special thanks to my good friends Malam Rufai Isah, Mr Kassim Alli, Engr, Johnson Otitolaye and Engr. Maiwada Abdul-Aziz whom without mentioning this acknowledgment will not be completed for their unending love, support and encouragement.

ABSTRACT

The need for a more reliable power from the utility grid and ever-increasing concerns on Greenhouse Gas (GHG) emission effect has globally promoting Renewable Energy Sources (RES). RES is increasingly being adopted in complementing traditional fossil fuels in the energy power supplies. Hybrid Renewable Energy (HRE) systems incorporating wind and solar sources offers lower costs, higher reliability, reduced investment risks, fuel diversification etc. However, wind speed and solar radiation are characterized by their limitations of inherent intermittency and variability. These limitations have led to the concept of optimal sizing and reliability assessments to maintain a balance between generated power and the system loads. Nonetheless, RES reliability assessment studies are site-specific, but existing studies are inexhaustive given the capacity availability and reliability requirements of various sites as well as their performance evaluations. This thesis presents the optimal sizing and reliability assessment of a hybrid solar and wind energy systems for a selected location. Weibull statistical method and air temperature amplitude based statistical models are adopted for wind and solar energy potential assessments of the selected site. The Weibull parameters were estimated using standard deviation method for wind energy potential assessment. Moreover, the air temperature based models of Hargreaves and Samani; Allen; Samani; and Bristow-Campbell models were used for solar energy potential assessment. Simulation of the uncertainty in the wind speed and its probability distribution is performed by using Auto-Regressive Moving Average (ARMA) model to improve wind speed normal distribution. In this approach, the best normal distribution for the simulated wind speed for the reliability analysis is chosen. To improve the performance of the Photovoltaic (PV) module, a single diode six parameter model is developed. First, the *P-V* and *I-V* curves were used to generate the required constraints. These constraints were then used to obtain the solution vector of the six parameters using MATLAB and System Advisor Model (SAM). Also, the system's capacity availability and reliability was assessed using Monte Carlo (MC) simulation. Finally, the result of the MC reliability assessment is later served as Loss of Power Supply Probability (LPSP) constraints to Artificial Bee Colony (ABC) algorithm for the system's optimal sizing and enhanced reliability assessment. Results from the study show that both wind and solar energy potential of the selected site is high and can generate power at utility level. The ARMA simulated wind speed shows an improvement of 21.8% in standard deviation over the measured wind speed. The adoption of the negative components in the ARMA model transformation resulted in least error of 23.34% in the final wind simulation. Results obtained based on the six parameter solution vector gives improved performance of the PV module. Using the developed MC technique, capacity availability of 100% and LPSP of zero is achieved. The developed ABC algorithm resulted in system reliability improvement of 98.92% when the MC results are constraint into the ABC for the optimal sizing. Various results were validated at appropriate sections and finally, the optimal sizing results of PV/battery RES power system is found to give the best reliability. Such a system has great reliability and can be implemented in facilities requiring constant power supplies such as critical infrastructure.

ABSTRAK

Keperluan terhadap tenaga yang boleh dipercayai daripada grid utiliti serta kebimbangan yang meningkat terhadap pelepasan gas rumah hijau (GHG) telah mempromosikan Sumber Tenaga Boleh Diperbaharui (RES) secara global. RES telah semakin diterima pakai bagi komplemen bahan api fosil tradisional dalam pembekalan tenaga. Sistem Tenaga Boleh Diperbaharui Hibrid (HRE) yang menggabungkan sumber angin dan solar menawarkan kos yang lebih rendah, kebolehpercayaan yang lebih tinggi, mengurangkan risiko pelaburan, kepelbagaian bahan api dsbnya. Walau bagaimanapun, kelajuan angin dan sinaran solar diklasifikasikan berdasarkan bawaan keterputus-putusan dan kebolehubahannya. Keterbatasan ini telah membawa kepada konsep pensaizan optimal dan penilaian kebolehpercayaan bagi mengekalkan keseimbangan antara kuasa yang dijanakan dan bebanan sistem. Walau bagaimanapun, kajian penilaian kebolehpercayaan RES adalah spesifik terhadap sesebuah tapak, akan tetapi kajian yang sedia ada tidak terperinci mengenai keperluan kebolehsediaan dan kebolehpercayaan dari pelbagai tapak serta penilaian terhadap prestasinya. Tesis ini membentangkan pensaizan optimal dan penilaian kebolehpercayaan bagi sistem solar dan tenaga angin hibrid untuk lokasi terpilih. Kaedah statistik Weibull dan amplitud suhu udara berasaskan model statistik telah dicadangkan untuk penilaian potensi tenaga angin dan solar ditapak terpilih. Parameter Weibull dianggarkan dengan menggunakan kaedah sisihan piawai untuk penilaian keupayaan tenaga angin. Tambahan lagi, model berasaskan suhu udara Hargreaves dan Samani; Allen; Samani; dan model Bristow-Campbell digunakan untuk penilaian keupayaan tenaga solar. Simulasi ketidakpastian dalam kelajuan angin dan taburan kebarangkalian dilakukan dengan menggunakan model Purata Bergerak Auto-regresif (ARMA) untuk meningkatkan taburan normal kelajuan angin. Dalam pendekatan ini, taburan normal yang terbaik bagi kelajuan angin simulasi untuk analisis kebolehpercayaan dapat dipilih. Untuk meningkatkan prestasi modul Fotovolta (PV), model diod tunggal enam parameter dibangunkan. Pertama, lengkuk *P-V* dan *I-V* digunakan untuk menjana kekangan yang diperlukan. Kekangan ini kemudiannya digunakan untuk mendapatkan vektor penyelesaian bagi enam parameter dengan menggunakan MATLAB dan Model Penasihat Sistem (SAM). Selain itu, ketersediaan dan kebolehpercayaan keupayaan sistem telah dinilai dengan menggunakan simulasi Monte Carlo (MC). Akhirnya, keputusan penilaian kebolehpercayaan MC kemudiannya digunakan sebagai kekangan Kebarangkalian Kehilangan Bekalan Kuasa (LPSP) kepada algoritma Koloni Lebah Buatan (ABC) untuk pensaizan optimal dan meningkatkan penilaian kebolehpercayaan sistem. Hasil daripada kajian menunjukkan bahawa keupayaan kedua-dua tenaga angin dan solar di tapak terpilih adalah tinggi dan boleh menjana kuasa pada tahap utiliti. Kelajuan angin yang disimulasikan oleh ARMA menunjukkan peningkatan sebanyak 21.8% dalam sisihan piawai berbanding dengan kelajuan angin yang diukur. Penggunaan komponen negatif dalam transformasi model ARMA telah mengurangkan sisihan sebanyak 23.34% dalam simulasi angin akhir. Hasil yang diperoleh berdasarkan enam vektor penyelesaian parameter telah meningkatan prestasi modul PV. Dengan menggunakan teknik MC yang telah dibangunkan, kapasiti kebolehsediaan sebanyak 100% dan LPSP sifar telah dicapai. Algoritma ABC yang dibangunkan telah menghasilkan peningkatan kebolehpercayaan sistem sebanyak 98.92% apabila hasil MC menjadi kekangan ke dalam ABC untuk pensaizan optimal. Pelbagai hasil telah disahkan pada bahagian yang sesuai dan akhirnya, keputusan pensaizan optimal bagi sistem kuasa RES PV/ bateri telah diperoleh dan memberikan kebolehpercayaan yang terbaik. Sistem sedemikian mempunyai kebolehpercayaan yang tinggi dan boleh dilaksanakan dalam kemudahan yang memerlukan bekalan kuasa malar seperti infrastruktur yang kritikal.

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LIST OF ABBREVIATIONS

ABC	-	Artificial Bee Colony
ACS	-	Annualized Cost of System
ADF	-	Augmented Duckey-Fuller
AI	-	Artificial Intelligence
AIC	-	Akaike Information Criterion
ANN	-	Artificial Neural Networks
ANN/SA	-	ANN and Simulated Annealing
AR	-	Auto Regressive
ARCH	-	Auto Regressive Conditional Heteroscedasticity
ARFIMA	-	Auto Regressive Fractionally Integrated Moving Average
ARIMA	-	Auto-Regressive Integrated Moving Average
ARIMAX	-	Auto Regressive Integrated Moving Average with Exogenous Variables
ARMA	-	Auto-Regressive Moving Average
ARMAX	-	Auto Regressive Moving Average Model with Exogenous Variables
BIC	-	Bayeisian Information Criterion
BOS	-	Balance of System
BP-ANN	-	Back Propagation Trained ANN
COE	-	Cost of Energy
CPC	-	Compound Parabolic Concentrators
CPF	-	Cumulative Probability Function
CRF	-	Capital Recovery Factor
CS	-	Cuckoo Search
CSP	-	Concentrated Solar Power
CVT	-	Continuous Variable Transmission
DME	-	Distance Measuring Equipment
DOD	-	Depth of Discharge

ECN	-	Energy Commission of Nigeria
EENS	-	Expected Energy not Supplied
ESS	-	Energy Storage System
FOR	-	Forced Outage Rate
FSWT	-	Fixed-Speed Wind Turbine
GA	-	Genetic Algorithm
GARCH	-	Generalized ARCH
GDP	-	Gross Domestic Product
HAWT	-	Horizontal Axis Wind Turbine
HRES	-	Hybrid Renewable Energy System
ILS	-	Instrument Landing System
LARIMA	-	Limited-ARIMA
LCE	-	Levelised Cost of Energy
LOLE	-	Loss of Load Expected
LPSP	-	Loss of Power Supply Possibility
MA	-	Moving Average
MC	-	Monte Carlo
MW	-	Mega Watts
NASA	-	National Aeronautics and Space Administration
NAV-AIDS	-	Navigational-Aids
NIMET	-	Nigerian Meteorological Agency
NOCT	-	Normal Operating Cell Ttemperature
NOX	-	Nitrogen Oxide
NPC	-	Net Present Cost
NREL	-	National Renewable Energy Laboratory
PDF	-	Probability Distribution Function
PSO	-	Particle Swarm Optimization
PV	-	Photo-Voltaic
RES	-	Renewable Energy Sources
RMSE	-	Root Mean Square Error
SAM	-	System Advisor Model
SD	-	Standard Deviation

SEC	-	California Energy Commission
SECS	-	Solar Energy Conversion System
SOC	-	State of Charge
STC	-	Standard Test Condition
SVM	-	Support Vector Machine
TPV	-	Total Present Value
VAR	-	Vector Auto Regressive
VAWT	-	Vertical Axis Wind Turbine
VSWT	-	Variable-Speed Wind Turbine
WDF	-	Weibull Distribution Function
WECS	-	Wind Energy Conversion System
WT	-	Wind Turbine

LIST OF SYMBOLS

A	-	Cross Sectional Area
ρ	-	Wind Flow Density
v	-	Wind Speed Velocity
P_w	-	Wind Instantaneous Power
P_m	-	WT Mechanical Power
C_p	-	Power Coefficient WT Blade
η_m	-	WT Efficiency
η_g	-	WT Generator Efficiency
c	-	Weibull Scale Factor
k	-	Weibull Shape Factor
h_1	-	Measure Wind Speed Height
h_2	-	Wind Speed at a Practical Height
α	-	Surface Roughness Coefficient of Wind Speed
v_{ci}	-	Cut-In Wind Speed
v_{co}	-	Cut-Out Wind Speed
v_r	-	Rated Wind Speed
v_{co}	-	Cut Out Wind Speed
$P(ele)$	-	WT Electrical Power
P_r	-	WT Rated Power
$P(v)$	-	Non Linear WT Power
C_{TC}	-	Total Cost
C_C	-	Capital Cost
$C_{O\&M}$	-	Operation and Maintenance Cost
NPC_T	-	Project Entire Life Cost
CRF	-	Capital Recovery Factor
i	-	Interest Rate
n	-	Project Life Time
$LOLE$	-	Loss of Load Expectation

$t_{outage}(t)$	-	Total Hour Load Exceeded Generated Capacity
$EENS$	-	Expected Energy Not Supplied
$E_{unserved}$	-	Amount of Energy Not Served
$LPS(t)$	-	Loss of Power at Hour t
P_L	-	Hourly Load
Γ(x)	-	Gamma Function
H_o	-	Extraterrestrial Global Solar Radiation
I_{SC}	-	Solar Constant
$\emptyset$	-	Location Latitude (Degrees)
δ	-	Solar Declination Angle (Degrees)
ω	-	Sunset Hour Angle
N	-	Day of a Year
α	-	Day Angle (Radians)
H_m	-	Horizontal Surface Global Radiation
K_T	-	Clearness Index
T_{max}	-	Daily Maximum Temperature (Degree Celsius)
, T_{min}	-	Daily Minimum Temperature (Degree Celsius)
K_r	-	Empirical Coefficient for Hargreaves and Samani
K_{ra}	-	Empirical Coefficient for Allen
A, B and C	-	Empirical Coefficient for Bristol-Campbell
y_t	-	ARMA Model Time Series
φ_i	-	Auto Regressive Coefficient
θ_j	-	Moving Average Coefficient
σ^2	-	Variance of the ARMA Time Series
λ	-	Box-Cox Transformation Coefficient
AIC	-	Akaike Information Criterion
m	-	Sum of Estimated ARMA Parameters (p, q)

p	-	Estimated AR Parameter in ARMA
q	-	Estimated MA Parameter in ARMA
T	-	Length of the ARMA Time Series
Q	-	Ljung-Box Test
r_K	-	Kth Auto-Correlation Coefficient of the Residuals
h	-	Number of Lags in Time Series
OW_t	-	Original Wind Speed Data at Time t
μ	-	Mean Wind Speed Value
SW_t	-	Simulated Wind Speed Data at Time t
I_{PV}	-	PV Module Output Current
I_{SC}	-	Module Short Circuit Current
V_{PV}	-	Module Terminal Voltage
V_{OC}	-	Module Open Circuit Voltage
I_{PH}	-	Photon Current
I_D	-	Diode Reverse Saturation Current
V_T	-	Thermal Voltage
T	-	Diode p-n Junction Temperature in Kelvin
K	-	Boltzmann Constant
$\boldsymbol{q}$	-	Electron Charge
N_{SER}	-	Number of Cell in Series
$\boldsymbol{n}$	-	Diode Non-Ideality Factor
$\boldsymbol{a}$	-	Modified Ideality Factor
E_g	-	Band Gap of the Semiconductor
α_{sc}	-	Short Circuit Current Temperature Coefficient
β_{oc}	-	Open Circuit Voltage Temperature Coefficient
γ	-	Maximum Power Point Temperature Coefficient
R_S	-	Module Series Resistance
R_{SH}	-	Module Shunt Resistance

$Adjust$	-	Temperature Coefficient Adjustment Factor
V_{MP}	-	Module Voltage at Maximum Power Point
I_{MP}	-	Module Current at Maximum Power Point
G_D	-	Diode Conductance at the Quiescent Point
R_D	-	Diode Resistance Equivalent Value
R_{Eq}	-	Module Equivalent Resistance at Maximum Power Value
$P_{PV.gen}$	-	PV System Output Power
$P_{mp.STC}$,	-	Module Rated Power
G_{STC}	-	Solar Irradiation at Wind Speed of 1 m/s (STC)
G		Solar Radiation at Operating State
T_{STC}	-	Temperature of Module at STC
K_T	-	Power Temperature Coefficient of the Module
T_{Cell}	-	Temperature of PV Cell
T_{amb}	-	Ambient Temperature ($°C$)
T_{NOCT}	-	Cell Temperature at Ambient Temperature of 20 $°C$
N_{PV}	-	Numbers of PV Panels
$P_{PV(t)}$	-	Total Power Generated by PV Panels
C_f	-	WT Capacity Factor
E_{out}	-	WT Final Output Energy
$C_{bat}(t)$	-	Battery Bank Capacity at Hour t
η_{bat}	-	Battery Efficiency
η_{inv}	-	Inverter Efficiency
AD	-	Battery Autonomy Days
$P_T(t)$	-	Total RES Generated Power
$SOC_{bat.min}$	-	Minimum Allowable Battery State Of

		Charge
$SOC_{bat.max}$	-	Maximum Allowable Battery State Of Charge
l_i	-	Lower Limit of Parameter
u_i	-	Upper Limit of Parameter
x_{mi}	-	ABC Algorithm Parameter
v_{mi}	-	ABC Algorithm Food Source Quality
$\emptyset_{mi}$	-	Generated Random Number in ABC Algorithm
$fit_m(\overrightarrow{x_m})$	-	Objective Function Value Solution of ABC Algorithm
p_m	-	Onlooker Bee Probability Value in ABC Algorithm

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CHAPTER 1

INTRODUCTION

1.1 Background

The ever increasing demand for energy due to the increasing world population and global climate change due to greenhouse gas (GHG) emission from the usage of fossil fuel are becoming sources of concern. The fast rate of fossil fuel depletion for power generation and the effect on the environment is quite alarming [1]. These prevailing conditions necessitated an urgent need for alternate energy sources [2]. Renewable energy sources (RES) such as biomass, wind, geothermal, tide and solar power systems are clean, source free and environmentally friendly alternative energy source [3].

The provision of reliable and affordable electrical energy to the end users customers is the sole responsibility of the electrical energy utility provider. However, the electric power supply situation in Nigeria has been a major source of serious concern. The irregular power supply throughout the nation has hindered the socio-economic growth and industrialization of the country. Additionally, it has lead an increase in air pollution due to individual stand-alone diesel generators. Various government incentives and policies have little or no effect to improve the availability and reliability of the electric power supply [4].

The aviation sectors in Nigeria are placed on the dedicated power supply because of the need for safe air navigation at both en-route and terminal navigational facilities. The point to point and azimuth position of the aircraft, distance position, precision runway centreline, and landing angle are provided for safe aircraft guidance and landing. These radio navigation aids are manufactured with high precision reliability and safety standards according to the international civil aviation organization (ICAO) standards and regulations. However, for these navigational systems to perform optimally for the purpose to which they are designed, they require constant stable, quality, and reliable power supply.

Recently, RES technology such as wind turbine (WT) and solar photovoltaic (PV) though stochastic in nature are becoming more popular for electricity generation. Wind and solar energy are of the most preferable renewable energy resources being utilized around the globe, Moreover, they are source free, inexhaustible in nature, sustainable, complementary, and green in nature as well as their integrative equipment for proper sizing and configuration [5]. Both wind speed and solar radiation are intermittent and variable globally. The wind speed probability distribution ultimately plays an important role in the planning, selection, and prediction of the output power of the wind energy conversion system [1].

The global solar radiation level which is a vital parameter in estimating the solar energy of a location is not always available and therefore the need for global solar radiation estimating models [2]. Also, the meteorological parameter such as sunshine hours and cloud cover for solar radiation estimation are not readily available in most locations due to limited meteorological stations and professional meteorological measuring instruments [3].

The inherent stochastic nature of wind speed is a major drawback for wind energy power systems. In order to represent the wind speed in its true characteristics, various models have been proposed for simulation of the wind speed [4].

The two major parameters that strongly determine the performance and availability of a PV module at a particular site location are the solar radiation level and the PV-module temperature. A detailed PV modelling required parameters beyond what is provided in the PV panel datasheet [5]. Various works have been done representing the PV module as a single diode model and the double diode model, however the double diode model is much complex in analysis [5]. The single diode five parameters model has been adopted for the PV module performance model prediction using such methods as panel I-V curve, analytical solutions, experimental and PV panel datasheet values [5] and each resulted in various degrees of accuracy.

Individual implementation of wind and solar RES power supply may lead to significant oversizing thereby resulting in the high cost of energy and poor system reliability. Therefore, to mitigate power fluctuations, improve reliability and for a cost effective energy system call for integration (hybridization) of the different RES technologies [6]. Several methods have been applied for modelling, optimal sizing and performance analysis of hybrid RES with different configurations. Recently, artificial intelligent technique has gained more popularity in RES optimal sizing and economic analysis. The analytic technique and probabilistic method and their variants are the most popular reliability performance assessment of the optimal sizing RES configuration adopted by the researchers [7]. The analytical technique in most cases is considered for a conventional power system while the probabilistic method is most prefer in stochastic RES power system reliability assessment.

Therefore, the aim of this research study is to address the problem of irregular power supply to sensitive equipment such as navigational aids system used in the aviation industries in Nigeria. The inherent uncertainties nature of the wind speed and solar radiation will form the basis for the formulation of the objectives of the research.

The current research work presents a study for a stand-alone hybrid wind/solar/battery power system with availability and reliability of 100%. The research study includes the development of models for wind and solar energy potential assessment of the selected location, the development of an improved simulation models for wind speed uncertainties distribution, to develop an improved solar PV performance model based on single diode model, the development of a new availability and reliability technique based on Monte Carlo and the development of an improve optimal sizing algorithm based on artificial bee colony optimization.

1.2 Problem Statement

From literature, the limitation of wind speed and solar radiation are mainly due to their inherent intermittency and variability and have been a source of major concern in the field of research studies globally. Studies have been carried out on reliability assessment and RES optimal sizing; however, limitations on the adopted methodology still exist. Wrong determination of the RES type selection as well as the energy conversion system capacity, improper representation of the wind speed in its true characteristics, as well as the effect of solar radiation level and PV-module temperature on the performance of the PV module based on the single diode parameters need to be improved.

Also, individual implementation of wind and solar RES power supply may lead to significant oversizing thereby resulting in high cost of energy and poor system reliability. Therefore, mitigation of the power fluctuations, improvement of reliability and effective energy system call for integration (hybridization) of the different RES technologies. Analytical technique, probabilistic method and their variants are the most popular reliability performance assessment of the optimal sizing of RES configuration adopted by researchers. The analytical technique in most cases is considered for conventional power system while the probabilistic method is most preferred in stochastic RES power system reliability assessment. To circumvent the limitations of the analytical method application in RES reliability assessment, an improved analytical based method for RES capacity availability needs to be introduced for improving the reliability assessment indices.

This research study, therefore, aims at developing an improved Monte Carlo based analytical method for optimal sizing and reliability of a hybrid RES stand-alone power system.

1.3 Objectives

Based on the above-mentioned problem statement, the research objectives are as follows:

i. To assess the potential of solar and wind RES of a selected geographical location in Nigeria.

ii. To develop an improved simulation framework for stochastic auto-regressive moving average (ARMA) time series model of wind speed using Box-Cox transformation.

iii. To develop solar radiation prediction algorithm based on MATLAB and SAM applications.

iv. To develop an improved technique based on Monte Carlo for accurate availability and reliability assessment of a stand-alone hybrid RES power system.

v. To develop an algorithm based on an artificial bee colony (ABC) for wind/solar hybrid RES optimal sizing.

1.4 Scope

The focus of this research work is on the design, development and optimal sizing of a stand-alone hybrid RES power supply system capacity availability and reliability assessment of the system. The scope of this research will include the following:

i. Wind and solar renewable energy sources are only considered for this research work. Other RES such as biomass, hydro, etc. will not be considered.

ii. Only the hourly and average monthly historical meteorological solar radiation, wind speed, temperatures, air pressure and relative humidity data will be utilized for this study.

iii. The research will involve feasibility study of the selected geographical location to determine its wind and solar energy potentials. The meteorological data utilized will be limited to the monthly average data.
iv. To accomplish the solar and wind energy potential assessment, Weibull and Samani statistical models are utilized.
v. The uncertainties nature of wind speed distribution will be investigated under time series analysis by developing auto-regressive moving average (ARMA) model based on Box-Cox transformation. Hourly meteorological wind speed data will be utilized.
vi. PV module model development for six parameters derivation for the forecasting and environmental effect on the performance of the selected module.
vii. Capacity availability and reliability assessment of the RES hybrid power system to be analyzed by developing a Monte Carlo based technique. Hourly meteorological data only will be utilized.
viii. The techno-economic analysis of the study will not be elaborated since the study is more focus on RES power system availability and reliability.
ix. The focus of the study is on RES power supply capacity availability and reliability assessment and optimal sizing therefore, only loss of power supply probability (LPSP) reliability concept will be analyzed.
x. Simulations are performed using MATLAB, R programming and System Advisor Model (SAM) environments.

1.5 Significance of the Study

The significance of the research study include the followings:

i. The developed technique for power system reliability assessment could be adopted in hybrid RES applications.
ii. Using the developed technique stand-alone RES power system can be implemented in facilities such as airports, nuclear power stations etc. where very high system availability and reliability are required for safety reasons. It could be also implemented in areas where utility main grids are not provided.

iii. A RES power system with high availability and reliability has great economic benefits by reducing/eliminating load and system components failures and the cost that follow such failure consequences.

iv. The introduction of RES hybrid power systems could enormously improve the economic and social status of rural communities, riverine and mountainous areas where utility transmission lines are absent.

v. A RES power with high reliability has zero carbon emission and therefore has environmental benefit and comply with the Kyoto Protocol international global climate change agreement of 11th Dec. 1997 aimed at reducing greenhouse gas emissions.

1.6 Thesis Organization

There are five chapters all in this thesis. Chapter 1 is introductory and gives the overall view of the study. It discusses the research background, problem statement, research objectives, research scope, and significance of the study.

Chapter 2 is devoted to the critical literature review of various research aspects as related to this study. The state of energy crisis in Nigeria and the RES potential, assessment and application was reviewed. The review of the solar energy conversion system along with solar radiation prediction models and PV array performance estimation was followed. Then the review of the wind energy conversion system along with wind turbine performance analysis and time series ARMA modelling was performed. The chapter also reviewed RES reliability assessment, hybrid RES systems and finally the optimal sizing of hybrid RES.

Chapter 3 is the presentation of the methodology applied to implement the objectives of the research work. The chapter began with methods adopted for RES data collection and this was followed with solar radiation prediction model development. The methodology adopted for solar and wind energy potential assessment of the selected site location was then described. In this chapter, the expected load demand of the aircraft ground navigation system was established. Furthermore, the ARMA time series modelling method was developed after which the PV prediction performance methodology was fully described. The sequential Monte Carlo technique developed for the system reliability assessment, ABC algorithm optimal sizing method, simulations and economic analysis of the RES methodologies were fully discussed in this chapter.

Chapter 4 presents the results and discussions. These include the RES potential of the selected site and the validation of the results, ARMA time series modelling analysis, the Monte Carlo reliability assessment and the different RES configuration scenarios.

Finally, Chapter 5 presents the conclusion of the outcome of this study, the contributions and suggestions and the recommendations for future research.

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