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Master Program of Renewable Energy and Sustainability

Techno-Economic Feasibility Analysis of Solar-Wind Energy Conversion System Utilizing Genetic Algorithm

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Joint mAster of Mediterranean Initiatives on renewabLe and sustainAble energy

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In partial fulfillment of the requirements for the degree of Master in Renewable Energy & Sustainability.

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Techno-Economic Feasibility Analysis of Solar-Wind Energy Conversion System Utilizing Genetic Algorithm

ABSTRACT

In recent years, the interest in using renewable energy sources has been growing globally since they are considered as a key solution to satisfy the world increasing demand for energy and for reducing the global carbon emission. Palestinians have previously started utilizing solar energy for heating water for domestic and industrial uses. Recently, a strong trend has been made to use solar energy to convert it into electrical energy using solar cells. In addition, the geographic and topographic configuration and the prevalence of dominant wind can be a good potential for small and medium wind energy conversion systems (Turbines).

The objective of this study is to simulate and optimize the renewable energy system of Palestine Polytechnic University (PPU) campus that is located in the Hebron city which consists of 230 kW photovoltaic energy conversion, by adding wind energy conversion system and changing the current system to on-grid hybrid renewable energy system HRES. This study is based on a configuration of (HRES) by using a genetic algorithm (GA) which enables the identifications of the optimum size that meets the possible demand along with most feasible economical values and ensuring the highest system reliability. The simulation results clearly show that the HRES is a more economical configuration than single renewable energy systems which has a total net cost of (410,743 $) and a cost of energy (COE) of (0.043) $/kWh.

تحليل و دراسة فنية واقتصادية لنظام تحويل طاقة الشمسية وطاقة الرياح باستخدام الخوارزمية الجينية

الملخص

تزايد الاهتمام مؤخرا باستخدام مصادر الطاقة المتجددة على مستوى العالم نظراً لاعتبارها حلّاً أساسياً لتلبية الطلب العالمي المتزايد على الطاقة النظيفة ذات الانبعاثات الكربونية الضئيلة. فتمثَّلَ استخدام الفلسطينيون للطاقة الشمسية مسبقاً بتسخينهم للمياه لإحتياجاتهم المنزلية والصناعية، وحديثاً أصبح التوجه لاستخدامها بشكلٍ فاعلٍ في إنتاج الطاقة الكهربائية من خلال الخلايا الشمسية المثبتة على أسطح المباني أوعبر الاستغلال الأمثل لطاقة الريح في المناطق تتميز بموقع جغرافِي وتكوين طوبوغرافي ملائمين لتوليد الطاقة الكهربية بواسطة العَنَفات (Turbines).

تهدف هذه الدراسة إلى محاكاة وتحسين نظام الطاقة المتجددة المستخدم في جامعة بوليتكنيك فلسطين (PPU) الواقعةِ في مدينة الخليل، والمكون من مجموعة من الألواح الضوئية بقدرة تصل إلى 230 كيلوواط، وذلك عبر تضمين النظام بأنظمة تحويل لطاقة الرياح بالإضافة إلى تحويل النظام الحالي لنظام طاقة متجددة هجين (HRES) مرتبط بالشبكة .

ترتكز منهجية الدراسة على استعمال تقنية التحسين من خلال النهج التكراري الذي تستخدمه خوارزمية التعلم الآلي الجينية (GA) للوصول لأفضل تصميم هجين يعمل بكفاءة مثلى ويحظى بجدوى اقتصادية عالية. تظهر النتائج التي تم الحصول عليها من الدراسة أن تصميم (HRES) كان اقتصاديا أكثر من أنظمة الطاقة المتجددة الفردية المتوافرة حاليا، حيث أن مجمل التكلفة الكلية له في هذه الدراسة بلغ (410،743 $) وتكلفة الطاقة (COE) بلغت (0.043) دولار / كيلوواط ساعة.

DECLARATION

I declare that the Master Thesis entitled " Techno-Economic Feasibility Analysis of Solar-Wind Energy Conversion System Utilizing Genetic Algorithm " is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Student Name: Woroud A. O. Alnatsha

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DEDICATION

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life,

My homeland Palestine, the warmest womb;

The great martyrs and prisoners, the symbol of sacrifice;

The Polytechnic University, my second magnificent home;

My great parents, who never stop giving of themselves in countless ways,

My beloved brothers and sisters; leads me through the valley of darkness with light of hope and support

My supervisors Prof . Imad Khatib and Dr. Fouad Zaro

My friends who encourage and support

All the people in my life who touch my heart,

I dedicate this research.

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Finally, I render my respect to my parents for giving me mental support and inspiration for carrying out my research work

List of Abbreviations

AC	Alternating current
AEP	Annual Energy power
AEP	Annual energy production
C	Cost of Component
CF	Capacity factor
CO_2	Carbone dioxide
COE	Cost of Energy
DC	Direct current
DG	Diesel Generator
Dy	Minimum distance between two adjacent rows
GA	Genetic Algorithms
GHG	Green House Gas
G_{ref}	Solar radiation at reference conditions
HBB-BC	Hybrid Big Bang -Big crunch
HRES	Hybrid Renewable Energy Systems
HS	Harmony Search
IEC	Israel Electricity Corporation
LCE	levelized cost of energy
LLP	loss of loud probability
LPSP	Loss of power supply probability
MOSADE	Multi-Object Self -Adapter Differential Evolution
MOSADE	Multi-Object Self -Adapter Differential Evolution
NOCT	Normal operating cell temperature in ^{o}C
NPC	Net Present Cost
NSGA-II	Non-dominated solving genetic algorithm
PPU	Polytechnic Palestine University
PSO	Particle swarm optimization algorithm
PV	Photovoltic
PWHS	PV -wind turbine hybrid system
RES	Renewable Energy system
RMSE	Root Mean Squared Error
SA	Simulated Annealing
STC	Standard test condition

Std	Standard deviation
STDEV	Standard Deviation Error value
TAC	Total annual cost
TS	Tabo Search
WG	Wind generator
WT	Wind Turbine

List of Nomenclature

A	Swept aria
I	Inflation rate
L_P	length of each installed array
$P_{R\text{-}PV}$	Rated power of PV
PV_{out}	Output power generated from the PV
Q	Probability of failure of component
r	Net interest rate
T	Lifetime
T_{amp}	Ambient air temperature
TC_f	Temperature coefficient of the PV panel
T_{ref}	Cell temperature at reference
α	Angle of solar radiation
OMC_o	Operation and maintenance cost at the first year
β	Tilt angle
$\overline{P}$	Average power in the wind
ρ	Air density
h	Hub height
$v\ (h)$	Wind speed at hub height
v	Wind speed
P_w	WT output power
P_r	Rated output power of WT
v_c	Cut-in wind speed
v_r	Rated wind speed
v_f	Cut-off wind speed
V_{avg}	Average wind speed
D	Diameter of swept area of WT
P_{WT}	WT average power
TPC	Total present cost

ALE	Annual load energy
RF	Capital recovery factor
IC	Initial cost
PV_p	PV price
C_{PV}	Capacity of the PV system
OMC	Operating and Maintaining Cost
WT_P	Wind turbine price
C_X	Capacity unit
C_{OM}	Cost of operating and maintenance unit
RC	Replacement cost
C_{RC}	Capacity of the replacement unit
N_{rep}	Number of unit's
C_u	Cost of replacement unit
PSV	Present salvage value the salvage
SV	Salvage value

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Chapter 1

Introduction

1.1 Background to the Study

Nowadays energy growth is directly linked to well-being and prosperity across the globe. Meeting the growing demand for energy in a safe and environmentally responsible manner is a key challenge. Today, most of the energy the world consumes comes from hydrocarbons. With crude oil as the dominant source for the transportation fuels, the increase in demands for this kind of energy source causes air pollution that leads to greenhouse effect and then the destruction of the environment. Because of the depletion of fossil fuels and the high-cost associated with it along with the growing demand for electricity in developing countries and the raising awareness of the technology's potential to alleviate pollution ,reduce carbon dioxide emissions and provide energy access, the world trend to search for renewable energy sources like solar, wind, hydro, biomass and geothermal in order to provide a constant energy source.

The sun is a major source of inexhaustible free energy for the planet Earth. Solar Energy is more versatile than other types of renewable energy due to its availability. In addition, the silicon which is the main constituent of solar cell used to trap solar energy is the second most ample element on the earth's crust. The need to increase the efficiency and to reduce energy costs has encouraged innovations in manufacturing and in product performance. Currently, new technologies are being employed to generate electricity from solar energy; solar energy technologies have become well-established and popular throughout the world [1]. Globally, the expansion of the market can be attributed to the increasing competitiveness of Photovoltaic (PV) was the top source of new power generation capacity in 2017 due to the large growth in China, global capacity was increased approximately 402 GWp [2].

Humans used wind as a source of energy for several thousands of years. With the growing development of electrical engineering and demand for electricity by the end of the 19^{th} century, the first experiments were carried out on the usage of windmills for generating electricity. Wind power over the last 20-30 years has become a competitive technology for clean energy production. The low prices for wind power have made it the least-cost option for power in many countries. Wind power markets become strong and reliable because of the energy's cost-competitiveness and its environmental and developmental benefit [3].

The main objective is to use the available renewable resources in order to improve the overall efficiency and cost-effectiveness of the system. It is good to diversify the use of renewable energy as hybrid energy system integrates different energy sources to form a single system in which the weaknesses or limitations of one energy source is being overcome by the strengths of other energy source .For example , wind power along with solar energy provides a more stable renewable energy supply since there are more wind during winter and there is less sun. should be combined renewable energy production with decreased energy consumption to reach the aspired reliability

Palestine depends on other countries for 100% of its fossil fuel imports and for 87% of its electricity imports. Therefore, most electricity is imported from Israel Electricity Corporation (IEC) and can be easily controlled by the Israeli side [4].There are several challenges facing the energy sector in Palestine such as the political instability and dependency on the Israeli electricity which means that the energy sector is difficult in transport, store, trade, and import from other countries. In addition, energy prices are very expensive, and the other challenge is energy demand. Weakness in the infrastructure and weakness in management and lack of strategies that is needed to deal with supply and demand for energy makes it difficult to improve the energy sector in Palestine [5]. It has become necessary to find sources of energy and encourage the use of renewable energy available in Palestine.Therefore, several optimization methods have been developed to find the optimal hybrid energy configuration.

The geographical location of Palestine is located between 29.15^o – 33.15^o north latitude and 34.15^o – 35.14^o east makes of it an ideal location for solar energy utilization, there are approximately 3000 sunny hours per year. The average solar radiation ranges from 5.4 $kWh/m^2/day$ to 6 $kWh/m^2/day$ [5]. Palestine have a fair previous experience in utilizing solar energy. The Palestinians have previously used solar energy mainly for water heating, drying of crops vegetable and fruits. The most common usage of solar energy in Palestine is for heating water in Palestine since this system can give a more economic and reliable source of energy.

Recent studies show that wind energy can be feasible in many locations in the west bank, It was found the monthly mean wind speed data of four stations in Palestine are fitted to the Weibull distribution function. Both Hebron and Nablus have higher mean wind speed values of more than 3.5 m/s, it's found the average annual and maximum wind power density of $37.85Wm^2$ was in July, the lowest mean power was 1.66W m^2 in January for Jericho [6]. It is estimated that solar sources have the potential to account for 13% of electricity demand and wind energy for 6.6% [7].

1.2 Research objective

The main objective of the thesis is to design an on-grid PV-wind turbine hybrid energy system. While taking the available area for PV arrays and wind turbine as a constrain. Also, to extract the maximum energy from the Hybrid system by the implementation of the optimization algorithm (genetic algorithm) to model the maximize energy and to find the values of the design parameter. Therefore, the objective of the research is to determine the optimal size of hybrid system taking into consideration both the technical and economic specification.

Specific objective:

- Discuss energy state in Palestine.
- Discuss important of renewable energy.
- Study the wind – solar potential for PPU.
- Present an optimization model that will be used to determine the optimum size of HRES in order to meet the load requirements with the minimum possible cost and maximum energy within the available area.
- Economic analysis of the wind – solar hybrid power generation system.

1.3 Motivation

The research that have tackled the subject of improve the hybrid renewable energy system of PV-wind turbine is reported in a few of work. The performance and design of highly efficient model with two constraint parameters within a restricted space, meanwhile maximizing the power generation is a challenge which needs to be explored.

Polytechnic Palestine University (PPU) spent more than 200,000 USD as service bills in the year of 2015 and as a result, PPU spends a considerable amount on operational expenses rather than development and scientific achievements. The energy consumption of electricity can be reduced by building a hybrid PV and wind generator (WG) system at PPU.

An optimization problem was devised to find the optimal system size to meet demand with minimum total system cost taking into account the seasonal change in the load profile along with measuring solar and wind energy resources and component and operation costs. In this work investigation is done to find the optimal size of the two different systems, the number of PV module, the number wind turbine in addition to feasibility study and payback of the system.

1.4 Thesis Structure

The thesis contains five chapter as follows:

Chapter 1: Introduction.

It provides the researcher with a brief introduction of the state of energy in Palestine and a background of the common renewable energy sources such as solar and wind energy. After that, the objective of this thesis is explained and motivation.

Chapter 2: Literature review.

Climate and environmental changes along with air pollution showed an imperative need to apply the principle of renewable energy and to use new technologies for the production of different forms of energy, as well as the integration of more than one renewable energy source in the energy production process.

Chapter 3: Modelling of hybrid system.

The current background of renewable energy used in this study thus provides the basic theory of solar and wind energy. It describes the modeling of renewable energy systems which includes design analyses and feasibility analysis for a combination of the hybrid renewable energy system.

Chapter 4: Methodology.

It includes the data needed to obtain optimization techniques applied to the hybrid system, and describe the methodology work GA optimization.

Chapter 5: Result.

This chapter provides with MATLAB results obtained from GA optimization techniques applied to HRES. also a comparison and a discussion of the obtained result and summary is provided.

Chapter 2

Literature Review

2.1 Introduction

Recently, power generation from renewable energy sources has been progressively gaining significance to become widespread due to fossil fuel depletion, the high cost of fossil fuel, and increasing environmental concern. The use of several renewable energy sources with storage and backup units to form a hybrid renewable energy system can create a more economic and reliable source of energy [8].

Wind and solar energy are the popular renewable sources that are used for their environmentally-friendly benefits. Furthermore, generous subsidized policies have been implemented by various countries to accelerate and stimulate investment in wind and solar energy development. However, despite the tangible benefits, the main hindrance to the public accepting wind and solar energy systems is the related high capital investment [9].

In hybrid systems which include wind turbines, calculation of wind turbine power is based on average wind speed, because considering instantaneous wind speed makes the design of the hybrid system complex and practically impossible. Taking into consideration the economic aspects of renewable energy technologies, HRES is becoming extensive in an isolated region owing to advancements in renewable energy technologies and a substantial rise in prices of fossil energy.

2.2 Solar Energy System

In recent years in Palestine, the interest in renewable energy sources for power generation has been progressively gaining significance in the entire world due to fossil fuel depletion, the high cost of fossil fuel and increasing environmental concerns .on the Palestinian level , these renewable energy sources have been gaining importance because of the previously mentioned disadvantages fossil fuels along with the dependence of the Israeli side as a supply for energy and the political instability in the region.

A photovoltaic (PV) system comprises a semiconductor panel converting sunlight into direct current electricity and an inverter converting direct current to alternative current used in the grid [10].

The use of PV systems for rural electrification in Palestine is economically more efficient and beneficial than using diesel generators or extension of the high voltage electric grid. Marwan and Imad [11],had present obtained results represent also a helpful reference for energy planers in Palestine and justify the consideration of PV systems more seriously, and more feasible than using diesel generators extension of high voltage electric grid. These results are helpful to encourage sector planers and decision makers in Palestine to use PV systems to reduce the negative impact on the environment by CO_2 emissions to the atmosphere when comparing with diesel generators.

One of the advantages of the spreading of the PV and its connection with the grid is that it reduces the dependence on the conventional energy source which causes many environmental problems. The PV generation is increasingly widespread in the distribution network but quality problems have been detected that may affect the operation of the network, which is a very big challenge [12].

2.3 Wind Energy System

Globally the wind has become a major source of energy today. It is clean, free, and inexhaustible source of energy. Wind power capacity increased by 19% bringing the world total to almost 283 GW [13]. Therefore, it became one of the most convenient and environmentally friendly paths of electricity generation [14].

In Palestine, potential of wind energy seems to be limited in the mountains (elevation of about 1000 m) where the speed surpasses 5m/s and potential about 600 kWh/m^2 [15].

Electricity generation by using wind requires studying windspeed based on the available data and topographical features of the land in different locations. The coastal strip region (Gaza Strip) is characterized by a very low wind speed throughout the year, with an annual average of about 2.5–3.5 m/s. While in the West Bank, the hilly regions such as Nablus, Ramallah, Jerusalem, and Hebron have an annual average wind speeds varying in the range of 4–8 m/s. The Jordan Valley, represented in Jericho, has very low wind speeds of an annual average of about 2–3 m/s. So, the wind energy potential seems to be limited to the mountains with heights about 1000 m above sea level. This would include regions of Nablus, Ramallah, and Hebron where the speed reaches 5m/s, which is suitable for operating a wind turbine [16].

De Meij et al [17], had illustrated the assessment of the wind energy resource in Palestine is based on the hourly wind speed data measured at 16 out of 20 stations the relation RMSE modo STDEV obs is valid, which is one of the conditions for good quality modeling results. The variations of wind power density and AEP over a 12-year period (2000–2011) are rather low in Gaza and West Bank. The AEP at 80 m shows that the east zone of Hebron is the most suitable area in West Bank. unfortunately, wind potential all over Gaza is not enough to considered at any level.

The values of wind speed are encouraging to use small wind turbines to electrify sites located far from the grid and have the high potential of wind speeds. In addition, another feasible application for small wind turbines is to use them for water pumping, especially for rural areas where diesel generators are used for this purpose.

2.4 Hybrid solar-wind power generation system

HRES is defined as an electric energy system which is made up of a combination of two or more renewable power generation systems. These sources could be conventional or renewable or mixed, that works in off-grid(standalone)or grid-connected mode, so they can address emissions, reliability, efficiency, and economic limitations of single renewable energy source [18,19,20].

Addition higher environmental protection, greenhouse gas emission, especially CO_2 and reduction in other pollutants emissions is expected due to the lower consumption of fuel. The cost of solar and wind energy can be competitive with nuclear and the diversity and security of natural resources which are free, abundant, and inexhaustible [21].

Deshmukha [22] had present the trends in HRES design show that the hybrid PV/wind energy system becomes more popular, a description for the methodology to model the hybrid renewable energy system component. Rajesh [23] had given the simulation results confirm of the effectiveness of the optimum solution of the hybrid system, confirmed that using load shifts can reduce the system size, reduce the cost of generated energy and increase the effectivity of the system. Belmili et al [24], HRES provide a more consistent year-round output than either solar or wind-only systems and can be designed to achieve desired attributes at the lowest possible cost.

HRES are becoming popular for standalone power generation in an isolated area due to the improvement and efficiency increment in renewable energy technologies and power electronic converters [25]. However, because of the PV–Wind changeable nature and dependence on climatic changes and weather conditions, a common drawback to PV and wind power generations is that both would have to be oversized to make their standalone systems reliable for the times when neither system is producing enough electric power to satisfy the load [26].

Ismail [27], had highlighted effective utilization of excess energy in standalone (HRES) by offering a new design for improving energy conversion and reducing the cost of energy, adding storage system and/or backup source to the renewable sources is one of the procedures used to guarantee the permanency of the power supply to the loads through improving the power reliability.

Renewable energy sources are characterized by variability and intermittent that involve variations of power outputs and uncertainty in the power available. Sizing and optimization techniques, for the HRES with grid, is still needed to improve the performance of the system. Establishing methods for facilitating their integration with other RES taking under constraints on reliability and sustainability.

2.5 Optimization of HRES

The problem of the size and the optimization of the hybrid system have been handled in a number of studies. One of the most important issues in the recent studies is to optimally design the hybrid renewable energy system components to meet all load requirements with minimum cost and maximum reliability. In view of the complexity of optimization of the hybrid renewable energy systems, it was imperative to discover an effective optimization method that is capable of giving accurate results.

In recent years, the economic constraints and optimization approaches that are used to compare the energy production cost and performance of various hybrid system configurations. therefore, there are remarkable research and development efforts concerning sizing techniques and the implementation of hybrid renewable energy units. These efforts focus on improving performance, then to generate good accuracy predictions, finally to guarantee the reliability and to reduce the cost of implementation HRES is more dependent on an optimal design to ensure power reliability and to minimize the cost investment.

In study in [28], the author proposes an optimization approach of a grid-connected photo-voltaic and wind hybrid energy system including energy storage considering voltage fluctuation in the electricity grid. A techno-economic analysis is carried out in order to minimize the size of the hybrid system by considering the minimum cost.

A.shahsaver et al. in [29] implemented cuckoo algorithm for find the optimum size is to design hybrid system based on solar and wind power coupled with energy storage unit that provides a remote area installed instead of a diesel generator and the result showed investigates the sensitivity of various input parameters like solar, wind resources and capital cost on the cost of energy. Sanajaoba and Fernandez [30], used cuckoo search algorithm to found that different criteria of sizing can be applied to choose various system components of hybrid renewable energy power plant.

In the study [31], Introduce optimal sizing of a PV/wind/diesel / HRES with battery storage is conducted using the Multi-Object Self -Adapter Differential Evolution (MOSADE) algorithm, the aim of the study to reduce the price of the renewable energy resources, especially for solar PV and wind energy, to make products more competitive for use in the energy industry and market, with the ultimate aim of accelerating renewable energy resources development and diversification plans.

Overall analysis including optimization and sensitive analysis are evaluated by HOMER software, a model of hybrid energy system fo. In this analysis a hybrid renewable system consists of of wind, biomass, and solar energy, the analysis is done in order to increase efficiency of the system with comparatively less cost [32,33].

Arul et al [34], had proposed sizing methodology to reaches an optimal size combined with the energy management strategy approach are built on GA using historical climate data and load demands over a period of one year. Proposed control strategies for a hybrid system by proposing a HRES configuration through interfacing power converters to supply alternating current (AC) to loads. The study in [35], presented a simulation program using GA was developed to simulate different scenarios for design of a complete hybrid system, to achieves the minimum cost while meeting the load requirement was selected, the result had given optimal tilt angle of the PV panels in order to increase the generated energy, and A techno-economic analysis had given the design consisting of PV panels, a battery system, and a diesel generator as a backup power source for a typical Malaysian village household. In the study [36], proposed an optimal sizing method to optimize the configuration of a hybrid solar-wind power generation system with a battery bank, the GA that has been applied to the analysis of a hybrid system which supplies power for a telecommunication relay station, and good optimization performance has been found. Fadaee and Radzi [37].

Ismail et al [38], used GA to the calculation of optimum tilt angle along year, Evaluate the different models used to analyze different aspects of solar radiation in the Palestinian territories had given the review concludes that the use of GA and PSO are the most useful and promising methods in HRES design.

Using GA to select the optimal number of units with minimum cost, subject to load demand fulfillment [39]. In another study presented a GA based optimal sizing of desalination systems by PV–wind generators as a power supplied unit [40]. Uses GA to optimize the configurations of hybrid solar–

wind–battery bank system where the decision variables are the number of PV modules, wind turbines, and batteries, the PV slope angle and wind turbine tower height [41,42].

Jose et al [43], proposed the revises the simulation and optimization techniques, as well as the tools existing that are needed to simulate and design stand-alone hybrid systems for the generation of electricity. Many are as are concerned with the applications of the HRES. Researches in [44,45] have focused on the performance analysis of demonstration systems and the development of efficient power converters, such as the maximum power point tracker sand bidirectional inverters [46,47]. Other researches focused on the battery management units and the storage devices [48]. In the last decade, various HRES have been installed indifferent countries, resulting in the development of systems that can compete with conventional, fuel based remote area power supplies [49].

Meenakumari and Suresh [50], had done discusses about the economic analysis and the optimal selection of solar PV, Wind, Diesel Generator and Battery connected hybrid energy systems for residential applications, a suitable Hybrid Optimized Model has been developed and the results have been discussed based on their Net Present Cost (NPC) and Cost of Energy (COE) and Green House Gas (GHG) emissions.

The technical-economic analysis of the HRES remains necessary for the efficient utilization of power generation of all RES ,Finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value cost of energy, presents a methodology to perform the optimal sizing of an autonomous hybrid PV/wind system, which meets the desired system reliability requirements, with the lowest value of levelized cost of energy, the device system choice plays an important role in cost reduction as well as in energy production[51,52,53].

In the study [54] integrates photovoltaics, wind turbine, storage model, and depend on the power reliability with (Loss of power supply probability) LPSP algorithm. In another hand used an artificial intelligence approach to optimize the sizing of hybrid systems. Using an optimization simulation program, the results showed that AI gives more accuracy by maximizing the power reliability and reducing the investment cost, but the program required more complexity of calculation.

The HRES integrated on the grid need an accurate and optimum design and size to minimize the cost of generated energy and maximize the system reliability. A novel intelligent algorithm based on smart applications is introduced to determine the optimum size of HRES in order to meet the load requirement with the minimum cost and highest reliability. Although the studies results were satisfactory the use of storage means a higher cost. Also, maintenance and operations cost especially for the storage element where not considered while building the objective function. In some way, results may be misleading, addition their many studies confirm using of PV generation system is feasible in Palestine and few studies for installing a wind turbine in Palestine.

Through a brief review about the sizing methodologies developed in recent years have been applied to find the optimum size of HRES. Hence, the present analysis was proposed to investigate the suitability of the GA for sizing the PV-wind hybrid energy system with grid.

Chapter 3

Modeling of Hybrid System

3.1 Introduction

To meet the continuously increasing energy demand while combating global warming, the utilization of clean energy has been given the top priority in the energy sector since the beginning of 21st century. In addition to the adverse impacts of non-renewable energy resources, manly oil and coal, the increases in their prices have lead scientists, researchers, and engineers around the world to innovate new technologies that extracts maximum energy from renewable resources like solar, wind, tidal and geothermal.

Among all renewable energy resources, solar energy is most reliable because it is available during the day time and seems to be abundant almost in all seasons. Silicon, which is the fundamental element used in large scale in forming PV modules is considered as the second most abundant element in the earth's crust after oxygen. Also, its availability and cost played an important role in the price of energy conversion.

Harnessing wind is one of the oldest methods that used for generating energy. Since ancient times, man has used windmills to grind the harvest and to pump water. With the emergence of electricity at the end of the nineteenth century, the first prototype of modern wind turbine was built by using technology based on the classical windmill. The sudden increases in the price of oil in 1973 stimulated a number of researches, development and demonstrations of wind turbines and other alternative energy technologies in different countries [55].

One of the most important issues in the recent studies is to optimally design the hybrid renewable energy system components to meet all power load requirements with minimum cost and maximum reliability. In view of the complexity of optimization of the hybrid renewable energy systems, it was imperative to discover an effective optimization method ready to give accurate optimization results.

This thesis presents an optimization model that will be used to determine the optimum size of hybrid renewable energy systems so as to generate maximum electric energy with minimum cost. The type of Iterative optimization technique is the known as Genetic algorithms (GA) that is used in this model for seeking the optimum size of hybrid renewable energy systems with the minimum cost of the generated energy. The following sections summarize and describe the mathematical form that is used in the literature section to analyze energy technology when studying HRES. Based on the findings, the mathematical model used to estimate the performance of energy technologies is found to be capable of achieving on optimal solution.

3.2 Modeling HRES

The hybrid energy system is a combination of energy sources of different characteristics when it comes to on-grid. Figure 3.1 shows a hybrid energy system of a PV and a WT system connected to the grid. A design of a hybrid energy system is a challenging process due to a number of reasons such as determining the best combination that reduces the initial capital investment, maintaining power supply reliability and reducing the maintenance of system component.

Having a combination of energy sources with different characteristics reduces the impact of emissions and increases the efficiency of energy generation process, where varying energy potential of renewable energy sources in some locations e.s. solar energy is available in the daytime, at tonight wind energy prevails.

The time varying nature of renewable energy makes it essential to incorporate it to storage or to grid. The optimal design of energy systems become vital in such circumstances which is always a challenging process where a number of techno-economic and environmental aspects need to be considered. Reaching the best energy production is not an easy task especially when several types of variable energy depend on the weather conditions where this dependency is taken into consideration and used when designing the system or even parts of it. Therefore, modeling using optimization is found to be better than using classical methods. In the system proposed the produced electricity is connected to the grid by using a bidirectional meter that allows customers to interconnect the converted energy to the electric grid.

3.2.1 Modeling of PV Energy System

The solar modules PV generate DC electricity whenever sunlight falls in solar cells. The solar modules should be tilted at an optimum angle for that particular location, face due south, and should not be shaded at any time of the day. The PV cells can be connected in series and in parallel in a PV module to obtain the desired voltage and current output. Figure 3.2 shows a PV system connected to the grid.

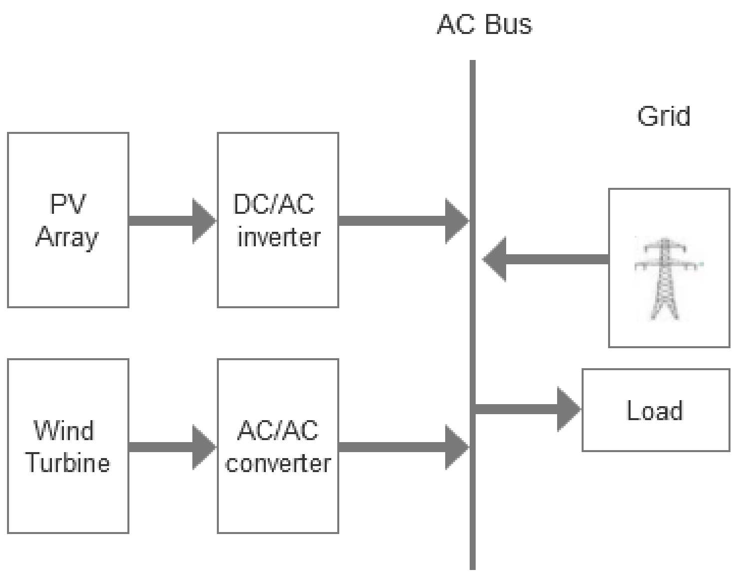


Figure 3.1 Configuration of grid-connected hybrid renewable energy system

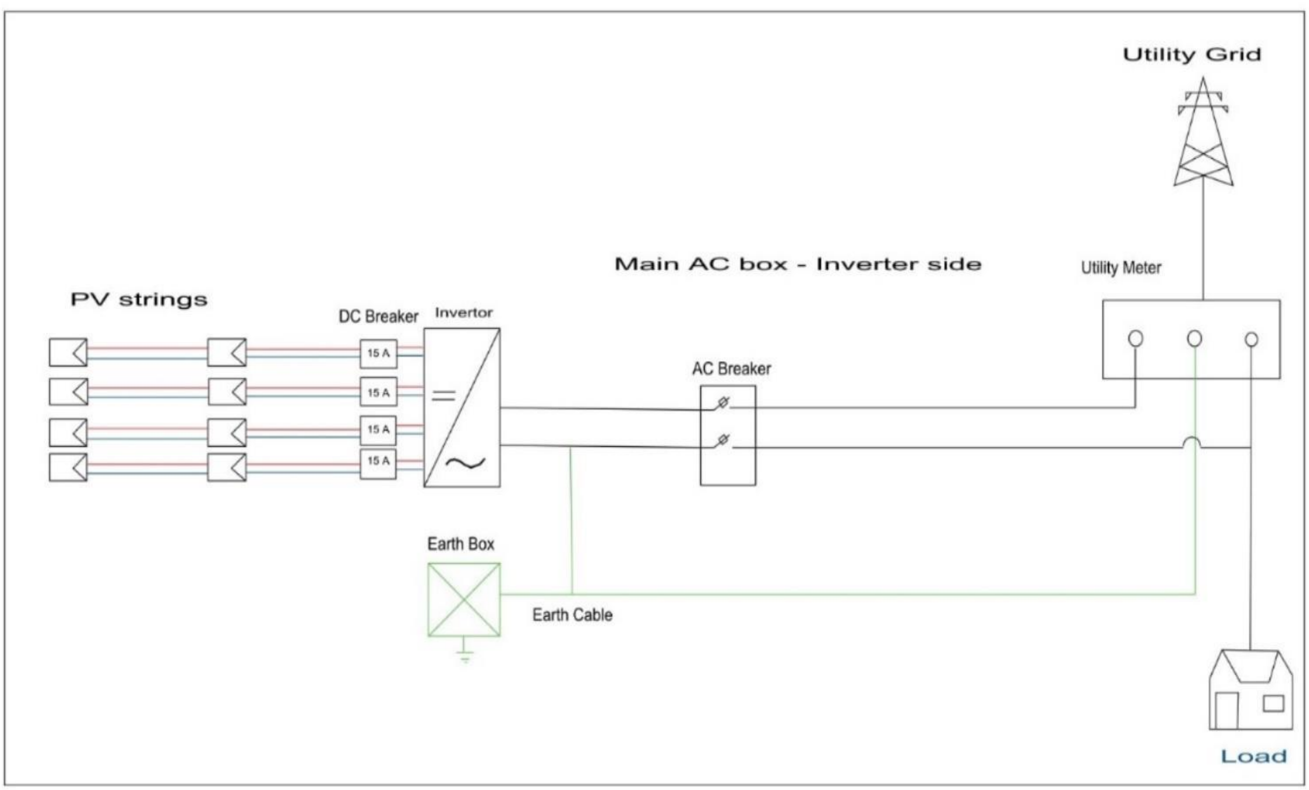


Figure 3.2 Schematic of PV generation system

In Palestine, solar radiations are considered as a potential renewable energy source as they have high solar energy potential over about 3000 sunshine hours per year and a high annual average of solar radiation amounting to 5.4 kWh/m^2/day measured on horizontal surface [56].

In the PV system, the PV module technical specification must satisfy the distribution of PV modules among the inverters and the diminution limitation of a available installation area.

The PV arrays tilt angle (β) is assumed to be constant throughout the year, the tilted PV panels south. The maximum output power of PV module on each day at hour t ($1 \leq t \leq 24$) under normal test condition. Equation (3.1) used to calculate the power generated [57]:

$$PV_{out} = P_{R-PV} \times \frac{G}{G_{ref}} \times \left[1 + TC_f\left(T_c - T_{ref}\right)\right] \quad (3.1)$$

Where PV_{out} is the output power generated from the PV panel, $P_{R-PV}$is the rated power of PV at standard test condition (STC), G is the correlated solar radiation in (W/m^2) taking into account the tilted surface,[G_{ref} is the solar radiation at reference conditions and it equals to 1000 W/m^2, T_{ref} is the cell temperature at reference conditions and it equals to 25 ^{o}C], TC_f is the temperature coefficient of the PV panel and it equals 3.7*10^{-3}(1 ^{o}C) for mono and polycrystalline silicon . equation (3.2) is used to calculate the cell temperature Tc such that [58]:

$$T_c = T_{amb} + \left(\frac{NOCT-20}{800}\right) \times G) \quad (3.2)$$

Where T_{amb} is the ambient air temperature in ^{o}C and NOCT is the normal operating cell temperature in ^{o}C . It is one of the PV module specifications and given by the manufacturer. The rated power P_{R-PV} can be calculated using equation (3.1) .

The minimum distance between two adjacent rows, Dy(m), to prevent mutual shading of corresponding PV module is calculated bt equation (3.3) [59].

$$D_y = L_P[\cos\beta + \sin\beta\ \cos\alpha] \quad (3.3)$$

where, α is the solar radiation angle and L_p (m) is the total length of each installed array, and β is the tilt angle, in the Figure 3.3 shows arrangement of PV solar panel.

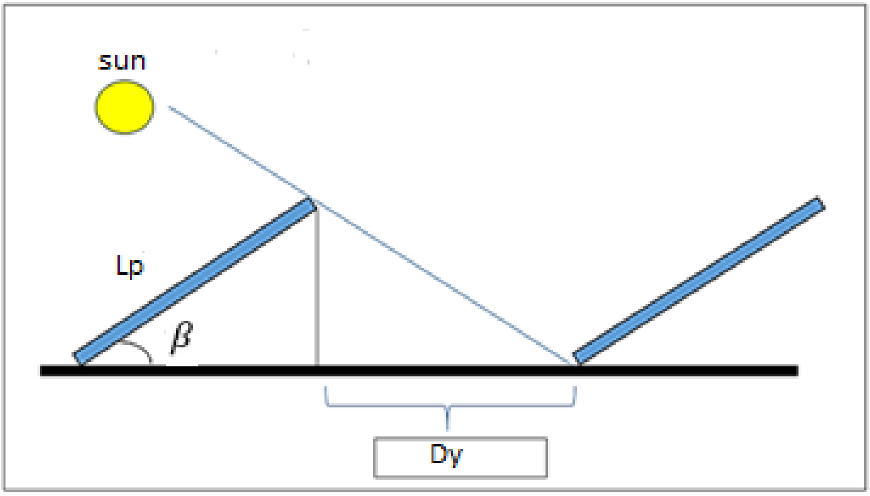


Figure 3.3 Arrangement of the PV modules in rows over the available installation area

3.2.2 Modeling of Wind Energy System

Wind turbines work by converting the kinetic energy in the wind, first to rotational kinetic energy in the turbine and then electrical energy that can be supplied to the grid. The energy available for conversion mainly depends on the wind speed and swept area of the turbine.

Wind turbines are available in various sizes from a large number of wind turbine manufacturers, agents, and developers. The wind turbine system consists of three main parts: the rotor, which includes the blades to convert wind energy to low speed rotational energy. The second part is the generator that includes the electrical generator, which includes all control circuit with gearbox that convert the rotational low speed in to electric power and finally the structure that hold all the previous components and that is the tower and nacelle.

Wind turbine consist of the following subsystems ash shown in Figure 3.4.

- Rotor Blades and hub.
- Nacelle contains shafts, gearbox, couplings, brake, and generator.
- Tower that hold the nacelles.
- Electrical system such as switchgear, transformers, cables, and power convertors.

Wind turbine is classified into main groups depending on their axis in which the turbine rotates. It can be classified into horizontal axis and vertical axis. Understanding of wind properties is very important for wind energy exploitation. Speed of wind is highly variable both geometrically from place to place and temporally, seasonal and in hourly means.

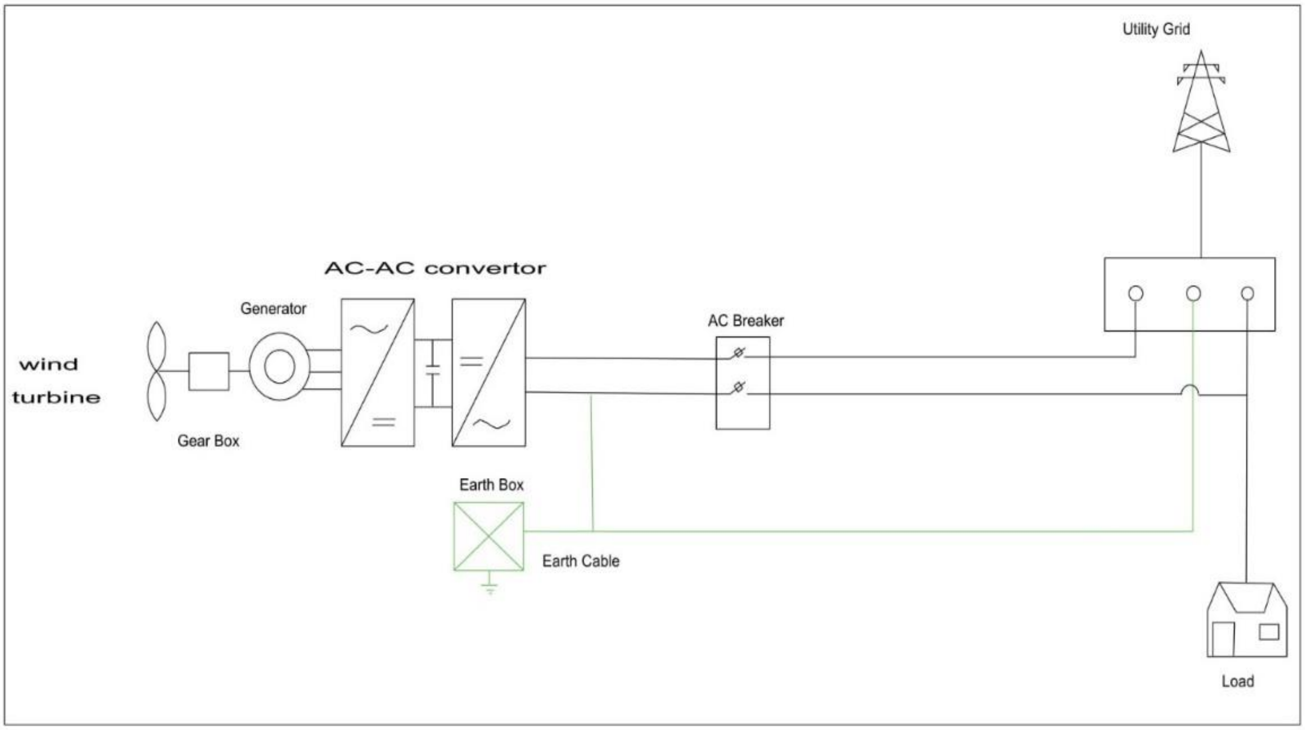


Figure 3.4 schematic of wind turbine generation system

The wind profile and wind speed at a specific site need to be evaluated to identify which turbine is suitable for the particular site condition. For low wind speed locations, different modifications of turbines might be available.

Coupling average wind speed with the assumption that the wind speed distribution follows Rayleigh statistics enables us to find the average power in the wind. Power, torque and thrust are three indicators that varying with the wind speed which characterize the performances of a wind turbine. the amount of energy capture by the rotor determine its power, the size of gearbox determine its torque, while the rotor thrust has a gear influence on the structural design of the tower.

A wind turbine capture energy from moving air and converts it into electricity. Air density, power coefficient, air density and turbine swept area and parameters that affect the captured energy. Therefore, assuming Rayleigh statistics, we can rewrite the fundamental relationship for average power in the wind as equation (3.4) [61]:

$$\bar{P} = \frac{6}{\pi}\frac{1}{2}\,\rho\,A\,v^3 \tag{3.4}$$

Where $\bar{P}$ is the average power in the wind measured in (watt), ρ is the air density (kg/m^3) at standard condition of T_{amp} at 15^{o}C, which equal 1.225 kg/ m^3, A is the swept area (m^2), and v is the wind speed (m/s).

Wind resources and the electric power output from WT at a particular location depend on wind speed at the hub height and the WT speed characteristics. In order to get higher wind output, one way is to mount the turbine on a taller tower. Surface winds are getting slowed by high irregularities such as forests and buildings. The following equation is for the effect of roughness of the earth's surface on the wind speed at the hub height of WT is calculated using the power law equation using the wind speed data collected at the anemometer height as equation (3.5) [60]:

$$v(h) = v(h_g)\left(\frac{h}{h_g}\right)^{\alpha} \tag{3.5}$$

Where $v\ (h)$ and $v\ (hg)$ are wind speeds at hub height (h) and anemometer height (hg) and α is the roughness factor.

The output power of WT is described in terms of wind speed from the typical power curve characteristics of the WT as in equation (3.6) [60]:

$$P_W\ (v) = \begin{cases} 0, & v < v_c\ or\ v > v_f \\ P_r\ \frac{v^2 - v_c^2}{v_r^2 - v_c^2}, & v_c \leq v \leq\ v_r \\ P_r v_r \leq v \leq v_f & \end{cases} \tag{3.6}$$

Where, P_w is the WT output power, P_r is the rated output power of WT, v_c is the cut-in wind speed, v_r is the rated wind speed, and v_f is the cut-off wind speed.

Where V_{avg} is the average wind speed, D is the diameter of swept area of WT. The average power generated by each WT can be calculated by following equation (3.7) [61]:

$$P_{WT} = CF \times P_r \tag{3.7}$$

Where P_{WT} is WT average power.

The capacity factor *CF* of WT can be calculated by equation (3.8) :

$$CF = \frac{0.087}{V_{avg}} - \frac{P_r}{D^2} \quad (3.8)$$

Because wind speeds increase with height, the turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence that can exist close to the ground because of obstructions in the vicinity such as hills, buildings, and trees. Relatively small investments in increased tower height can yield very high rates of return in power production [62].

There are two types of towers: self-supporting (free-standing) and guyed as shown Figure 3.5, guyed towers, which are the least expensive and consist of lattice sections, pipe, or tubing (depending on the design); supporting guy wires and the foundation. They are easier to install than self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require space to accommodate them. Although tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller lightweight turbines (usually 5 kW or smaller). Tilt-down towers can also be lowered to the ground during hurricanes and other hazardous weather conditions. Aluminum towers are prone to cracking and should be avoided. Most turbine manufacturers provide wind energy system packages that include a range of towers options [63].

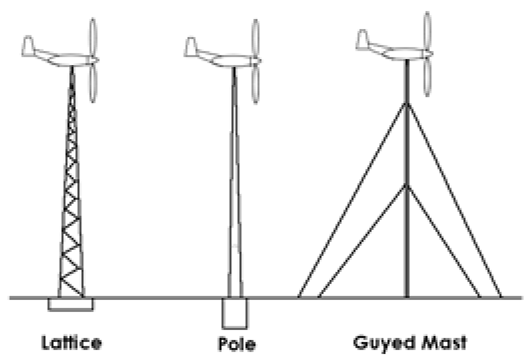


Figure 3.5 Types of tower [63].

3.2.3 Modeling of Energy Cost

Cost of energy COE is a standout the most common and applied to measure of economic analyses of HRES to found it by the following equations [64]:

$$COE = \frac{TPC \times CRF}{LAE} \quad (3.9)$$

where TPC is the total present cost of the entire system, $LAE$is the annual load demand, and CRF is the capital recovery factor. CRF and TPC are expressed by equations (3.10), (3.11) respectively:

$$CRF = \frac{r(1+r)^T}{(1+r)^T - 1} \tag{3.10}$$

where, r is the net interest rate, and T is the system lifetime in years (the system lifetime has been chosen as 25 years).

$$TPC = IC + OMC + RC - PSV \tag{3.11}$$

IC is the Initial Cost of the HRES components, installation cost, and electrical connections and testing. IC can be determined by the following equation (3.12) :

$$IC = PV_P \times C_{PV} + WT_P \times P_r \times NWT \tag{3.12}$$

Where, PV_p is the PV price per kW ($/kW), $C_{PV}$is the rated power of the PV system (kW), $WT_P$is the WT price per kW ($/kW).

Operating and Maintaining Cost (OMC) this is the sum of all yearly schedule operation and maintenance costs,OMC includes such items as an operator's salary, inspections, insurance and all scheduled maintenance,OMC can be determined using the following equation (3.13) [65]:

$$OMC = OMC_0 \left(\frac{1+i}{r-i}\right)\left(1 - \left(\frac{1+i}{1+r}\right)^T\right) \tag{3.13}$$

if i equal r can be determined using the equation (3.14) [65]:

$$OMC = OMC_0 \times T \tag{3.14}$$

where OMC_0 is the operation and maintenance cost at the first year of the project lifetime, can be determine using the equation (3.15) [66]:

$$OMC_o = C_X \times C_{OM} \tag{3.15}$$

Where C_X is the capacity unit and C_{OM} is the cost of operating and maintenance unit ($/kW). Where $OMC_o$is the operation and maintenance cost at the first year of the project lifetime. Replacement cost (RC), this is the sum of all repairs and equipment replacement costs anticipated over the life of system and can be calculated by equation (3.16) [67]:

$$RC = \sum_{j=1}^{N_{rep}} \left(C_{RC} \times C_U \times \left(\frac{1+i}{1+r}\right)^{T*j/(N_{rep}+1)} \right) \tag{3.16}$$

where i is the inflation rate of replacement unit, C_{RC} is the capacity of the replacement unit, and N_{rep} is the number of unit's replacement over 25 year, and C_U is the cost of replacement unit ($/kW) of each system can be calculated by equation (3.17) [67]:

$$C_U = C \times Q \tag{3.17}$$

C is the Cost of Component in year $/ kW, Q is the probability of failure of component in each yearPSV present salvage value the salvage this is the system's net worth in the year of its life-cycle period can be expressed by using the equation (3.18) [68]:

$$PSV = \sum_{j=1}^{N_{rep}} SV \times \left(\frac{1+i}{1+r}\right)^{T*j/(N_{rep}+1)} \tag{3.18}$$

Where SV is a salvage value. In this thesis has calculated the PSV when tack SV has been assumed as the percentage of capital the project for WT and PV [69].

Chapter 4

Methodology

4.1 Optimization Strategies of HRES

This chapter will present optimization techniques used for the sizingof HRES between wind and solar energy conversion systems.

Values of Wind and solar energy depend on weather conditions which change from one hour to another during the year. It is important to generate maximum power with minimum cost within the available area to satisfy required demand.

Therefore, in this work, done collected the data for solar, wind speed and data load required for PPU on monthly basis and analysis of loads 24 hours be provided, and deal with building the structure of the hybrid energy system, analyzing the parameter and price of the system component and identifying the optimizing technique methodology nonlinear approaches are known as the genetic algorithm (GA).

The objective function for optimally designing the HRES must be minimized as expressed in the following equation. The objective function of the optimization problem is the minimization of the aggregate system cost function, $TPC(X)$. This function incorporates capital cost $IC(X)$, operation and maintenance cost $OMC(X)$ and the replacement cost $RC(X)$ throughout the lifetime of the installed system, with consideration take present salvage cost $PSV(X)$ at the end life time of the project.

$$TPC(X) = IC(X) + OMC(X) + RC(X) - PSV(X)$$

where, X is vector of sizing variable, $X = NW, C_{PV}$. Where the NW is number of wind turbine, and C_{PV} is the capacity of PV system.

4.2 Weather Data

The hourly data of solar radiation, temperature and wind speed for PPU location is using a case study area located 31 30 N, 35 5. In this thesis, the observation data have been obtained from a weather station of renewable energy department started in November and December of 2018 to March 2019 and completed other months from 2006 . Data include daily, hourly solar radiation, temperature and wind speed. Figure 4.1 shows hourly solar radiation along the year which equals 8760 hours. The figure presents solar radiation for location in MJ/m^2 for each hour during the year. Starting from January where the value comes up to reach the highest point at the Summer then decrease in autumns to December. Obviously, the maximum total solar radiation value about 8 MJ/m^2 at midday in winter season rises to reach about 13 MJ/m^2 at midday in summer season. After that, it decreases in autumns to reach about 10 MJ/m^2 at midday, and continue to decrease in winter.

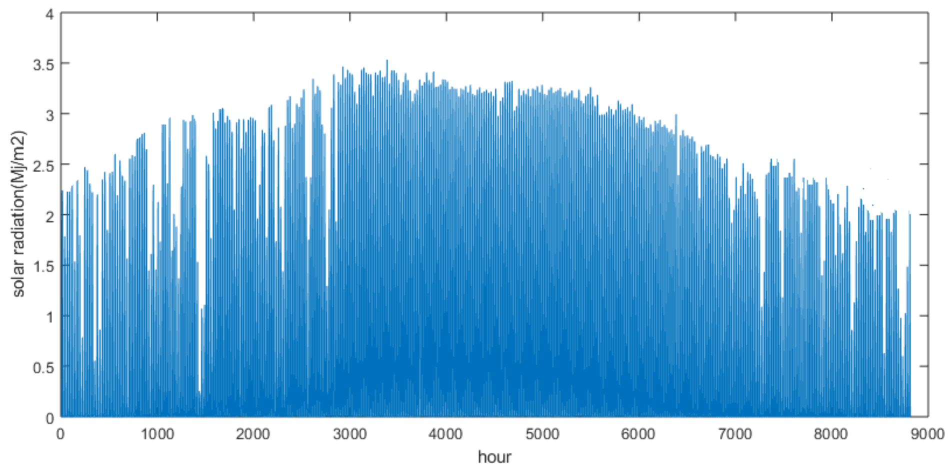


Figure 4.1 Hourly solar radiation

Figure 4.2 shows the hourly wind speed along year which equals 8760 hour. The figures present wind speed for location in m/s for each hour during the year. The value is fluctuating along the year. In January and December, value seems to be higher related to other months. Overall, the max wind speed value is about 16 m/s in winter season.

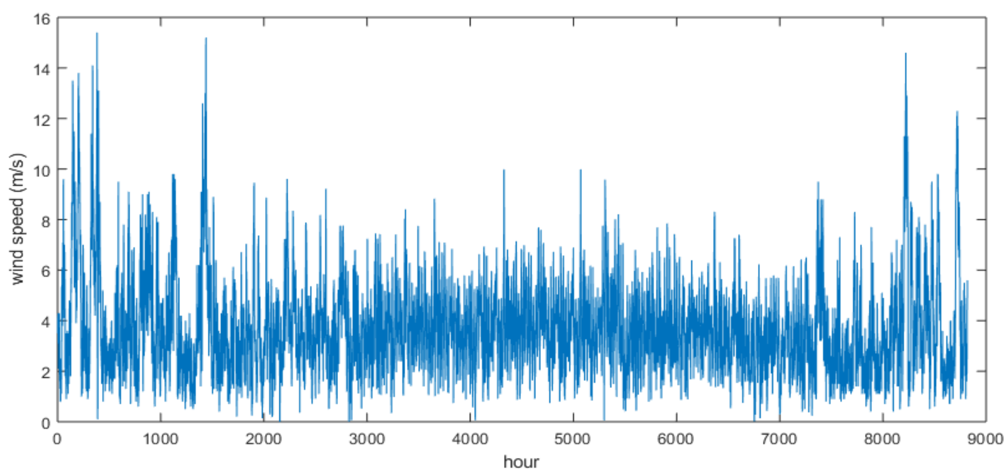


Figure 4.2 Hourly wind speed (m/s)

Table 4.1 provides the average monthly temperature, solar radiation, mean wind speed and max wind speed. The table clearly shows the following information: the temperature in ^{o} C, solar radiating in KWh/m^2, and wind speed in m/s for each month.

Table 4.1 Average monthly temperature, solar radiation and wind speed.

Month	Temperature ^{o} C	Radiation kWh/m^2	Average wind speed (m/s)	Average max wind speed (m/s)
January	13.14	2.95	3.34	3.78
February	14.43	3.66	3.08	3.54
March	17.12	5.30	3.01	3.47
April	19.89	6.32	3.33	3.83
May	23.25	7.52	3.17	3.68
June	26.06	8.35	3.21	3.68
July	28.65	8.14	3.39	3.87
August	28.85	7.51	3.18	3.68
September	26.74	6.39	3.14	3.64
October	24.05	5.06	2.60	3.03
November	24	3.66	2.92	3.32
December	18.8	2.91	2.97	3.43
Average	18	5.647	3.11	3.57

From the above data, the solar radiation plot can be drawn as in the Figure 4.3. The annual average solar radiation is calculated as of 5.647 kWh/m2/day. The figures present solar radiation for location in kWh/m2/day for each month during the year. Starting from January where the value goes up gradually to reach highest point at Summer then decrease in autumns to December. Obviously, the highest solar radiation value is about 8 kWh/m2/day in Jun and the lowest solar radiation value about 2.5 kWh/m2/day in December. Figure 4.4 shows the annual max wind speed which is calculated as of 3.5m/s.The figures present wind speed for location in m/s for each month during the year. It is obvious that the highest wind speed value is about m/s in January, April and July, and the lowest wind speed value seems to be about 3 m/s in October.

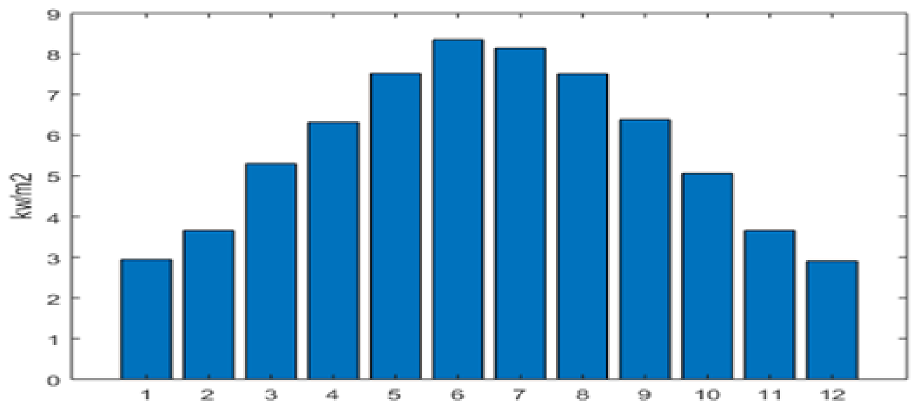


Figure 4.3 Monthly average solar radiation

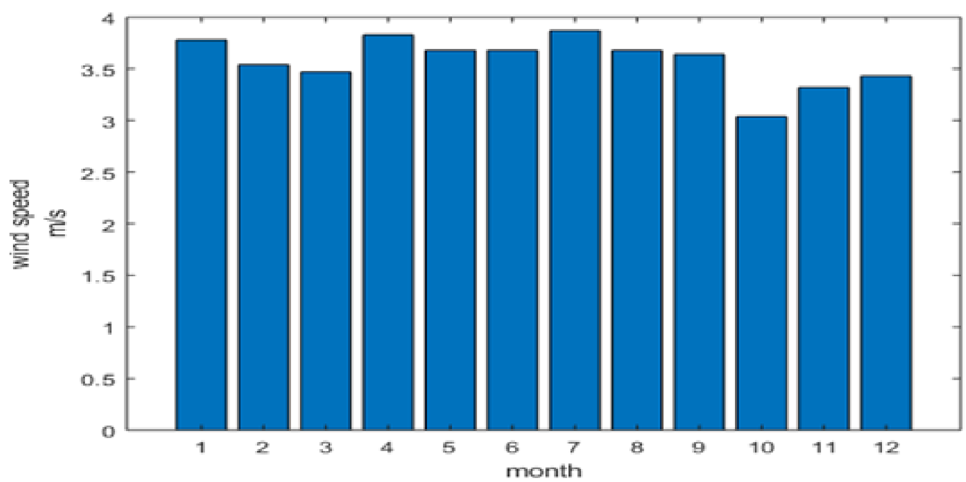


Figure 4.4 Monthly max wind speed

4.3 Specification Component of HRES

4.3.1 Specification of PV module

In the HRES system, the PV module technical specification must satisfy the distribution of PV modules among the inverters and also the dimension limitation of available installation area.

The PV system use Q-cell with rated power output 320 W under standard test conditions (STC) meaning radiation 1 kW/m^2, a cell temperature of (25 ^{o}C), normal operating temperature NOCT (45pm 3 ^{o}C), are adopted in this work. The technical specification for PV panel is illustrated in Table 4.2.

Table 4.2 Technical parameters of PV Specification

Item	Specification
Power (W)	325
Short circuit current I_{sc}(A)	9.44
Open circuit voltage V_{sc}(V)	46.43
Efficiency	17.4
Area (m^2)	2

4.3.2 Specification of WT

In this thesis, the 5-kW wind turbine made by Hengfeng will be used to build the hybrid renewable system. The technical specification for WT of 5 kW from Hengfeng adopted in this work is illustrated in the table.

Table 4.3 Technical parameters of Wind Turbine Specification

Item	Specification
Power (W)	5000
Diameter (m)	6
Cut – in wind speed V_c (m/s)	3
Rated wind speed V_r(m/s)	8
Seviral wind speed V_f (m/s)	25

Based on the above data, the Hengfeng 5 kW wind turbine characteristic curve is shown as the Figure 4.5.

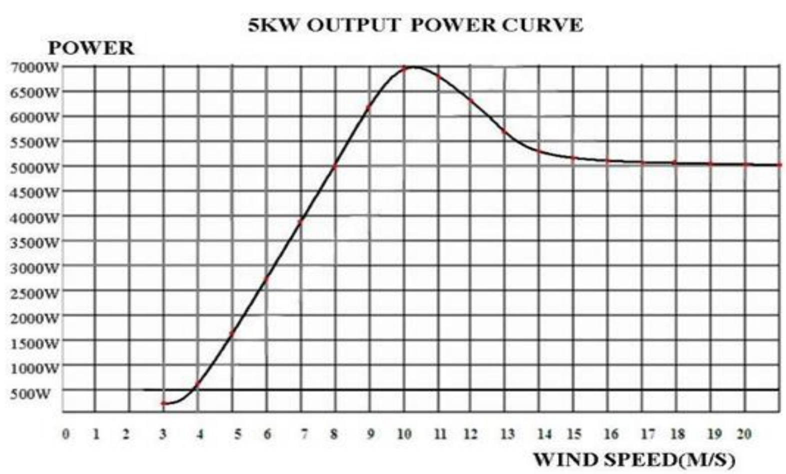


Figure 4.5 The characteristic curve of 5kW turbine [70].

Figure 4.6 diagram of hours per year and KWh per year at each wind speed for each Hengfeng 5 kW wind turbine the total energy delivered each turbine about 9690 kWh/year was calculated by used equations (6.45 to 6.48) in [61].

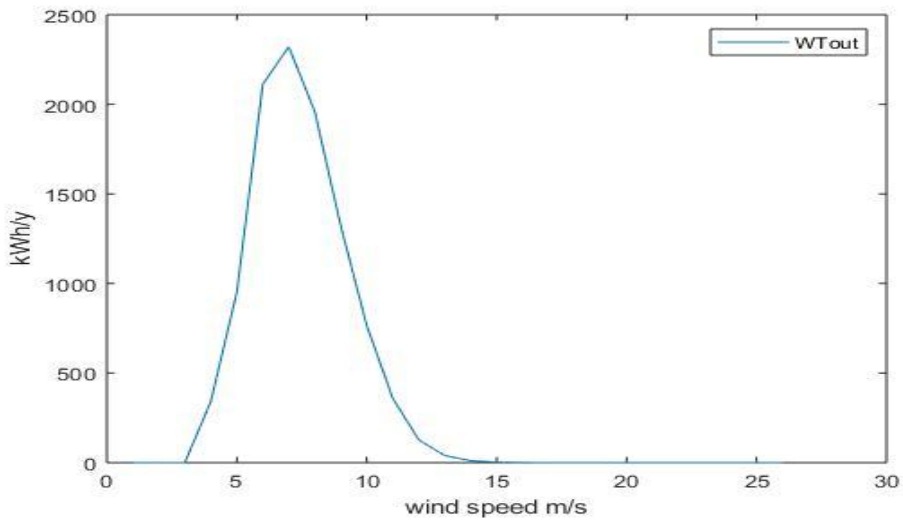


Figure 4.6 Hour per year and kWh per year at each windspeed for the Hengfeng 5 kW turbine and Rayleigh winds with the max average speed 3.5 m/s

4.4 Economic data

IC is the initial capital cost of the HRES components, including the installation cost, and electrical connections and testing. In this study, it is expressed in a price per kW system that is determined for first time.

OMC which stands for Operating and maintenance cost per year can be expressed as follows : the annual maintenance cost has been set as 3% of capital cost for WT, 1% of capital cost for the PV generator, OMC has been used as a fixed cost per capacity of each component of the HRES [71].

Life time T is the system lifetime in years (the system lifetime has been chosen in this thesis as 25 years).

RC Replacement cost which is the sum of all repair and equipment replacement cost anticipated over the lifetime of the system the cost of replacing this component has been set 1% of capital for PV, 3% of capital cost for WT) [72,73].

Scrap; in this study the analysis assumes the scrap or salvage (SV) of each component as 20% for WT and 10% for the solar array [74]. All of that is illustrated in Table 4.4.

Table 4.4 Economic and technical parameters of Wind Turbine Specification

Item	IC	Life time	OMC	Scrap	RC
PV	1045$/kW	25 year	1%	10%	1%
WT	1160 $/kW	25 year	3%	20%	3%

4.5 Load

In this thesis, a hybrid energy system will be designed to supply power to one of PPU campuses in Palestine. Table 4.5 shows the monthly consumption of the assigned PPU Campus in Wadi AlHaruya estimated above 153,000 $ per year for 2017-2018 [75].

Table 4.5 Monthly Load

Month	Consumption (kWh)	Cost (bill)($)
January	61,552	11,969
February	62,388	12,131
March	85,665	16,657
April	67,912	13,205
May	73,967	14,382
June	65,287	12,694
July	50,348	9,790
August	46,752	9,090
September	68,757	13,369
October	60,998	11,860
November	74,917	14,567
December	68,624	13,343
Total	787,167	153,057

Appendix B presents the hourly load day for PPU Campus in Wadi al Haruya for four days in March during 24 hour. The load was calculated the main metering by VEGA78 at 5-March, 6-March, 7-March, and 9-March for 2017 in midday and completed night hour from 2019. In the beginning, the start of the day seems to have a lower load rate than midday. Overall the load calculated was illustrated tend to be stable at morning and evening, then the load goes up starting from midday.

4.6 Distribution of Single Energy System

The capacity of the system PV and Wind energy for Wadi El Hariya PPU depends on rooftops available area. Table4.7 presents the area for each building.

4.6.1 PV Array Distribution

The Site of Wadi Alhariya includes four main buildings that form a viable site for PV solar system installation due to their heights and rooftop areas. The capacity of Wadi A Hariya PPU rooftops for the PV system of about 230 kW.Table 4.7 shows it for each building.

The Figure 4.7 shows the distribution of PV panel on the top roof of buildings A, A+, C, B&B+ respectively the orientation of panels is south, which is done by ATUCAD program. Each 1 kW of PV requires an area of about 9 m^2 .

Table 4.6 Solar Array Distribution

Building	Area rooftop m^2	PV capacity (kW)	No.of PV panels
A	608	40.95	126
A+	560	46.45	144
C	1200	47.45	146
B & B+	1465	94.9	292
Total	3833	230.1	708

4.6.2 Distribution of Wind Turbines

Distribution of wind turbines depends on rough rules of tower spacing of such rectangular arrays. Recommended spacing is 3-5 rotor diameters separating towers within a row and 5-9 diameters between rows, the offsetting, or staggering on one row behind another, the distribution WT on top roof of four main buildings [76]. The maximum capacity of Wadi El Hariya PPU rooftops for the WT system is about 70 kW. Figure 4.8 shows the distribution of WT on the top roof of buildings A, A+, C, B&B+ respectively. Every wind turbine needs an area about 46 m^2 for fixing tower.

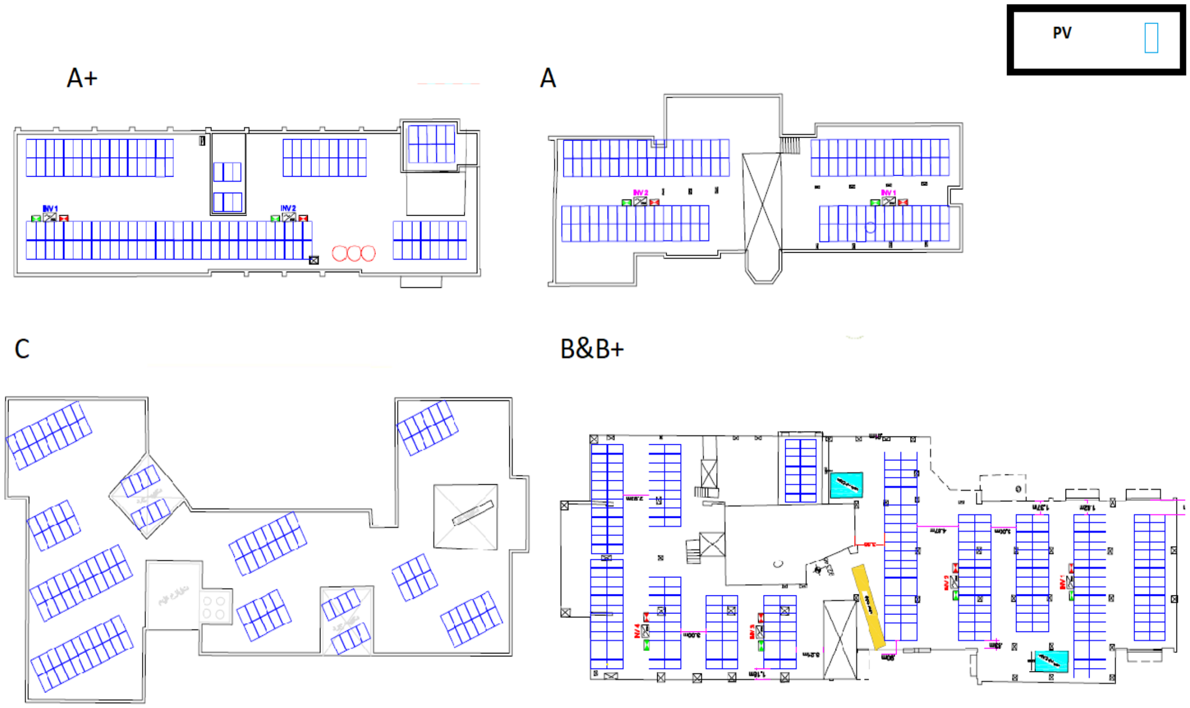


Figure 4.7 Solar array distribution

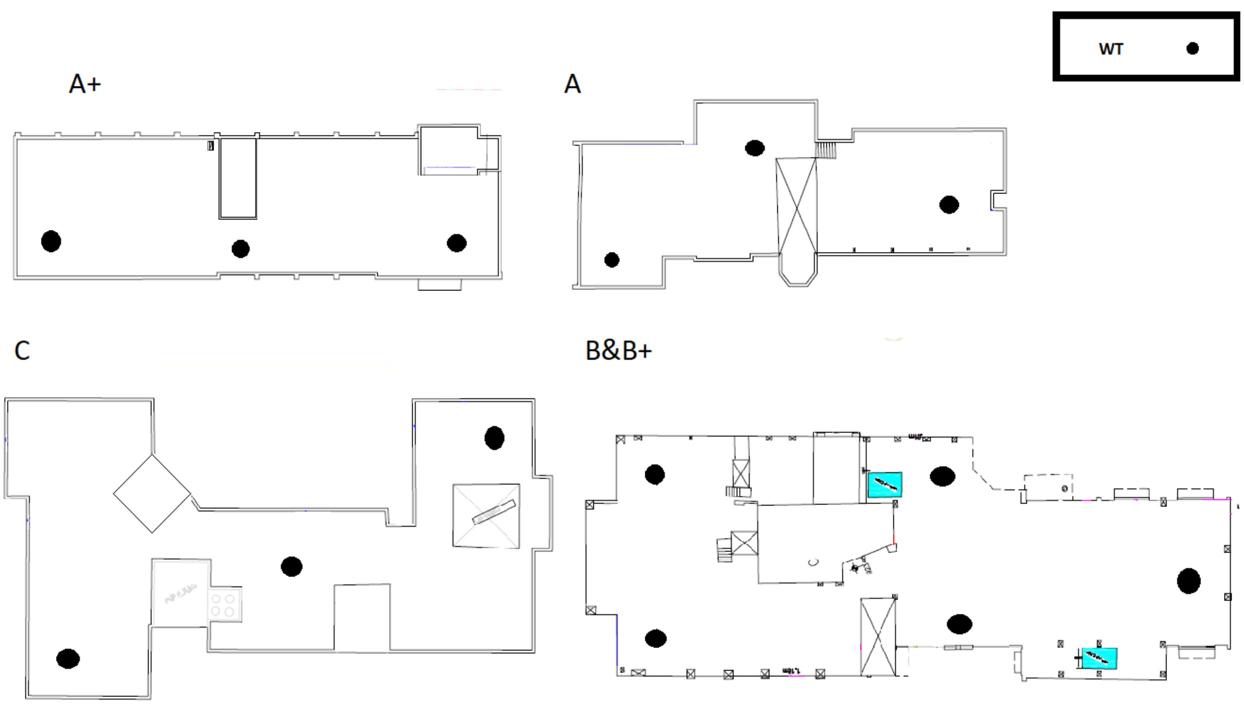


Figure 4.8 Wind Turbine distribution

4.5 Genetic Algorithms (GA)

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that are based on natural selection in the process that drives biological valuation [77].

The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals from the current population to be parents and uses them to produce the children for the next generation.

Over successive generations, the population toward an optimal solution. The genetic algorithm can be applied to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the fitness function is the function needed to optimize. For standard optimization algorithms, objective function is discontinuous, stochastic, or highly nonlinear. The genetic algorithm can address problems of mixed integer programming where some components are restricted to be integer-valued.

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population:

- Selection rules select the individuals, called parents that contribute to the population at the next generation.
- Crossover rules combine two parents to form children for the next generation.
- Mutation rules apply random changes to individual parents to form children.

4.5.1 How does the Genetic Algorithm works

The process of GA follows a pattern for solving the formula as shown in figure 4.9. [78].

- The algorithm begins by creating a random initial population.
- The algorithm then creates a sequence of new populations. At each step, the algorithm uses the individuals in the current generation to create the next population. To create the new population, the algorithm performs the following steps:
  - Scores each member of the current population by computing its fitness value.
  - Scales the raw fitness scores to convert them into a more usable range of values.
  - Selects members, called parents.
  - Scales the raw fitness scores to convert them into a more usable range of values.
  - Selects members, called parents.
  - Some of the individuals in the current population that have lower fitness are chosen.

- Produces children from the parents. Children are produced either by making random changes to a single parent mutation or by combining the vector entries of a pair of parent ‘crossovers.
- Replaces the current population with the children to form the next generation.

- The algorithm stops when at the optimum solution.

The concept of implementation sequence is the survival of the fittest. The reproductive success of a solution is directly tied to the fitness value which is assigned during evaluation. The least fit solution may not reproduce at all. The major advantage of GA lies in their computational simplicity and their powerful search ability to obtain the global optimum. Its further attraction of GA is that it's extremely robust with respect to the complexity of the problem.

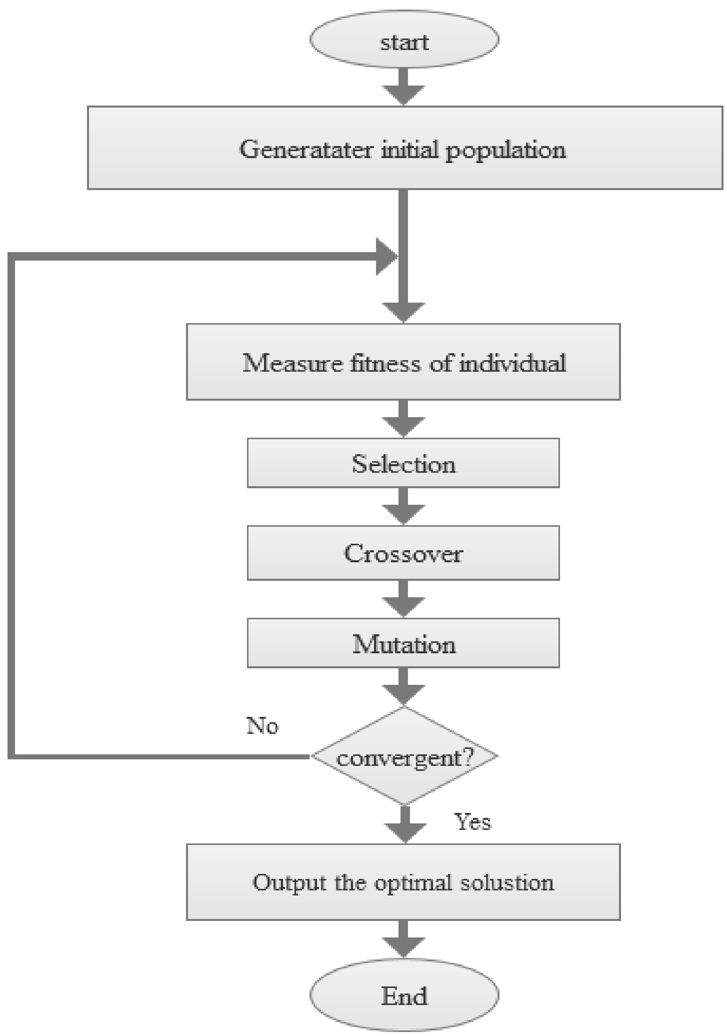


Figure 4.9 Flow chart of the Genetic algorithm (GA)

4.7 Methodology of the Optimization Model

GA provides a balance between the component of HRES and the overall cost. In order to meet maximum of energy on a variable area for the PPU. The proposed optimization algorithm suggests a list of economic and technical specification of wind turbine and PV specification for a 25-year time and component system under the objective function of minimum cost. In the following steps to approach the optimum size, the flowchart diagram for this program is shown in figure 4.10.

- First step Input data needs
  - The meteorological data of wind and solar radiation and temperature.
  - The input data for this program consist of mean hourly global radiation, hourly wind speed, and temperature,
  - Technical specification of PV models.
  - Technical specification of WT.
  - Economic data of the system component.
  - The load power data.
  - The available area over the rooftop

- Second step GA
  - The algorithm begins by creating a random initial population size is 20.
  - Maximum of generation 200

  It means the GA algorithm then creates a sequence of new populations capacity of PV and number of wind turbine

- Third step Fitness function steps
- Applied constrained function
  - PV energy generation by applied equation (3.1)
  - WT energy generation by applied equation (3.7)

    Examination of the total power generation reach to satisfy the load in this constrain (P_{load}<=(P_{PV}+P_{WT}))
  - Examination the total area does not exceed the area of the top roof in this constraint ($A_{toproof}$=>(A_{WT}+A_{PV}))

- Calculate the cost of this system and run the fitness function to achieve the main object the minimum cost and applied steps of GA
    - Selection
    - Crossover
    - Mutation

- Final step the algorithm stops when at the optimum solution.

From the above objective, a genetic algorithm has been developed to carry out the sizing and optimization process. This enables the optimization and simulation of the proposed HRES by conducting energy balance calculations for each hour during the year. The genetic algorithm can determine the optimum size of each component of HRES depending on the minimum cost of the generated energy.

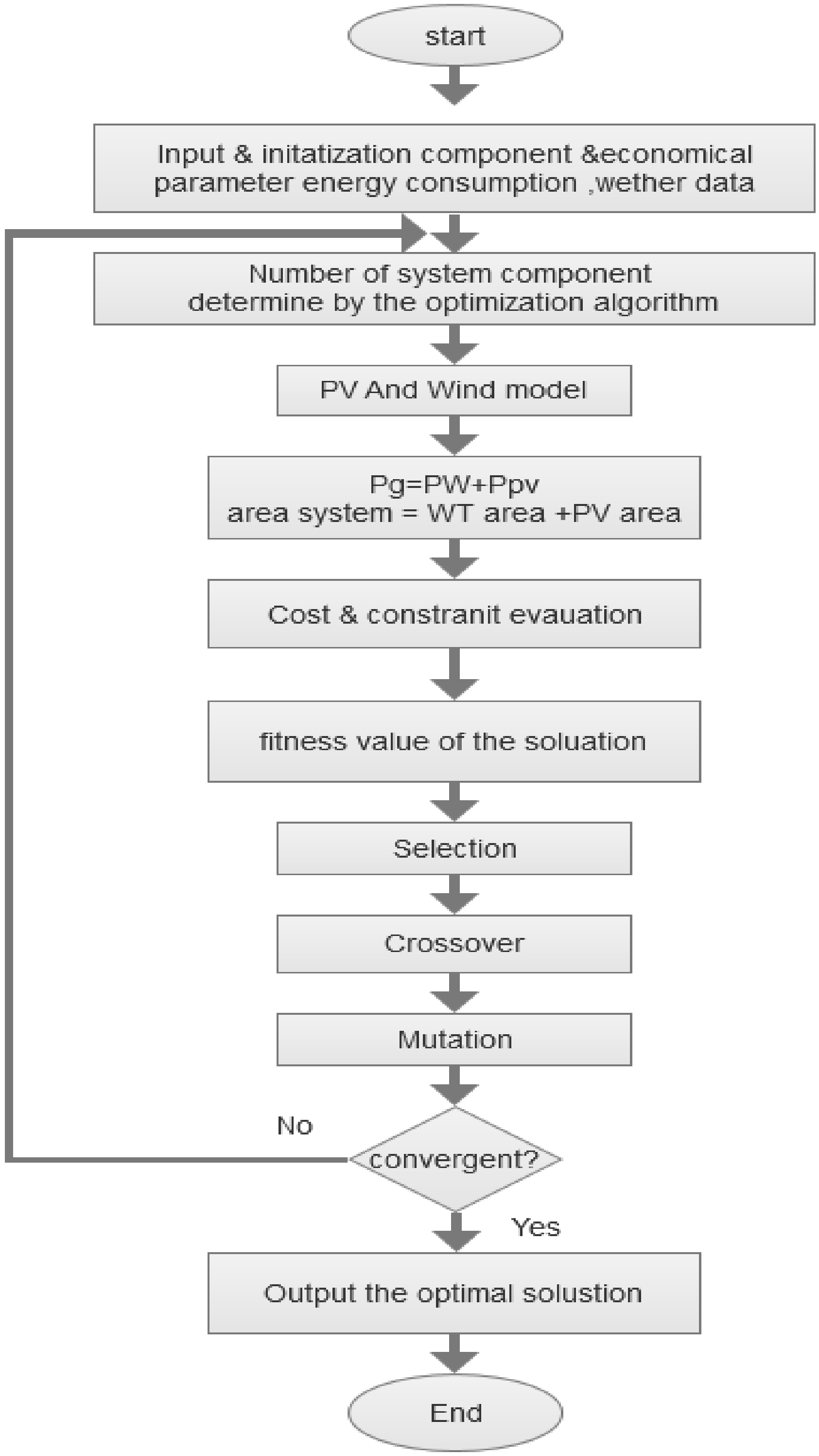


Figure 4.10 Sizing optimization flowchart

Chapter 5

Analysis and Discussion of Results

5.1 Overview

As stated in previous chapters, some renewable energy generation systems such as solar and wind energy seem to be not fully reliable since they are cannot meet stable electricity demand due to several reasons. Power generation using wind and solar energy can be unstable since the first depends on wind speed and the later depends on sun light during daytime not to mention that they are both subject to any change in weather conditions. Therefore, this puts us in a need to design a hybrid system that is made up of wind and solar power for the proposed site. A system that can produce highest amount of energy production, within the existing space available, at the lowest possible price.

In this chapter, the results of the study are presented and discussed with reference to previously-mentioned aim of the study, which was to design a hybrid system using solar and wind energy as sources for energy. The results obtained from this study were put through GA optimization analysis and are presented in this chapter. Results of the proposed optimized wind-solar hybrid energy generation system are thoroughly analyzed and the conclusions of findings are drawn.

In order to get the best efficient size and to better understand the results, three scenarios are suggested: the first scenario on-grid PV system, the second scenario suggests a on-grid WT, while the third scenario presents a PV-wind hybrid energy system.

5.2 Results of an On-grid PV System

The Figure 5.1 shows the results of optimization for each hour a long year (i.e. 8760 hour). The Figure also presents the output of the PV for all hours during the year applied by applied steps that was explanted in previous chapter, starting from January where the value rises up to reach the highest point at summer then decrease in autumns all the way to December.

Table 5.1 illustrates how the proposed solar system with a capacity of 230 kWp able to generate 373,760 kWh/y; an output that can cover 53% of demand. The total cost of this system is US $ 331,049 which includes capital cost and operating and management in the case study of PPU.

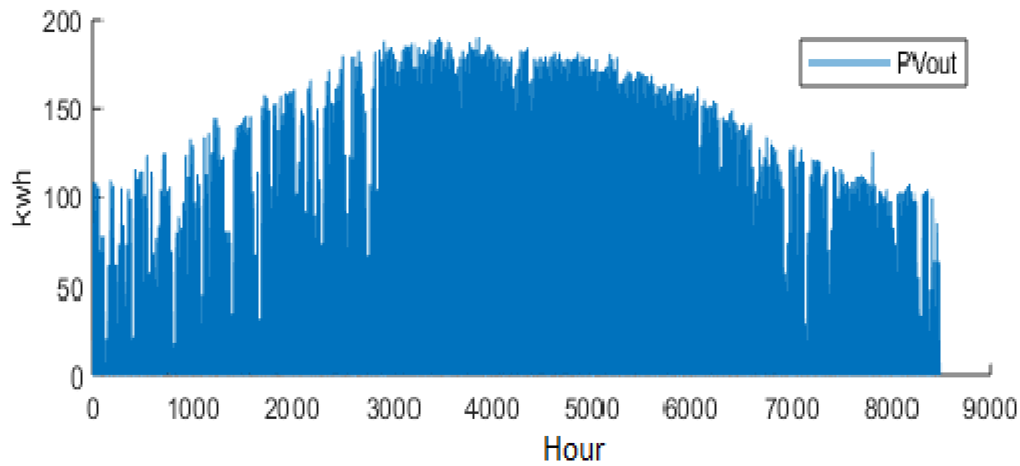


Figure 5.1 energy generation system with hourly radiation

Table 5.1: Solar energy system with hourly solar radiation

Type of generator	Product	Capacity (kWp)	Output (kWh/y)	Output after 25 year
PV	Q cell	230	372,669	8.2GWh

Table 5.2 presents a cost analysis of the PV system in which it clearly shows the capital cost, total OMC over the course of 25-years , salvage value and the total cost of the system after 25 years. By looking at the table below, it can be clearly noted that the energy cost of this system equals 0.042 $/kWh.

Table 5.1 Cost summary of PV generation system after 25 years.

Generator Type	Capital Cost ($)	OMC ($)	RC ($)	Salvage ($)	Total cost ($)	Energy cost($/kWh)
PV	239,890	57,574	57,574	23,989	331,049	0.042

Figure 5.2 shows the cash flow of the PV system. As shown in the graph, the proposed system provides the highest lifetime savings, nearly US $ 4,636,316 in this case. The payback period of investment starts after 4 years and 4 months.

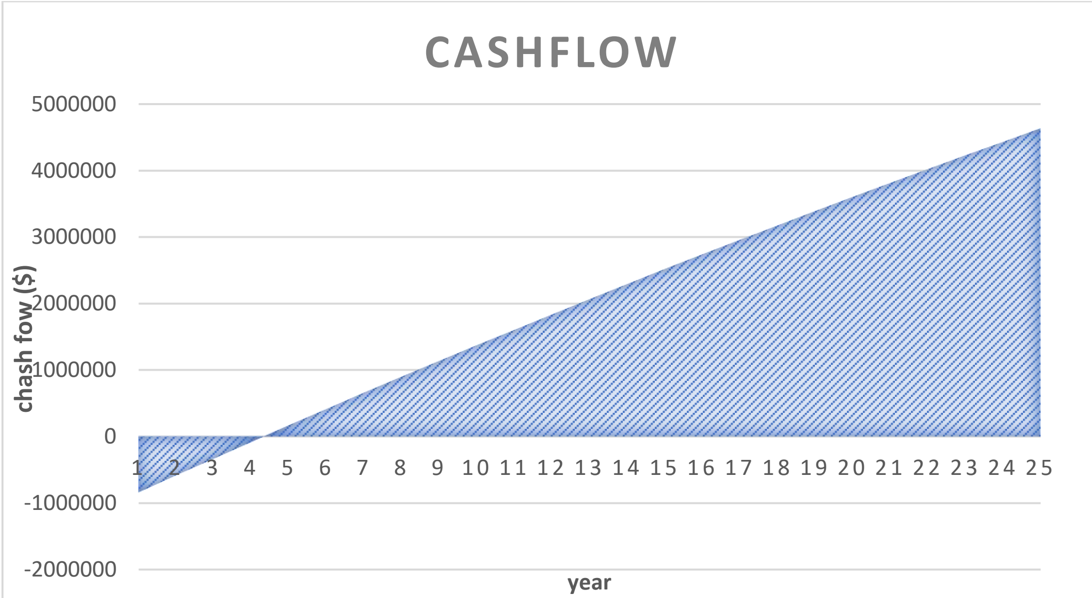


Figure 5.2 Cash flow of PV system

Table 5.3 presents the results of optimization of PV for one day in the middle of each month and the results of optimization each month using hourly solar radiation. Also, it is clear that the highest value of energy generation and the lowest cost of energy seems to be in summer months. On the contrary, the lowest energy generation and highest cost energy occurs in winter season. Where the Figure 5.3 represents the results in this table.

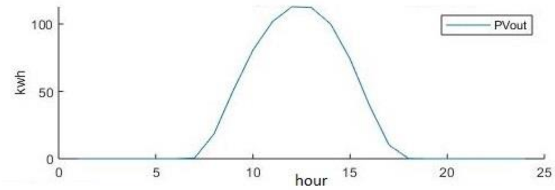
Where the output of PV generation at one day in the middle of each month illustrates the highest total output on 15th of may where the total energy generated during that day equals 1513 kWh/day and the lowest cost energy reaches 0.028 $/kWh. The lowest energy value seems to be at the 15th of November where the total energy generated during that day equals 304.8 kWh/day and highest cost of energy reaches 0.14 $/kWh. The cost of energy from May to September is relatively similar about 0.030 $/kWh.

The output of PV generation for each month shows that June has the highest total output where the total energy generated during that day equals 46,201 kWh/month and the lowest cost of energy as it reaches 0.028 $/kWh. However, December seems to have the lowest output where the total energy generated during that day equals 16,083 kWh/month and the highest cost of energy as it reaches 0.082 $/kWh. The cost of energy from May to September is relatively similar about 0.030 $/kWh.

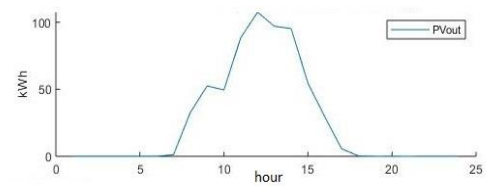
Figure 5.3 shows the output of PV generation for 15 th of each month.PV production starts gradually increasing from January where the value reaches 100 kWh at midday where it reaches the highest value in May. The value was about 200 kWh at midday, the energy production in summer months remains tight and starts decreasing in October. The lowest energy value occurs in November where the it reaches approximately 80 kWh at midday. Where the Appendix C shows the output of PV generation each month.

Table 5.2 The results of the optimization PV generation for one day of each month and for each month using hourly solar radiation values

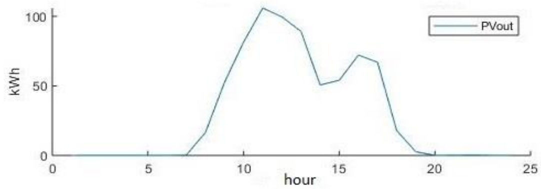
	For day		For month	
Month	Output PV (kWh/day)	Energy cost ($/kWh)	Output PV (kWh/month)	Energy cost ($/kWh)
January	701.24	0.062	20,233	0.065
February	617.8	0.070	19,121	0.068
March	711	0.061	29,348	0.045
April	848.8	0.051	30,242	0.043
May	1513	0.028	44,747	0.029
June	1449.7	0.029	46,201	0.028
July	1338	0.032	44,823	0.029
August	1448.6	0.03	42,126	0.031
September	1156	0.037	34,040	0.038
October	665.5	0.063	24,754	0.053
November	304.8	0.14	20951	0.063
December	431.7	0.10	16083	0.082
Total			372,669	Average :0.042



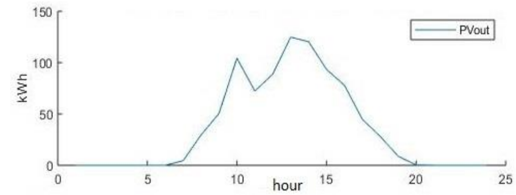
15- January



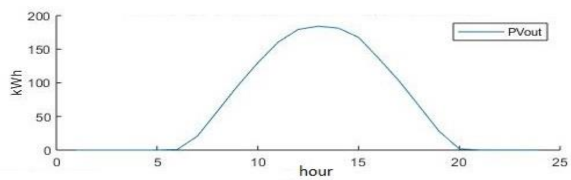
15- February



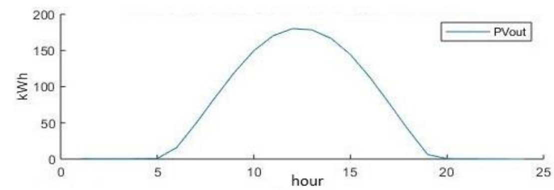
15- March



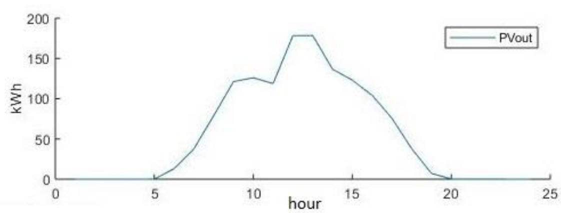
15-April



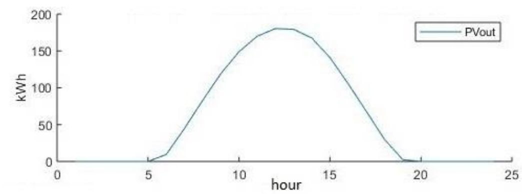
15-May



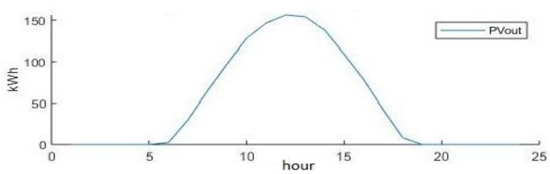
15-June



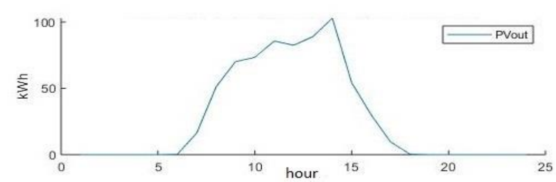
15-July



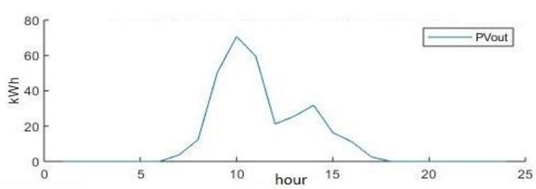
15-August



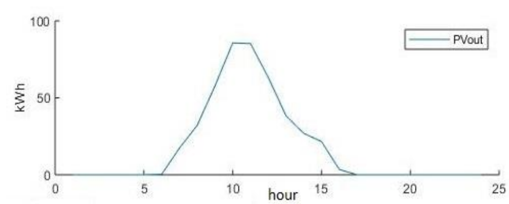
15-September



15-October



15-November



15-December

Figure 5. 3 PV generation output for one day each mid-month

5.3 Results of anOn-grid Wind Energy generation System

Figure 5.4 shows the result of optimization for each hour along the year. The Figure present output of the WT of all hours during the year by applied steps that was explanted in previous chapter, The value of production is fluctuating along year. In January and December, the value is the highest compared to other months.

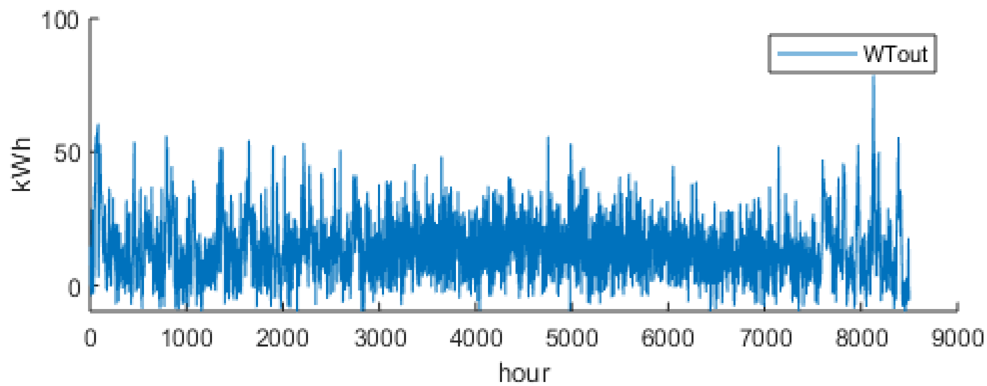


Figure 5. 4 Hourly output of WT system.

Table 5.4 illustrates wind energy system compound of 14 wind turbines. The capacity of each is 5 kW. The total capacity of the single system equals 70 kW with total output is equal 131,437 kWh/y covering 18.5% of the demand. The total cost is US $ 181,888 which includes the capital cost and OMC along 25 year.

Table 5.3 Wind Energy System with daily average wind speed

Type generator	Product	Capacity (kW)	Output (kWh/y)	Output after 25 year
WT	Hengfeng	70 kW	131,437	3.2 GWh

Table 5.5 presents the cost analysis for the WT system where it shows the capital cost and the total OMC along 25-year, salvage value, and the total cost of the system after 25 year and the cost of energy is going to be 0.053 $/kWh.

Figure 5.5 shows the cash flow of the WT system as shown in the graph. The system provides the highest lifetime savings is approximately US $ 1,500,000 in this case. The payback of investment period 25 years.

Table 5.4 Cost summary of WT generation system after 25 years

Type generator	Capital Cost ($)	OMC ($)	RC ($)	Salvage ($)	Total cost ($)	Energy cost ($/kWh)
WT	81,200	58,464	58,464	16,246	181,888	0.053

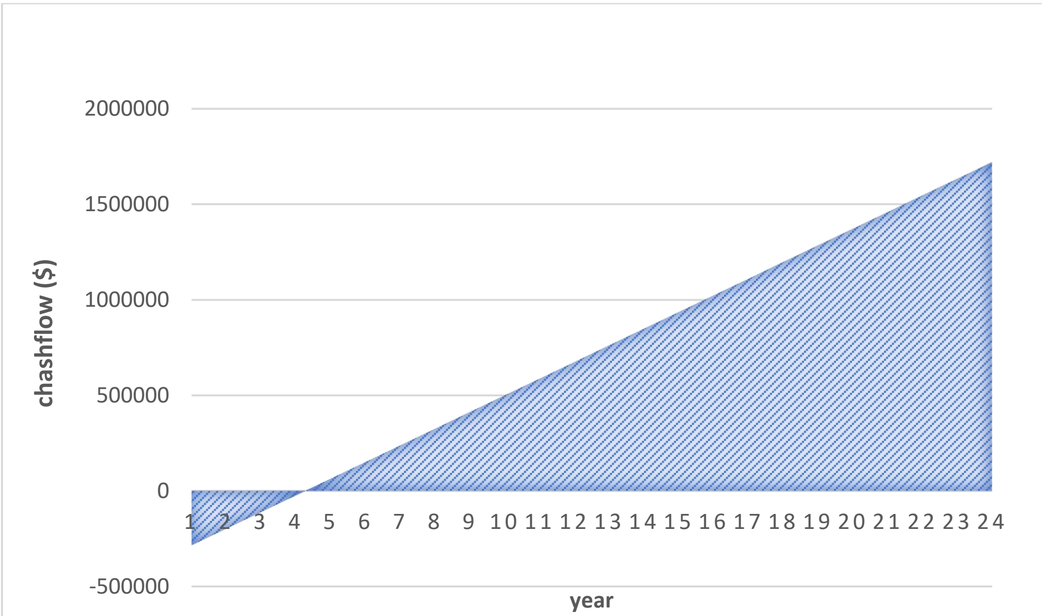


Figure 5.5 Cash flow of WT.

Table 5.6 presents the results of optimization of WT single generation system for one day in the middle of each month and the results of optimization of each month using hourly wind speed. Where the Figure 5.6 represents the results in this table.

It is obvious that the highest value of energy generation and lowest cost of energy is in winter. On the contrary, in summer season has the lowest energy generation and highest cost of energy. The output of WT generation at one day in the middle of each month is presented. As for the 15th of January, it can be noted that this day has the highest total output where the total energy generated during that day equals 672.4 kWh/day and has the lowest cost of energy as it reaches 0.029 $/kWh.

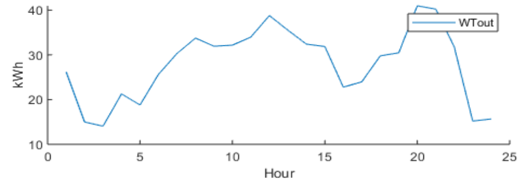
While the 15th of August seems to have the lowest energy value occurs as the total energy generated during that day equals 113.2 kWh/day and the highest cost of energy reaches 0.17 $/kWh. The cost of energy in May, March and September is relatively similar at about 0.054 $/kWh. The cost of energy in February, April, June and October are relatively similar around 0.042 $/kWh.

The table below shows the output of WT generation for each month which clearly shows that the highest total output occurs in January where the total energy generated during that day equals 15,322 kWh/month and the lowest cost of energy reach 0.038 $/kWh. It also shows that the lowest energy value occurs in November where the total energy generated during that month equals 7,477 kWh/month and highest cost of energy reaches 0.075 $/kWh.

Table 5.5 The results of the optimization WT single for one day of each month and for each month use hourly solar radiation values

	For day		For month	
Month	Output WT (kWh/day)	Energy cost ($/kWh)	Output WT (kWh/month)	Energy cost ($/kWh)
January	672.4	0.029	15,322	0.038
February	874.6	0.022	12,088	0.049
March	266.0	0.073	8,874	0.067
April	462.9	0.042	11,257	0.052
May	269.5	0.072	10,863	0.054
June	445.6	0.044	11,028	0.054
July	476.0	0.041	11,763	0.054
August	113.2	0.173	10,881	0.05
September	301.43	0.065	10,252	0.05
October	457.2	0.042	7,893	0.076
November	141.5	0.138	7,477	0.075
December	598	0.032	13,739	0.043
Total			131,437	Average 0.052

Figure 5.6 shows the output of WT generation for one day in the middle of each month. The Figures present the output of the WT of all hours during the day. The output of WT generation is fluctuating from hour to hour during the day depending on wind speed. WT energy generation reaches highest value in January ranging from 30 to 40 kWh while it reaches the lowest value in August. The value reaches between 0 to 10 kWh while the highest value on this day reaches about 20 kWh.Where the Appendix D shows the output of WT generation each month.



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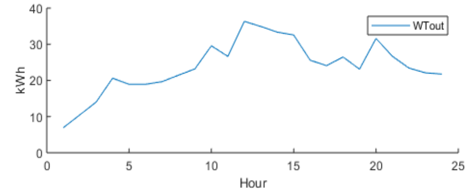

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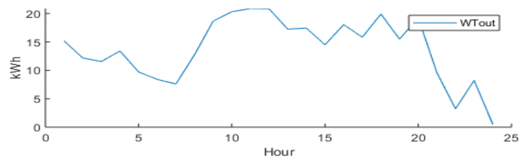

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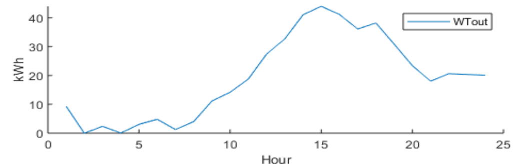

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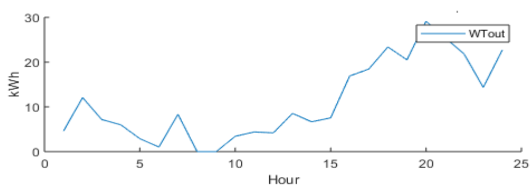

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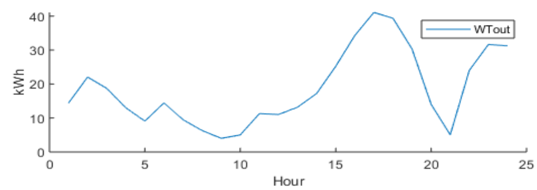
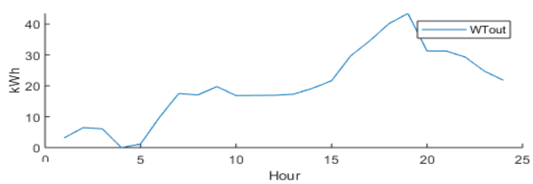


15 June



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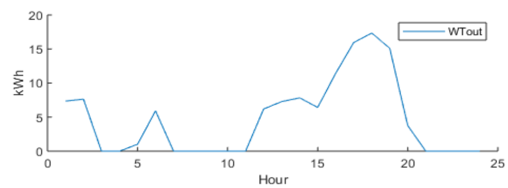

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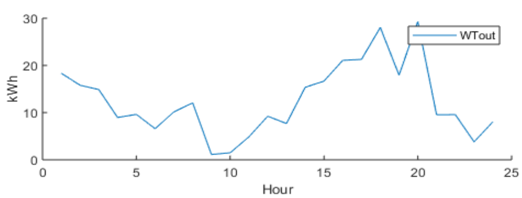

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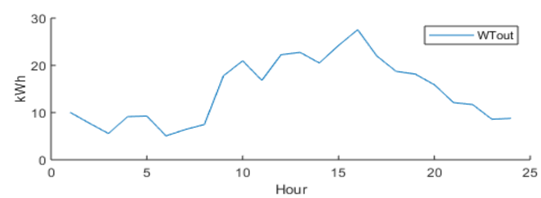

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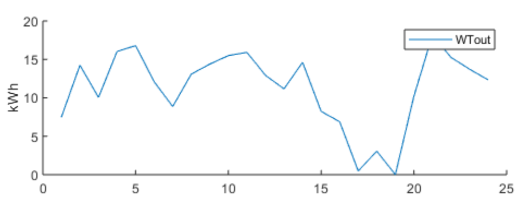
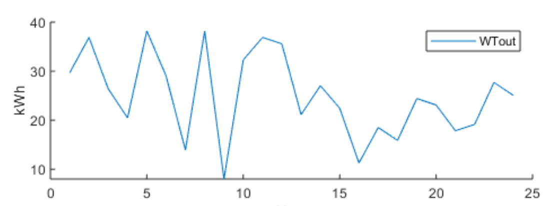


15 November



15 December

Figure 5. 6 WT generator output for one day each mid-month

4.3 Results of a PV-Wind Hybrid Energy System

The formulated optimization problem of the PV-wind hybrid energy system is solved based on hourly solar radiation and wind speed data. The Figure 5.7 shows the results of optimization for each hour along the year (i.e.8760 hour). The Figure presents the output of PV-wind energy generation for all hours during the year. Wind generation which is highly erratic peaks in the winter while solar generation which is far smoother peaks in the summer.

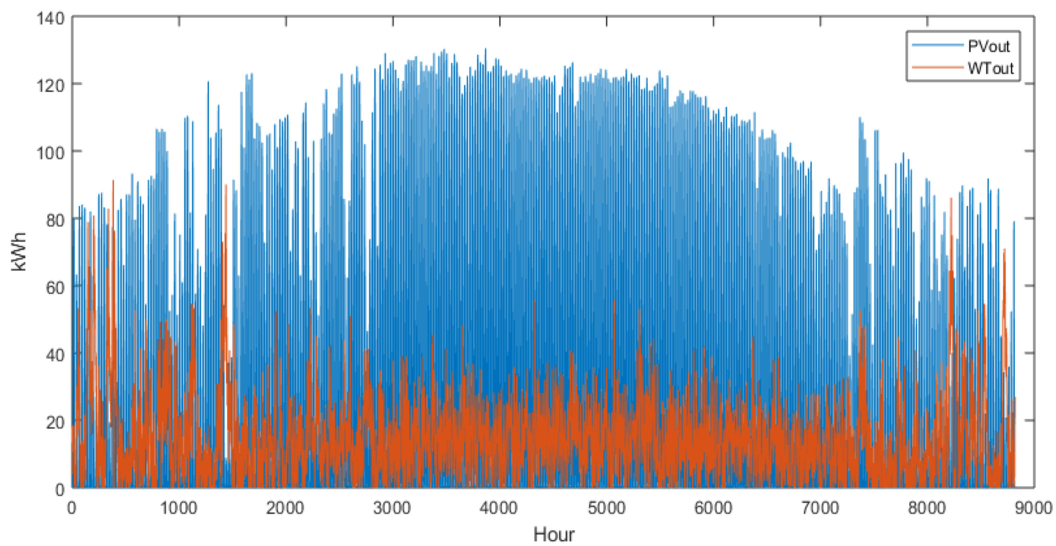


Figure 5:7 Hourly output of hybrid system

Table 5.7 illustrates results of hybrid PV-Wind energy system. The capacity of PV 158 kW and wind turbine 70 kW. The total energy generation of the PV and WT was about 409,325 kWh/y. The production of renewable energy covers 58.4 % of demand and the total energy generation of the HRES after 25 year is going to reach 10,233,125 kWh.

Table 5.6 PV-wind hybrid energy system with hourly

Type generator	Capacity (kW)	Output (kWh/y)	Output after 25 year
PV	158	277,888	6.9 GWh
WT	70	131,437	3.2 GWh
PV-WT	228	409,325	10.2 GWh

Table 5.8 shows a cost summary of HRES. The table presents the capital cost and the total OMC cost along 25 year. Salvage value and the total cost of the system after 25 year will cost US $ 409,259 which includes: the capital cost, OMC and RC cost in the case study of PPU along 25 years. The cost energy equals 0.043 $/kWh.

Table 5.7 Cost summary of HRES after 25 years

Type generator	Capital Cost ($)	OMC ($)	RC ($)	Salvage ($)	Total cost ($)	Energy cost ($/kWh)
PV-WT	245,994	97,992	97,992	32,719	409,259	0.043

The Figure 5.8 shows the cash flow of the HRES shows the cash flow for system along 25 years as shown in the graph. The System provides the highest lifetime savings nearly US $ 5,320,000. The payback of investment over 4 year and 2 months.

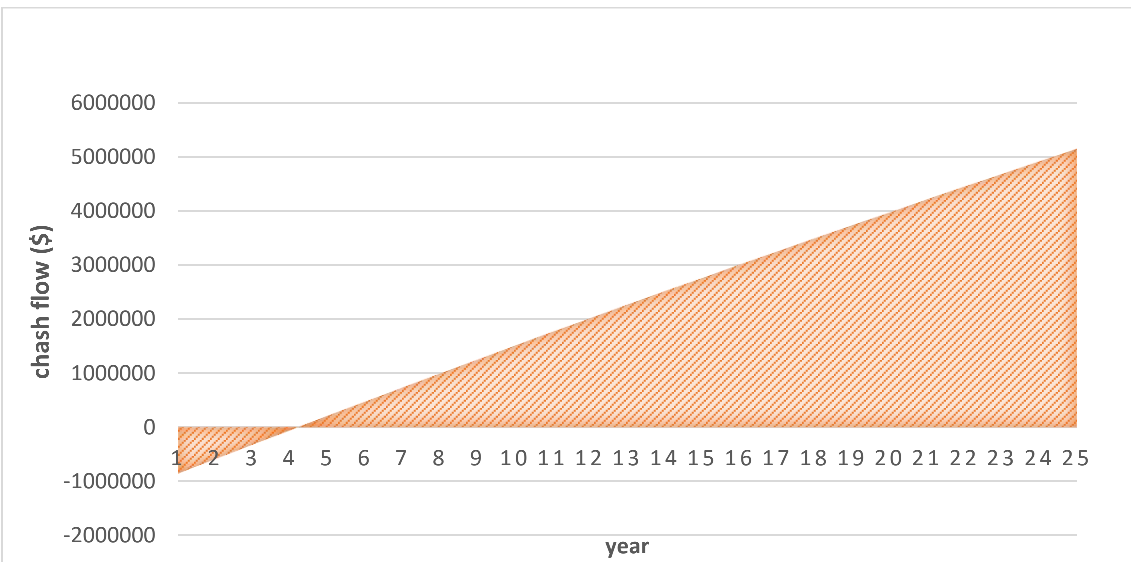


Figure 5.8 Cash flow of the HRES.

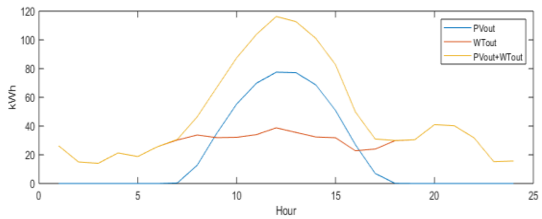
Table 5.8 presents the results of optimization of PV- Wind hybrid energy system for one day in the middle of each month and the results of optimization by using hourly solar radiation and wind speed. The information presents energy generation output PV and WT generation system for one day in the middle of the month. In general, it is clear the highest value of energy generation occurs in summer months and lowest cost of energy. On the contrary, in winter season occurs the lowest energy generation and highest cost of energy.

While performing optimization illustrates highest total output at 15-June where the total energy generated during that day equals 1,475.8 kWh/day and lowest cost of energy reaches 0.032 $/kWh. The 15th of -November seems to have the lowest energy value as the total energy generated during that day equals 519.8 kWh/day and highest cost energy reach 0.071$/kWh. The total energy in January, April, August, September and December is relatively similar about 1100 kWh/day and the energy cost around 0.04$/kWh. The total energy in February, June, May, June and July and is relatively similar about 1400 kWh/day and the energy cost is around 0.035 $/kWh.

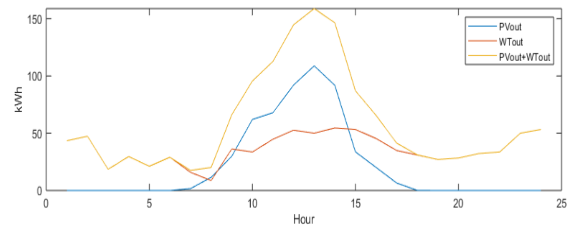
Table 5.8 the result of optimization for one day from each month with use max wind speed each hour

Month	Output PV (kWh/day)	Output WT (kWh/day)	Total (kWh/day)	Energy cost ($/kWh)
January	481.7	672.4	1154.1	0.04
February	526.2	874.6	1171.6	0.03
March	488.4	266.0	819.1	0.05
April	583.1	462.9	1043.53	0.045
May	1,039.7	269.5	1304.72	0.037
June	1030.2	445.6	1475.83	0.032
July	919.1	476.0	1394.5	0.034
August	995.1	113.2	1072.83	0.046
September	794.1	301.43	1095.53	0.044
October	349.4	457.2	806.6	0.067
November	378.3	141.5	519.8	0.07
December	553.9	598	1151.9	0.04

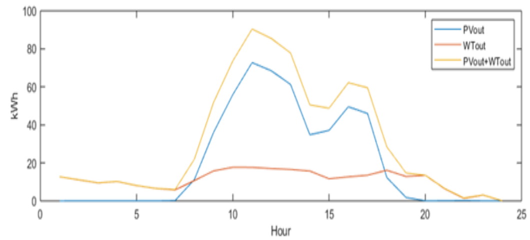
The Figure 5.9 shows the output of HRES generation for one day from the middle of each month. The figures present an output of the PV and WT of all hour during the day. One hand, solar energy starting from sunrise the value comes up to reached highest value at the midday then goes down to reach the lowest at sunset. On the other hand, the wind energy is fluctuating hour to next hour during the day, depending on wind speed. The total output of energy for PV-wind hybrid energy generation appears to generate energy along the day. The total energy reaches the highest in February about 150 kW/h at midday. From April to September, the total energy reaches about 140 kWh at middy and the total energy reaches the lowest in March and November about 100kW/h at midday.



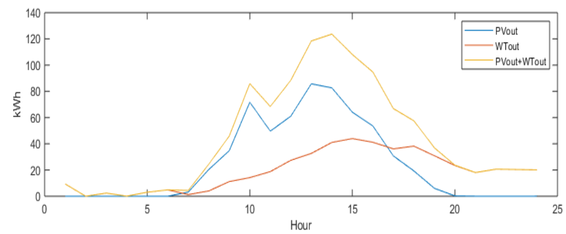
15-January



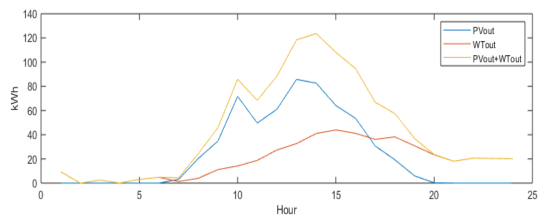
15-February



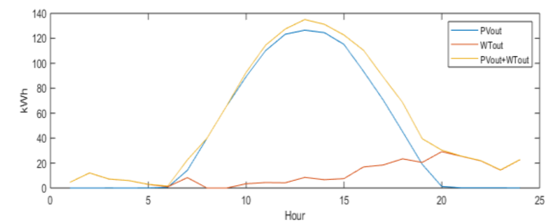
15-March



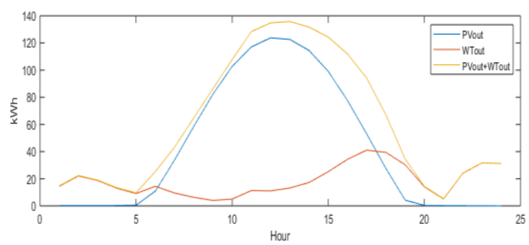
15-April



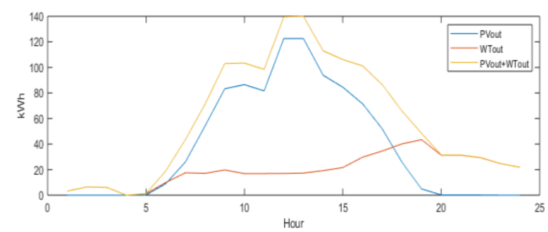
15-May



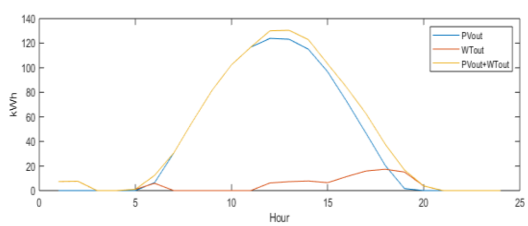
15-June



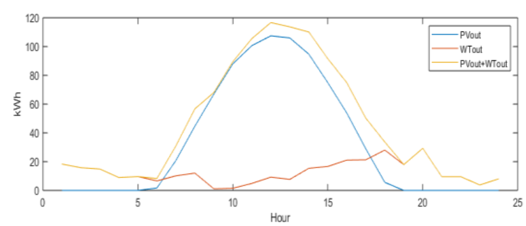
15-July



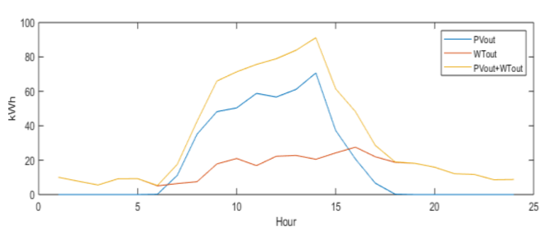
15-August



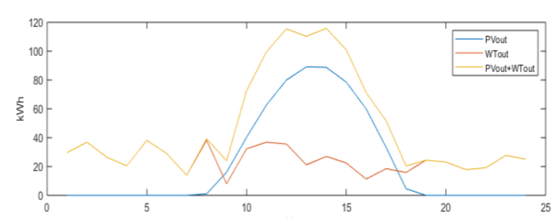
15-September



15-October



15-November



15-December

Figure 5. 9 HRES output of each month

Table 5.9 shows the result of HRES optimization for each month. The table presents the output of PV and WT generation system and total energy generation in kWh for each month along with the cost of energy. Obviously, the output energy of optimization of HRES seems to be higher in summer than winter.

Performing optimization shows that the highest point is in June where the total energy generated during that days equals 42,766 kWh/day and the lowest energy value seems to be in November where the total energy generated during that day equals 21,638 kWh/month.

The total amount of energy in January and Mach is relatively similar about 29000 kWh/day and the cost of energy around 0.05$/kWh.

The total amount of energy in February, October is relatively similar about 25,700 kWh/day. It is also clear that the total amount energy in May, June, July, August and December is relatively similar about 42000 kWh/day and the energy cost around 0.035$/kWh. Where the Appendix F shows the output of PV-wind generation each month.

Table 5.9 The result of HRES optimization for each month

Month	Output PV (kWh\month)	Output WT (kWh/month)	HRES (kWh/month)	Energy cost ($/kWh)
January	13,899	15,322	29,221	0.049
February	13,704	12,088	25,792	0.056
March	20,663	8,874	29,537	0.05
April	20,775	11,257	32,032	0.045
May	30,739	10,863	41,602	0.035
June	31,738	11,028	42,766	0.034
July	30,791	11,763	42,554	0.035
August	28,938	10,881	39,819	0.036
September	23,389	10,252	33,641	0.043
October	17,005	7,893	24,898	0.051
November	21,638	7,477	29,115	0.05
December	24,609	13,739	38,348	0.038
Total	277,888	131,437	409,325	0.043

Figure 5.10 illustrates the results of HRES optimization for each month. The figure presents the output of PV and WT generation system and total energy generation in kWh for each month. Overall, it clears the output of PV is highest compare of output of WT in summer.

While the performing optimization illustrates the highest at the June where the total energy generated during that days is equal 42,766 kWh/month, the lowest energy value at the November where the total energy generated during that day is equal 21,638 kWh/month. The total energy in January and Mach are relatively similar about 29000 kWh/month. The total energy in February, October are relatively similar about 25,700 kWh/month.

The total energy in May, June, July, August, December are relatively similar about 42,000 kWh/month.

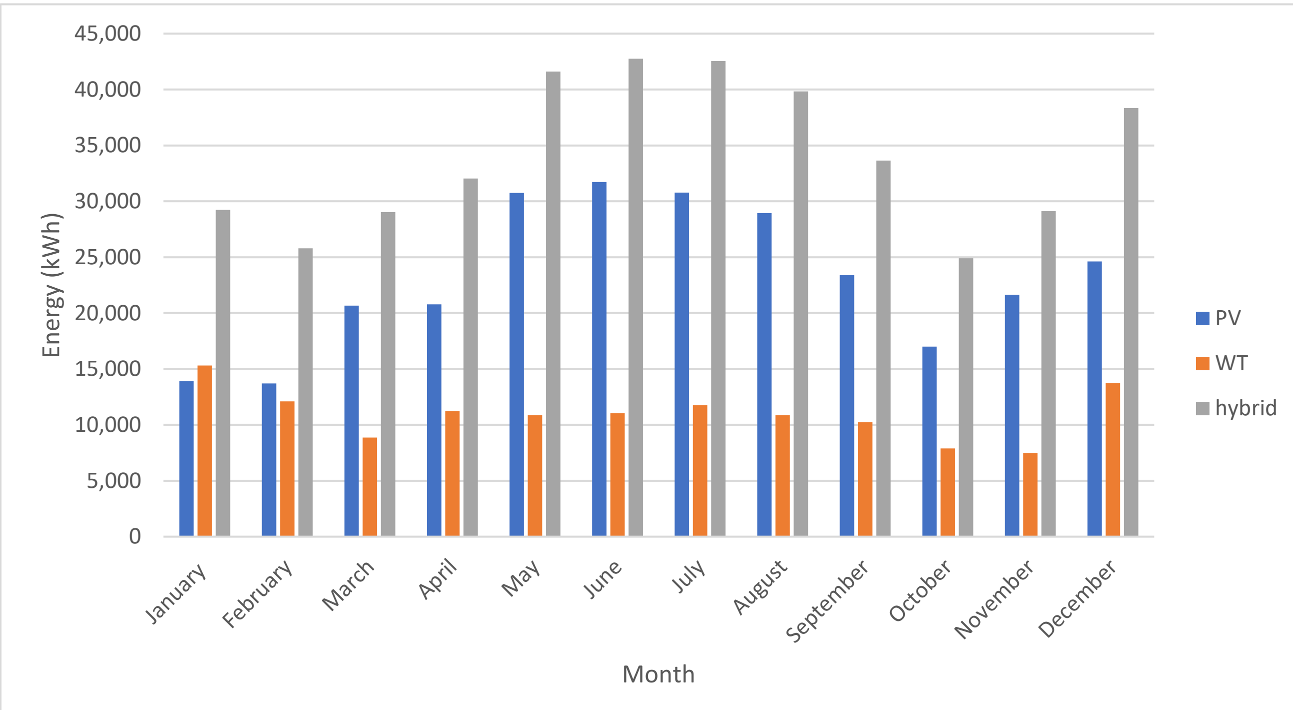


Figure 5.10 Result of HRES optimization for each month.

Based on daily load in Table 4.6, for four days in March , put this data in the software , it output s the simulation result of HRES that constitutes of 158 kW PV, 70 kW wind turbine . Table 5.10 shows the result of optimization for days in march with load using hourly solar radiation and wind speed. The table presents four days in march 5,6,7 and 9 of march and present the total output of PV and WT energy generation for each day.

Performing optimization shows that the highest value seems to be on the 9th of March where the total energy generated during that day is equal 975.13 kWh/day. It covers 50 % of demand, the lowest value seems to be on the 5th -March as the total energy reaches 396.6 kWh/day which can cover 16% of demand on that day.

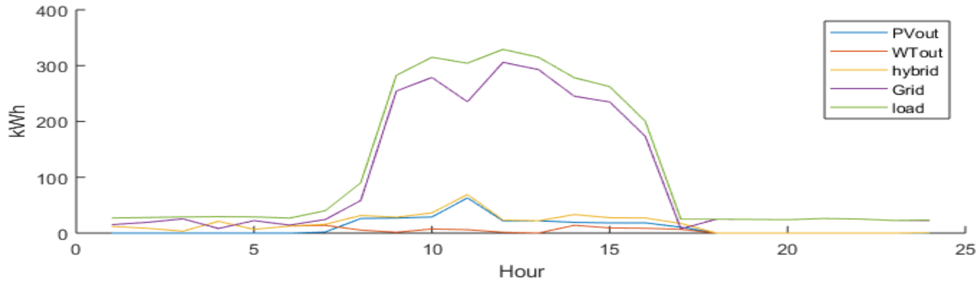
Table 5.10 the result of optimization for days in march with load with use hourly solar ration and wind speed

Day	Load (kWh/day)	Output PV (kWh/day)	Output WT (kWh/day)	Total (kWh/day)	% / load
5-March	2782.72	257	139.54	396.6	16 %
6-March	2786.24	737.5	189	926.6	33.2%
7-March	2249.17	605.54	306.23	911.78	40.5%
9-March	1948	863.16	111.97	975.13	50%

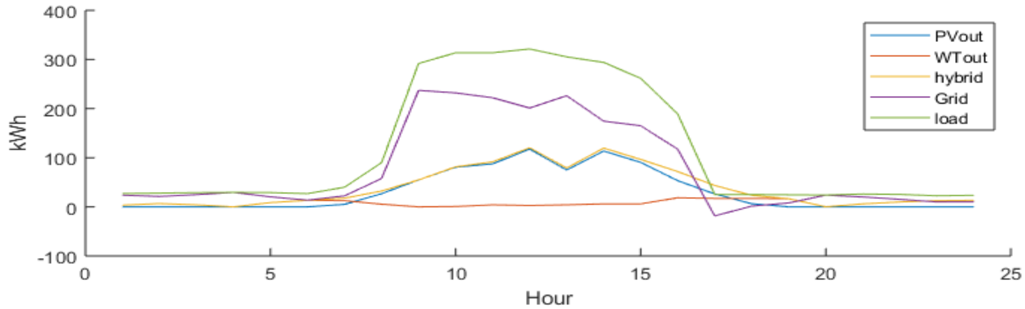
The Figure 5.11 illustrates the result of optimization for 4 days in March with the daily load. As shown in figures below, these days have different load hour to hour. The load in midday seems to be higher than in morning and evening. The optimization formulated in 5, 6, 7th of march was is HRES. However, in the 9th of march, the optimization was formulated as a single PV system depending on wither data. In addition, the Figure shows the grid decreases was compensated for the production of PV and the production of WT.

The main system components are shown in Figure 5.12, which include PV arrays, wind turbines, DC-AC inverter, AC-AC converter, DC and AC isolation system, meters, the grid and considered load.

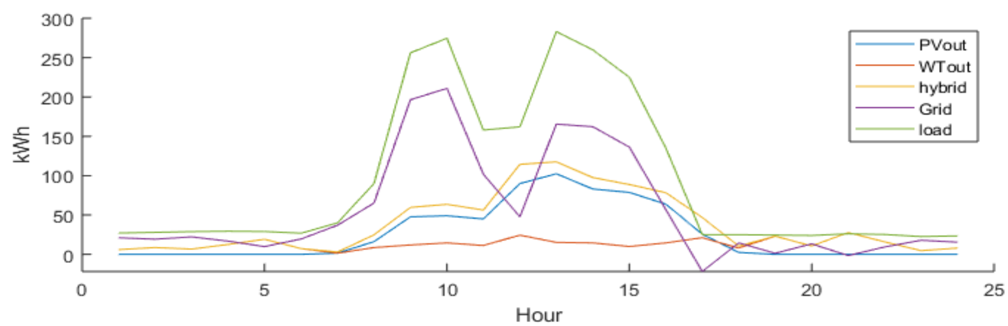
The confirmation of hybrid PV- wind include 14 WT of rated power 5 kW and 14 AC-AC converter, and 31 string of PV each string include 16 PV module in series, the rated power of PV module used 320 W, and 8 DC-AC inverter.



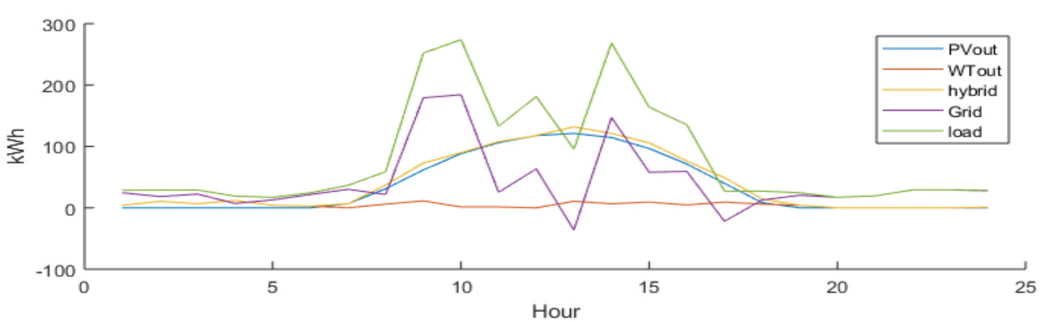
5 March



6 March



7 March



9 March

Figure 5.11 PV-wind hybrid system output of days in march with load

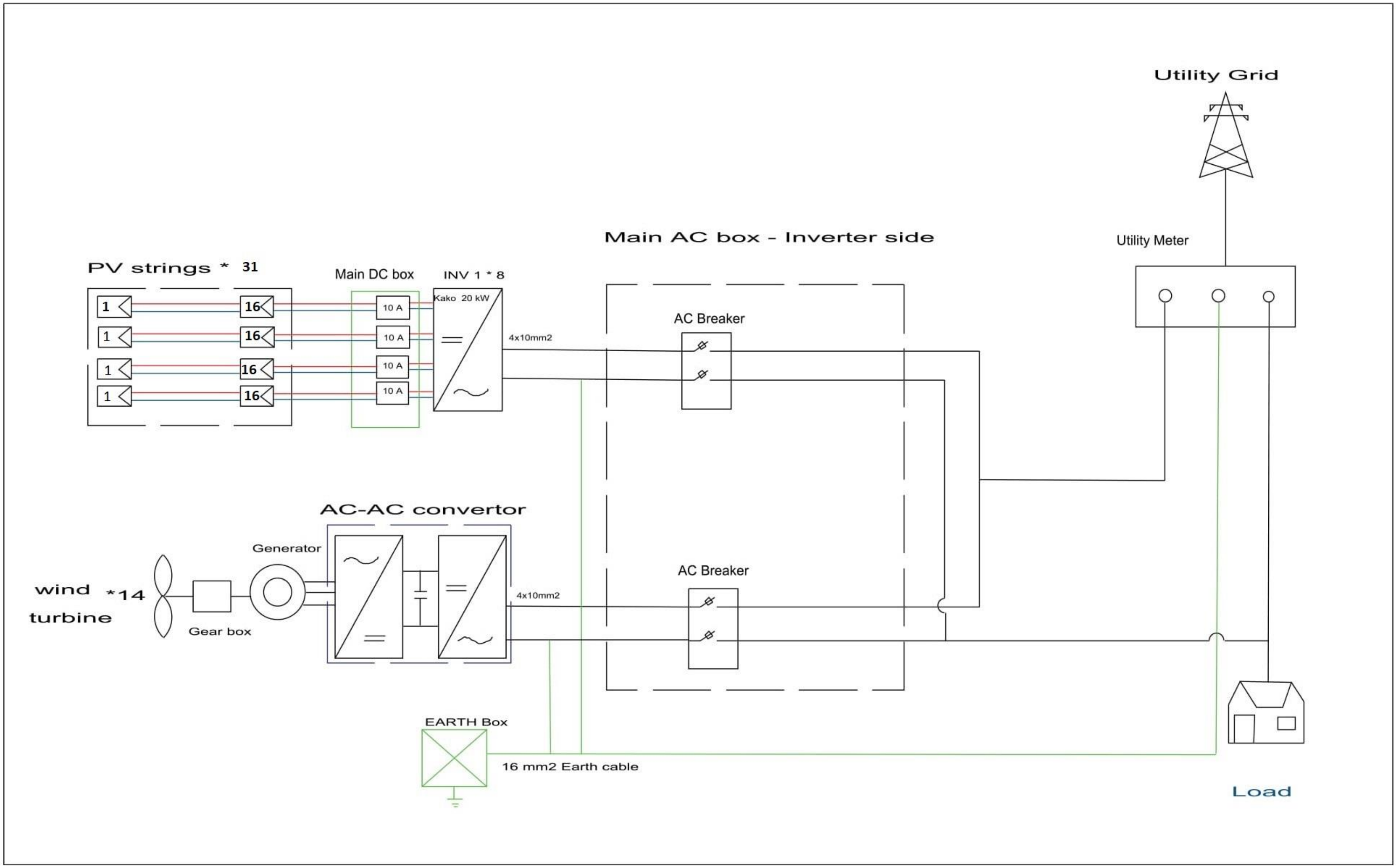


Figure 5.10 Schismatic diagram of PV-WTG hybrid energy system

Chapter 6

Conclusion Remarks

6.1 Summary

In this thesis, a hybrid renewable energy system is designed to supply electricity for PPU in Hebron, Firstly, the load is specified and statistically stated on yearly, monthly and daily basis. Secondly, the solar and wind speed data is collected. Thirdly, the structure of hybrid renewable power is built and the parameter and price of component parts are discussed. Finally, the optimization method introduced.

A sizing of hybrid renewable energy system (HRES) which consist of solar and wind energy was studied by employing a GA based optimization technique to achieve optimal sizing. In addition to the modeling of system component and optimal energy, the sizing technique has been put to the test by considering weather data, technical data of component and economic detail. In this work, the optimization problem was formulated to achieve a minimum total cost for the system components and to ensure that the load is served effectively. The results showed that the GA converges very well and the proposed technique is feasible for sizing either of PV- wind hybrid energy system. In addition, the proposed technique is adjusted by radiation, wind speed, load demand, variable area, and initial cost of each component participating in the system are changed. The results showed that using the PV-wind hybrid energy systems is the most economic and reliable solution for PPU.

The scenarios discussed in this thesis considered important design perspectives which can highly affect the cost of energy obtained from renewable energy such as initial cost operating and maintenance cost, replacement cost and salvage value.

Through the simulation process, installation of 230 kW on-grid PV system the result showed the output covered 53 % of demand with the payback of investment during 4 years and 4 months. And installation of 70 kW on-grid WT system the result showed the output covered 18.5 % of demand with the payback of investment during 5 years.

The result of the installation of the PV-Wind Hybrid energy system contains of 70 kW wind turbines and 158 kW solar PV was identified as economically most feasible design to supply average 58 % of load connected to the grid where payback period of the design is 4 years. The results prove that a hybrid PV/wind energy system is a more reliable and most efficient energy conversion system.

6.2 Recommendations

In this thesis, it is obvious that the HRES can be good way to supply the electricity and reduced the cost of electric energy. In addition, this system helps to control the global warming and reduce the pollutant emission. The optimal design of PV-wind energy conversion system can further be remodeled with a grid for the domestic. The optimal design of PV- wind energy conversion system can further be remodeled by adding other types of renewable sources in order to make HRES more reliable. There are companies specializing in the manufacture of high-capacity wind turbines operating in areas where wind speeds are low, can be redesigned for a PV- wind energy conversion system plant to supply electricity to remote areas.

Reference

[1] Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A. and Kim, K.H., 2018. Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, *82*, pp.894-900.

[2] REN 21, Renewable 2013 global states report, 2013, < https://www.ren21.net/wp-content/uploads/2019/05/GSR2013_Full-Report_English.pdf >.

[3] REN 21, Renewable 2018 global states report, 2018, < https://www.ren21.net/wp-content/uploads/2019/08/Full-Report-2018.pdf >

[4] Hamed, T.A., Flamm, H. and Azraq, M., 2012. Renewable energy in the Palestinian Territories: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *16*(1), pp.1082-1088.

[5] Juaidi, A., Montoya, F.G., Ibrik, I.H. and Manzano-Agugliaro, F., 2016. An overview of renewable energy potential in Palestine. *Renewable and Sustainable Energy Reviews*, *65*, pp.943-960.

[6] Kitaneh, R., Alsamamra, H. and Aljunaidi, A., 2012. Modeling of wind energy in some areas of Palestine. *Energy conversion and Management*, *62*, pp.64-69.

[7] Hamed, T.A., Flamm, H. and Azraq, M., 2012. Renewable energy in the Palestinian Territories: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *16*(1), pp.1082-1088.

[8] Deshmukh, M.K. and Deshmukh, S.S., 2008. Modeling of hybrid renewable energy systems. *Renewable and sustainable energy reviews*, *12*(1), pp.235-249.

[9] Ellabban, O., Abu-Rub, H. and Blaabjerg, F., 2014. Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, *39*, pp.748-764.

[10] Jadeja, K., 2012. *Major technical issues with increased PV penetration on the existing electrical grid* (Doctoral dissertation, Murdoch University).

[11] Mahmoud, M.M. and Ibrik, I.H., 2006. Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid. *Renewable and sustainable energy reviews*, *10*(2), pp.128-138.

[12] González, P., Romero-Cadaval, E., González, E. and Guerrero, M.A., 2011, February. Impact of grid connected photovoltaic system in the power quality of a distribution network. In *Doctoral Conference on Computing, Electrical and Industrial Systems* (pp. 466-473). Springer, Berlin, Heidelberg.

[13] REN 21, Renewable 2013 global states report, 2013, < https://www.ren21.net/wp-content/uploads/2019/05/GSR2013_Full-Report_English.pdf >

[14] Montoya, F.G., Manzano-Agugliaro, F., López-Márquez, S., Hernández-Escobedo, Q. and Gil, C., 2014. Wind turbine selection for wind farm layout using multi-objective evolutionary algorithms. *Expert Systems with Applications*, *41*(15), pp.6585-6595.

[15] Yaseen, B.T., 2009, December. Renewable energy applications in Palestine. In *Proceedings of the DISTRES Conference*.

[16] Kitaneh, R., Alsamamra, H. and Aljunaidi, A., 2012. Modeling of wind energy in some areas of Palestine. *Energy conversion and Management*, *62*, pp.64-69.

[17] De Meij, A., Vinuesa, J.F., Maupas, V., Waddle, J., Price, I., Yaseen, B. and Ismail, A., 2016. Wind energy resource mapping of Palestine. *Renewable and sustainable energy reviews*, *56*, pp.551-562.

[18] Bajpai, P. and Dash, V., 2012. Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Renewable and Sustainable Energy Reviews*, *16*(5), pp.2926-2939.

[19] Ekren, B.Y. and Ekren, O., 2009. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. *Applied Energy*, *86*(9), pp.1387-1394.

[20] Zahraee, S.M., Assadi, M.K. and Saidur, R., 2016. Application of artificial intelligence methods for hybrid energy system optimization. *Renewable and Sustainable Energy Reviews*, *66*, pp.617-630.

[21] Chong, W.T., Naghavi, M.S., Poh, S.C., Mahlia, T.M.I. and Pan, K.C., 2011. Techno-economic analysis of a wind–solar hybrid renewable energy system with rainwater collection feature for urban high-rise application. *Applied Energy*, *88*(11), pp.4067-4077.

[22] Deshmukh, M.K. and Deshmukh, S.S., 2008. Modeling of hybrid renewable energy systems. *Renewable and sustainable energy reviews*, *12*(1), pp.235-249.

[23] Karki, R. and Billinton, R., 2004. Cost-effective wind energy utilization for reliable power supply. *IEEE Transactions on Energy Conversion*, *19*(2), pp.435-440.

[24] Belmili, H., Haddadi, M., Bacha, S., Almi, M.F. and Bendib, B., 2014. Sizing stand-alone photovoltaic–wind hybrid system: Techno-economic analysis and optimization. *Renewable and Sustainable Energy Reviews*, *30*, pp.821-832.

[25] Ribeiro, E.F.F., Cardoso, A.M. and Boccaletti, C., 2009, April. Uninterruptible energy production in standalone power systems for telecommunications. In *International conference on renewable energies and power quality, Valencia*.

[26] Kabalci, E., 2013. Design and analysis of a hybrid renewable energy plant with solar and wind power. *Energy Conversion and Management*, *72*, pp.51-59.

[27] Ismail, M.S., Moghavvemi, M., Mahlia, T.M.I., Muttaqi, K.M. and Moghavvemi, S., 2015. Effective utilization of excess energy in standalone hybrid renewable energy systems for improving comfort ability and reducing cost of energy: A review and analysis. *Renewable and Sustainable Energy Reviews*, *42*, pp.726-734.

[28] Saib, S., Gherbi, A., Kaabeche, A. and Bayindir, R., 2018. Techno-Economic Optimization of a Grid-Connected Hybrid Energy System Considering Voltage Fluctuation.

[29] Shahsavar, A., Talebizadeh, P. and Tabaei, H., 2013. Optimization with genetic algorithm of a PV/T air collector with natural air flow and a case study. *Journal of Renewable and Sustainable Energy*, *5*(2), p.023118.

[30] Sanajaoba, S. and Fernandez, E., 2016. Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System. *Renewable energy*, *96*, pp.1-10.

[31] Ramli, M.A., Bouchekara, H.R.E.H. and Alghamdi, A.S., 2018. Optimal sizing of PV/wind/diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm. *Renewable energy*, *121*, pp.400-411.

[32] Nag, A.K. and Sarkar, S., 2018. Modeling of hybrid energy system for futuristic energy demand of an Indian rural area and their optimal and sensitivity analysis. *Renewable energy*, *118*, pp.477-488.

[33] Ahmad, J., Imran, M., Khalid, A., Iqbal, W., Ashraf, S.R., Adnan, M., Ali, S.F. and Khokhar, K.S., 2018. Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar. *Energy*, *148*, pp.208-234.

[34] Arul, P.G., Ramachandaramurthy, V.K. and Rajkumar, R.K., 2015. Control strategies for a hybrid renewable energy system: A review. *Renewable and sustainable energy reviews*, *42*, pp.597-608.

[35] Ismail, M.S., Moghavvemi, M. and Mahlia, T.M.I., 2013. Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate. *Energy conversion and management*, *69*, pp.163-173.

[36] Yang, H., Zhou, W., Lu, L. and Fang, Z., 2008. Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar energy*, *82*(4), pp.354-367.

[37] Fadaee, M. and Radzi, M.A.M., 2012. Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: A review. *Renewable and sustainable energy reviews*, *16*(5), pp.3364-3369.

[38] Ismail, M.S., Moghavvemi, M. and Mahlia, T.M.I., 2013. Analysis and evaluation of various aspects of solar radiation in the Palestinian territories. *Energy conversion and management*, *73*, pp.57-68.

[39] Potirakis A. Kalaitzakis K. Koutroulis E, Kolokotsa D., 2006. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Sol Energy.

[40] Koutroulis, E. and Kolokotsa, D., 2010. Design optimization of desalination systems power-supplied by PV and W/G energy sources. *Desalination*, *258*(1-3), pp.171-181.

[41] Yang, H., Zhou, W., Lu, L. and Fang, Z., 2008. Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar energy*, *82*(4), pp.354-367.

[42] Yang, H., Wei, Z. and Chengzhi, L., 2009. Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. *Applied Energy*, *86*(2), pp.163-169.

[43] Bernal-Agustín, J.L. and Dufo-Lopez, R., 2009. Simulation and optimization of stand-alone hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, *13*(8), pp.2111-2118.

[44] Bajpai, P. and Dash, V., 2012. Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Renewable and Sustainable Energy Reviews*, *16*(5), pp.2926-2939.

[45] Paiva, J.E. and Carvalho, A.S., 2013. Controllable hybrid power system based on renewable energy sources for modern electrical grids. *Renewable energy*, *53*, pp.271-279.

[46] Moradi, M.H., Tousi, S.R., Nemati, M., Basir, N.S. and Shalavi, N., 2013. A robust hybrid method for maximum power point tracking in photovoltaic systems. *Solar Energy*, *94*, pp.266-276.

[47] Hong, C.M., Ou, T.C. and Lu, K.H., 2013. Development of intelligent MPPT (maximum power point tracking) control for a grid-connected hybrid power generation system. *Energy*, *50*, pp.270-279.

[48] Iverson, Z., Achuthan, A., Marzocca, P. and Aidun, D., 2013. Optimal design of hybrid renewable energy systems (HRES) using hydrogen storage technology for data center applications. *Renewable energy*, *52*, pp.79-87.

[49] Al-Badi, A.H. and Bourdoucen, H., 2012. Feasibility analysis of renewable hybrid energy supply options for Masirah Island. *International Journal of Sustainable Engineering*, *5*(3), pp.244-251.

[50] Suresh, M. and Meenakumari, R., 2018. Optimal Planning of Solar PV/WTG/DG/Battery Connected Integrated Renewable Energy Systems for Residential Applications using Hybrid Optimization. *International Journal of Industrial Engineering*, *2*(1), pp.15-20.

[51] Hosseinalizadeh, R., Shakouri, H., Amalnick, M.S. and Taghipour, P., 2016. Economic sizing of a hybrid (PV–WT–FC) renewable energy system (HRES) for stand-alone usages by an optimization-simulation model: case study of Iran. *Renewable and Sustainable Energy Reviews*, *54*, pp.139-150.

[52] Diaf, S., Diaf, D., Belhamel, M., Haddadi, M. and Louche, A., 2007. A methodology for optimal sizing of autonomous hybrid PV/wind system. *Energy policy*, *35*(11), pp.5708-5718.

[53] Belmili, H., Haddadi, M., Bacha, S., Almi, M.F. and Bendib, B., 2014. Sizing stand-alone photovoltaic–wind hybrid system: Techno-economic analysis and optimization. *Renewable and Sustainable Energy Reviews*, *30*, pp.821-832.

[54] Zhou, W., Lou, C., Li, Z., Lu, L. and Yang, H., 2010. Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. *Applied energy*, *87*(2), pp.380-389.

[55] Ghenai, C., 2012. *Life Cycle Analysis of Wind Turbine*. INTECH Open Access Publisher.

[56] Hamed, T.A., Flamm, H. and Azraq, M., 2012. Renewable energy in the Palestinian Territories: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *16*(1), pp.1082-1088.

[57] Ismail, M.S., Moghavvemi, M. and Mahlia, T.M.I., 2013. Techno-economic analysis of an optimized photovoltaic and diesel generator hybrid power system for remote houses in a tropical climate. *Energy conversion and management*, *69*, pp.163-173.

[58] Ismail, M.S., Moghavvemi, M. and Mahlia, T.M.I., 2013. Analysis and evaluation of various aspects of solar radiation in the Palestinian territories. *Energy conversion and management*, *73*, pp.57-68.

[59] Kerekes, T., Koutroulis, E., Séra, D., Teodorescu, R. and Katsanevakis, M., 2012. An optimization method for designing large PV plants. *IEEE Journal of Photovoltaics*, *3*(2), pp.814-822.

[60] Eltamaly, A.M., Addoweesh, K.E., Bawah, U. and Mohamed, M.A., 2013. New software for hybrid renewable energy assessment for ten locations in Saudi Arabia. *Journal of Renewable and Sustainable Energy*, *5*(3), p.033126.

[61] Masters, G.M., 2013. *Renewable and efficient electric power systems*. John Wiley & Sons.

[62] Suzanne Rynne, AICP, Larry Flowers, Eric Lantz, Erica Heller, AICP, 2011, Planning for Wind Energy, American Planning Association.

[63] Bryce Alsten, Wind aid instituted, Redesiging the wind turbine tower assembly , 2016, < https://www.windaid.org/redesigning-the-wind-turbine-tower-assembly/?fbclid=IwAR0yqdSR XSfb88s8OQWatyPEokAnR6vXfSVzsrAK1Qg36hWkX5sI8shYfQ >

[64] Diaf, S., Belhamel, M., Haddadi, M. and Louche, A., 2008. Technical and economic assessment of hybrid photovoltaic/wind system with battery storage in Corsica island. *Energy policy*, *36*(2), pp.743-754.

[65] Erdinc, O. and Uzunoglu, M., 2012. Optimum design of hybrid renewable energy systems: Overview of different approaches. *Renewable and Sustainable Energy Reviews*, *16*(3), pp.1412-1425.

[66] Lazou, A.A. and Papatsoris, A.D., 2000. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. *Solar Energy Materials and Solar Cells*, *62*(4), pp.411-427.

[67] Kaabeche, A., Belhamel, M. and Ibtiouen, R., 2010. Optimal sizing method for stand-alone hybrid PV/wind power generation system. *Revue des Energies Renouvelables (SMEE'10) Bou Ismail Tipaza*, pp.205-213.

[68] Lazou, A.A. and Papatsoris, A.D., 2000. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. *Solar Energy Materials and Solar Cells*, *62*(4), pp.411-427.

[69] Lazou, A.A. and Papatsoris, A.D., 2000. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. *Solar Energy Materials and Solar Cells*, *62*(4), pp.411-427.

[70] Alibaba, 5 kw low rpm alternator wind generator turbine, 2017, < https://www.alibaba.com/product-detail/Hot-sale-5-kw-low rpm_60806248434.html?spm=%20a2700.7735675.2017115.37.ewHmWE&fbclid=IwAR3HrJ4k1e67WWs2z CEAV8-zVuDzMMipjJvET4ovZdJatTOEJQOsYbCVzso&s=p >.

[71] Lazou, A.A. and Papatsoris, A.D., 2000. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. *Solar Energy Materials and Solar Cells*, *62*(4), pp.411-427.

[72] Donn ,2015, < https://dddusmma.wordpress.com/2015/10/13/costs-and-dangers-of-wind-turbinefailures/ ?fbclid=IwAR1Lb3W9ZvTPpEZLKyVFCepzicR4e3RxBqyXRJQBNJnHeMsgr7jr4mOIh6Y >.

[73] Kuitche, J.M., 2014. *A statistical approach to solar photovoltaic module lifetime prediction*. Arizona State University.

[74] Lazou, A.A. and Papatsoris, A.D., 2000. The economics of photovoltaic stand-alone residential households: a case study for various European and Mediterranean locations. *Solar Energy Materials and Solar Cells*, *62*(4), pp.411-427.

[75] Naseem sultan, 2018, Electric bill report, Department of finance of PPU". In: (2017-2018).

[76] Masters, G.M., 2013. *Renewable and efficient electric power systems*. John Wiley & Sons.

[77] Goldberg, D.E., 1989. Genetic Algorithms in Search. Optimization and Machine Learning. Addism1—Wesley. *Reading, MA*.

[78] Larbes, C., Cheikh, S.A., Obeidi, T. and Zerguerras, A., 2009. Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system. *Renewable energy*, *34*(10), pp.2093-2100.

Appendix A: Weather data for the 15th of each month

January			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
5.476	4.63925	0.00003	7.7
3.763	3.329	0.00004	7.4575
3.622	3.323	0.00003	7.0615
4.722	4.24225	0.00004	6.82225
4.343	4.25325	0.00002	7.12675
5.39	4.5445	0.00003	6.839
6.097	5.221	0.01076	6.54825
6.622	6.17175	0.36074	7.5275
6.345	6.026	0.99385	8.9525
6.382	5.96375	1.55877	10.3175
6.66	6.18775	1.96376	10.76
7.39	6.9785	2.17367	11.3675
6.891	6.533	2.1608	11.735
6.417	6.15575	1.92013	12.145
6.335	6.0685	1.41977	12.2425
4.95	4.75725	0.75714	12.345
5.134	4.648	0.19671	11.1475
6.018	5.62425	0.00414	10.215
6.121	5.2035	0	9.675
7.72	6.6235	0.00001	9.245
7.61	7.278	0	9.0375
6.325	5.637	0	8.8875
3.797	3.75375	0	8.6475
3.867	3.78025	0	9.09

February			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
2.817	2.534	0.00154	10.0075
3.161	3.07275	0.00181	9.3725
4.115	3.616	0.00113	9.48
4.914	4.62175	0.00113	9.515
4.628	4.36525	0.00183	8.8825
4.728	4.3655	0.00124	8.475
4.714	4.47625	0.02293	8.0925
5.237	4.748	0.6378	8.3
5.758	5.0135	1.02372	8.29
6.37	5.9875	0.96643	8.0925
6.443	5.54025	1.72183	8.9725
7.48	7.017	2.08356	9.74
7.48	6.80125	1.87717	10.3675
6.907	6.562	1.841	10.66
6.883	6.4415	1.05229	10.48
5.703	5.38025	0.57091	9.935
5.589	5.1495	0.10998	8.8325
6.655	5.5145	0.00537	6.88525
5.437	5.00125	0.00083	6.22
7.12	6.2955	0.0011	6.18575
6.054	5.54325	0.00075	6.0625
5.533	5.0485	0.0012	6.2125
5.024	4.8485	0.00142	6.34025
5.12	4.795	0.0013	6.2515

March			
vmax(m/s)	v_avg	H(MJ)	T(^{o}C)
3.795	3.416	0.00053	9.51
3.338	3.16575	0.0022	8.6775
3.24	2.926	0.0019	8.5575
3.524	3.036	0.00143	8.425
2.962	2.70925	0.00121	7.9925
2.762	2.48075	0.0015	7.6575
2.638	2.36025	0.00572	7.34
3.422	3.11275	0.31908	7.745
4.325	3.8885	1.02261	8.5975
4.577	4.178	1.58227	9.355
4.661	4.17225	2.04954	10.325
4.654	4.07425	1.92243	11.1225
4.109	4.00475	1.71818	11.38
4.138	3.878	0.97756	11.0575
3.689	3.2585	1.04141	11.2975
4.231	3.40975	1.38898	11.5675
3.892	3.545	1.28803	11.8025
4.514	3.9395	0.34633	10.495
3.842	3.4415	0.05104	9.58
4.415	3.53625	0.00181	8.9125
2.944	2.46575	0.00335	8.34
1.973	1.6835	0.0059	8.0575
2.734	1.9475	0.00219	8.6325
1.557	0.74875	0.00215	8.31

April			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
2.907	2.06925	0.00026	23.55
1.101	0.863	0.00021	23.825
1.844	0.7125	0.00019	23.5325
1.49	1.29675	0.0003	23.755
1.945	1.26425	0.00019	22.8225
2.217	1.573	0.00033	23.19
1.672	1.38625	0.0841	22.8825
2.094	1.729	0.54646	22.845
3.179	2.25875	0.9394	20.9625
3.642	3.4365	1.97024	16.5925
4.34	4.11	1.37005	15.4925
5.655	4.99875	1.68698	15.2175
6.457	6.2615	2.37209	14.885
7.73	6.74325	2.28596	14.9375
8.18	7.6375	1.77655	14.4575
7.75	6.58275	1.48624	14.13
6.982	6.79275	0.85435	13.63
7.3	6.6755	0.53767	12.93
6.183	5.89025	0.16868	11.8425
5.047	4.11025	0.00677	10.8525
4.231	3.877	0.00088	11.4575
4.622	3.66475	0.00045	11.405
4.581	4.36575	0.00065	10.8825
4.541	3.823	0.00134	10.23

May			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
2.181	2.065	0.00042	16.085
3.322	2.31325	0.0007	15.3775
2.573	2.19975	0.00145	14.46
2.395	1.939	0.00065	14.605
1.922	1.61625	0.00204	13.6675
1.636	1.27725	0.0154	13.9475
2.751	1.6905	0.39329	14.9875
1.292	0.9735	1.09497	16.86
0.982	0.68875	1.78797	18.9375
2.002	1.6875	2.42668	19.3525
2.151	1.9775	2.98495	20.315
2.12	1.85625	3.32588	21.435
2.781	2.2735	3.40741	21.97
2.497	2.16075	3.3446	22.7725
2.628	2.43025	3.08496	23.375
4.057	3.498	2.51027	22.9525
4.291	4.059	1.9079	21.62
5.045	4.34225	1.22455	20.1725
4.606	4.00325	0.51935	18.8475
5.92	5.01075	0.03374	16.215
5.359	4.77975	0.00462	14.2575
4.8	3.97975	0.00427	13.59
3.667	3.2085	0.00454	12.6825
4.944	4.2475	0.00232	13.65

June			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
3.677	3.637	0.00855	17.665
4.842	4.5065	0.0081	16.9
4.333	4.10425	0.00694	15.3275
3.465	2.72375	0.00896	15.61
2.865	2.3145	0.0147	16.0725
3.683	2.8655	0.29682	16.7225
2.927	2.42	0.92041	18.3725
2.442	2.06675	1.58672	19.965
2.094	1.93025	2.22467	21.085
2.246	1.9185	2.76297	22.385
3.203	2.45175	3.13837	23.28
3.163	2.9785	3.30514	24.23
3.491	3.3005	3.26646	24.8775
4.104	3.75325	3.05228	24.71
5.322	5.1245	2.65263	23.675
6.705	5.83775	2.08253	23.055
7.74	6.9305	1.42747	22.1175
7.48	6.69625	0.74567	21.0175
6.099	4.8975	0.11532	19.3925
3.619	2.98775	0.00895	17.76
2.252	1.98325	0.00633	16.73
5.139	3.622	0.00414	17.2775
6.303	5.35975	0.0018	17.8025
6.242	5.65925	0.00103	17.3075

July			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
1.961	1.72775	0.00031	17.72
2.466	2.01725	0.00037	17.38
2.407	1.421	0.0003	17.105
1.375	1.2195	0.00021	17.2875
1.659	1.34475	0.00233	17.285
2.986	2.167	0.24652	17.205
4.151	3.9105	0.71058	17.6775
4.08	3.96425	1.47676	18.945
4.487	4.1815	2.25607	20.43
4.048	3.79775	2.33504	21.5075
4.056	3.92275	2.19777	21.965
4.063	3.6035	3.27874	23.715
4.115	3.8035	3.26758	24.7575
4.404	4.25675	2.50311	24.5725
4.777	4.30225	2.25598	24.3325
6.005	5.38625	1.91506	23.7425
6.746	6.2775	1.39541	22.9475
7.59	7.23375	0.69807	22.115
8.1	7.04075	0.13262	21.135
6.247	5.89525	0.00466	20.08
6.246	5.89525	0.0039	19.55
5.946	5.6255	0.00369	20.6475
5.254	5.173	0.00092	21.54
4.802	4.67375	0.0008	21.1125

August			
vmax(m/s)	v_avg	H(MJ)	T (^{o}C)
2.601	1.7015	0.00059	18.1625
2.644	1.29125	0.00082	17.5425
0.49	0.2275	0.00065	18.9875
1.306	0.754	0.00042	18.03
1.635	1.0395	0.00066	18.945
2.382	1.4545	0.17722	17.6275
0.856	0.38975	0.83461	19.5475
0.994	0.774	1.53676	21.01
1.372	1.06525	2.19323	23.295
1.323	1.0815	2.72239	25.33
1.467	1.3285	3.08556	27.0175
2.424	2.0165	3.26087	28.11
2.59	2.133	3.23323	28.9475
2.673	2.28275	3.00713	30.095
2.459	2.13875	2.52762	30.235
3.223	2.629	1.89625	29.5975
3.911	3.001	1.22399	28.91
4.124	3.63375	0.54083	26.4825
3.783	3.36425	0.04366	23.9075
2.052	1.2165	0.00059	22.3525
0.712	0.34425	0.00078	22.5275
0.415	0.2425	0.00056	22.385
0.886	0.4305	0.00038	22.485
1.067	0.93875	0.00034	24.25

September			
vmax	v_avg	H	T (^{o} C)
4.276	3.928	0.00006	17.9725
3.888	3.64575	0.00008	17.915
3.747	3.667	0.00005	17.6925
2.847	2.0905	0.00008	17.575
2.947	2.21375	0.00007	17.485
2.485	1.8435	0.04591	17.3575
3.028	2.06175	0.56781	17.915
3.317	1.9625	1.21278	19.71
1.653	1.42625	1.80892	21.0325
1.708	1.37125	2.36383	22.63
2.223	1.947	2.6943	23.56
2.887	2.402	2.86824	24.325
2.652	2.32875	2.81533	25.6975
3.822	3.0615	2.51676	25.6125
4.022	3.78825	1.99637	24.8125
4.692	4.1205	1.43737	24.065
4.723	4.5065	0.77693	23.0275
5.754	4.5085	0.15203	21.155
4.214	3.26075	0.00033	19.855
5.941	4.01575	0.00007	18.99
2.937	2.80125	0.00005	18.6425
2.938	2.279	0.00007	18.5825
2.06	1.759	0.00004	19.4725
2.707	2.53475	0.0001	18.88

October			
vmax	v_avg	H	T (^{o} C)
3.011	2.68825	0.00004	15.91
2.662	2.27825	0.00003	15.8575
2.328	1.81725	0.00002	15.83
2.874	2.55625	0.00007	15.675
2.892	2.372	0.00006	15.5575
2.252	2.1655	0.00541	15.5375
2.456	2.21975	0.30747	15.5975
2.619	2.4065	0.96529	16.52
4.192	3.542	1.32062	17.4
4.675	4.281	1.38017	17.505
4.043	3.74425	1.60771	18.1275
4.871	4.48375	1.54828	18.2725
4.947	4.67225	1.66432	19.18
4.604	4.425	1.91958	19.77
5.17	4.68275	1.01442	19.035
5.678	5.284	0.56478	18.1325
4.83	4.5505	0.1817	17.34
4.336	3.79325	0.00678	16.7075
4.247	3.81875	0.00004	16.215
3.903	3.77725	0.00005	15.9275
3.327	2.9655	0.00003	15.52
3.262	3.101	0.00007	15.6825
2.79	2.58175	0.00007	15.7475
2.817	2.4715	0.00008	15.5925

November			
vmax	v_avg	H	T (º C)
2.623	2.32125	0.00003	12.1025
3.651	3.3875	0.00001	11.83
3.012	2.89325	0.00002	11.5
3.924	3.512	0.00008	11.505
4.039	3.91275	0.00004	11.3875
3.323	2.9515	0.00017	10.87
2.832	2.383	0.06989	10.73
3.474	2.821	0.23746	10.99
3.674	3.50425	0.9682	11.7375
3.842	3.46075	1.35232	13.2
3.906	3.734	1.13603	13.6875
3.45	2.61	0.40598	12.6975
3.182	2.73975	0.49114	12.295
3.709	2.806	0.60981	12.65
2.736	2.29575	0.3122	12.6475
2.53	2.2765	0.21173	12.59
1.554	1.33125	0.04853	12.5125
1.948	1.36275	0.0001	12.255
1.341	1.1065	0.00001	11.975
3.036	2.63625	0.00003	11.905
4.248	3.387	0.00003	11.835
3.806	3.245	0.00003	11.7875
3.573	3.12325	0.00004	11.63
3.36	2.782	0.00004	11.4175

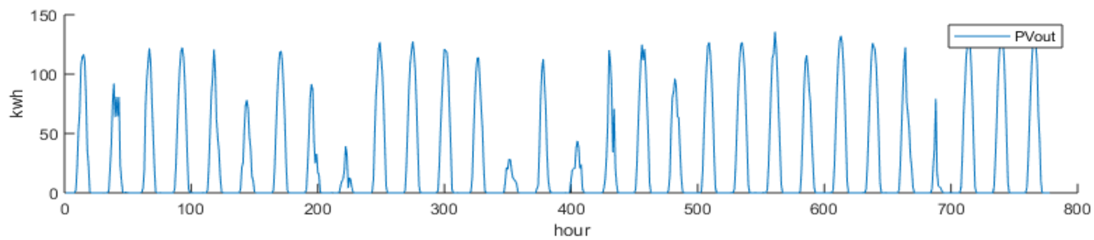
December			
vmax	v_avg	H	T (º C)
2.112	1.504	0	7.8375
1.998	1.52625	0	7.27925
1.866	1.74	0	7.655
2.948	2.683	0	7.5925
2.392	2.1085	0	7.4275
2.27	2.12675	0.00678	7.078
2.008	1.75825	0.33866	7.575
1.877	1.70425	0.62461	8.68
3.697	3.18275	1.11927	9.41
2.028	1.62325	1.64743	11.735
2.402	1.8505	1.63212	12.96
3.31	2.23975	1.21426	12.3425
2.533	1.92725	0.73688	12.005
2.984	1.903	0.51838	11.25
4.452	3.73775	0.41538	11.6325
2.835	2.51875	0.06648	10.515
1.806	1.52	0.00012	9.635
1.144	0.64725	0.00004	9.1875
1.386	1.20975	0.00001	8.8775
2.097	1.97175	0	8.88
2.163	1.93	0.00001	9.195
2.182	1.5665	0.00001	8.99
3.573	3.12325	0.00004	11.63
3.36	2.782	0.00004	11.4175

Appendix B: Load profile

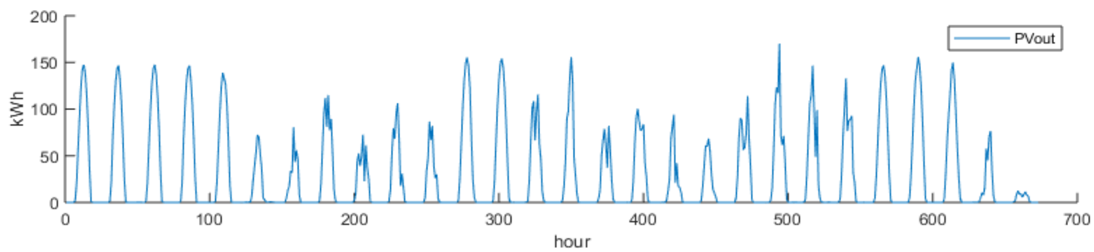
Daily load

Hour	5-March Load kWh	6-March Load kWh	7-March Load kWh	9-March Load kWh
0	27.0955	27.0955	27.0955	28.59
1	27.938	27.938	27.938	29
2	28.894	28.894	28.894	29
3	29.387	29.387	29.387	19
4	29.0185	29.0185	29.0185	17
5	26.8865	26.8865	26.8865	24.4
6	40	40	40	36.56
7	90	90	90	58.859
8	282.68	292.072	256.108	252.071
9	315	313.542	274.587	273.924
10	304.324	313.744	158.012	132.898
11	329.183	321.473	162.015	181.223
12	314.971	305.358	283.093	95.65
13	278.461	294.085	259.821	268.285
14	262.455	261.736	225.019	163.864
15	200.483	189.074	135.354	135.354
16	25	25	25	27.201
17	25	25	25	27.201
18	24.493	24.493	24.493	24.461
19	23.981	23.981	23.981	17.081
20	26.137	26.137	26.137	19.371
21	25.258	25.258	25.258	29.097
22	22.607	22.607	22.607	29.317
23	23.463	23.463	23.463	28.595
Total	2782.72	2786.24	2249.17	1948

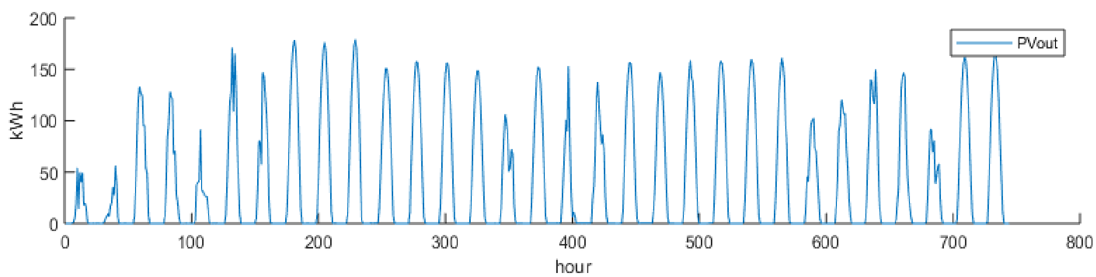
Appendix C: PV generation output for each month



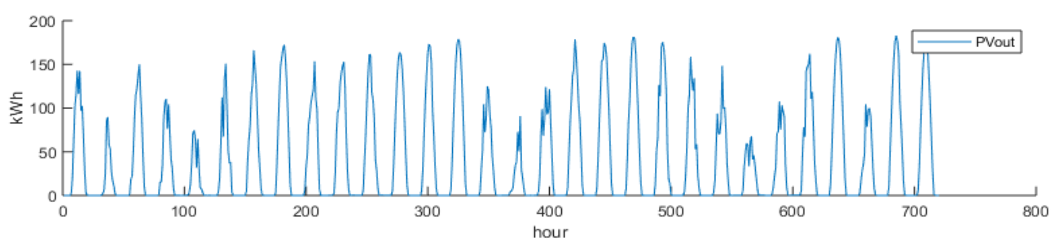
January



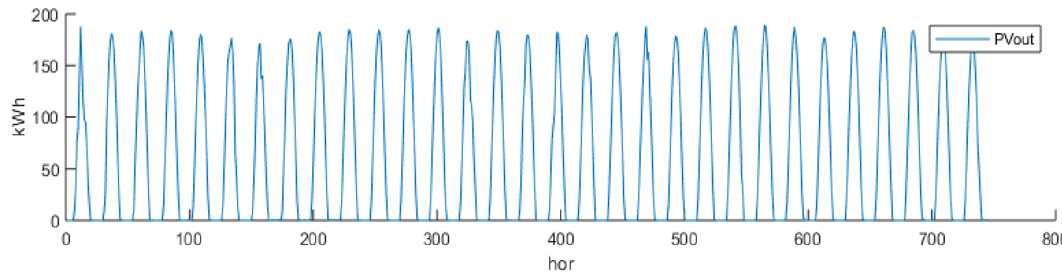
February



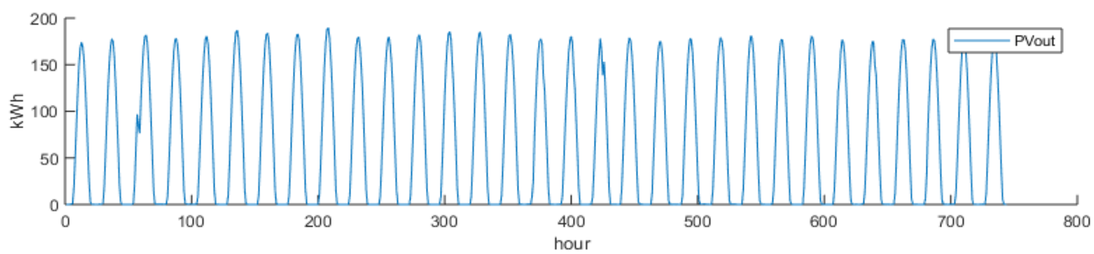
March



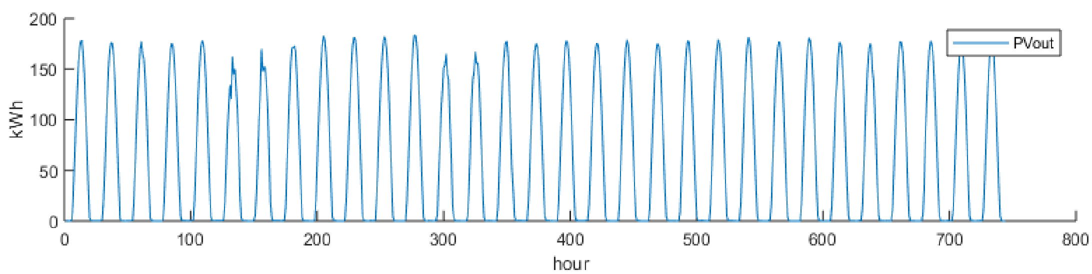
April



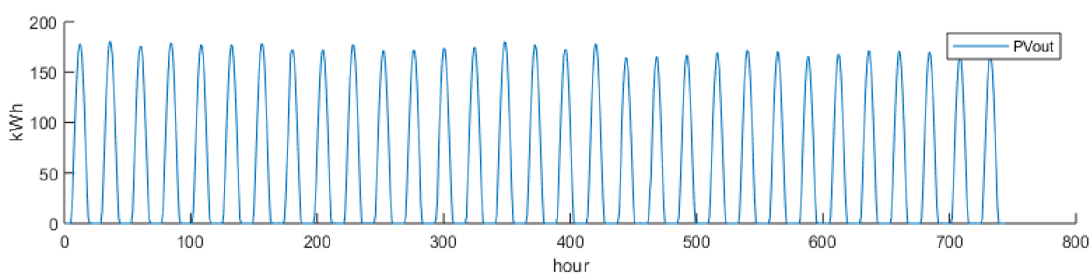
May



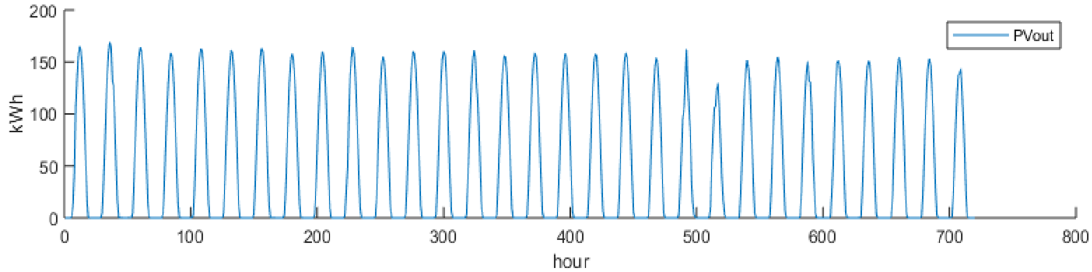
June



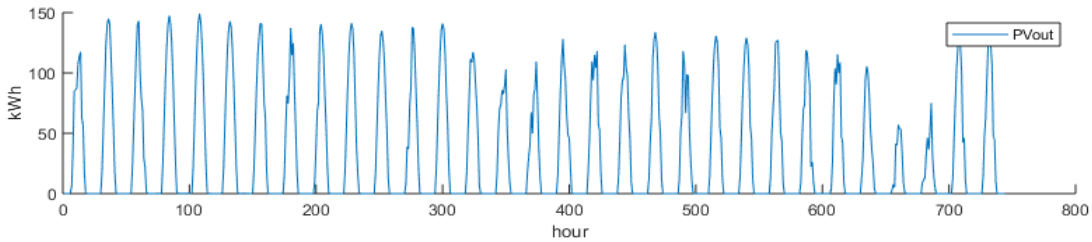
July



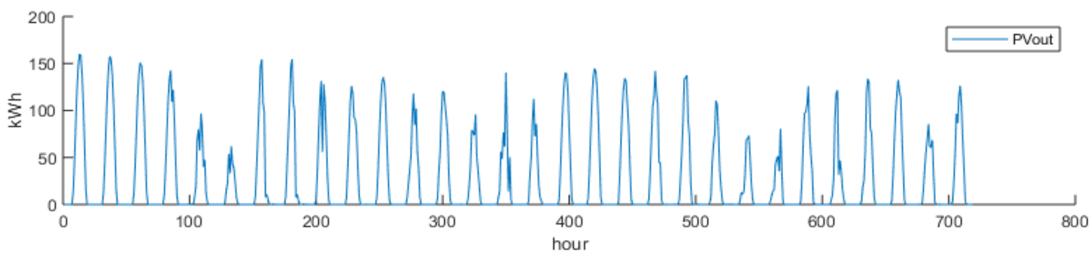
August



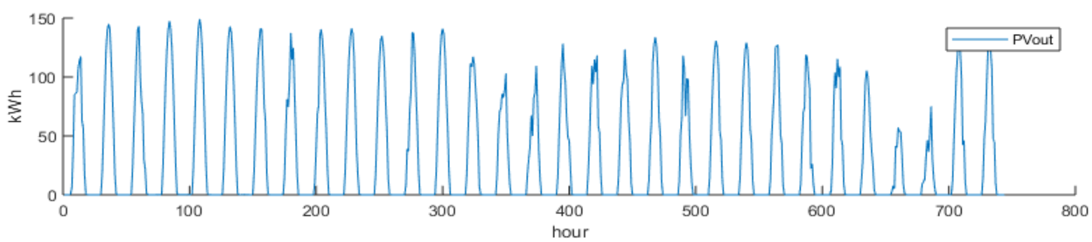
September



October

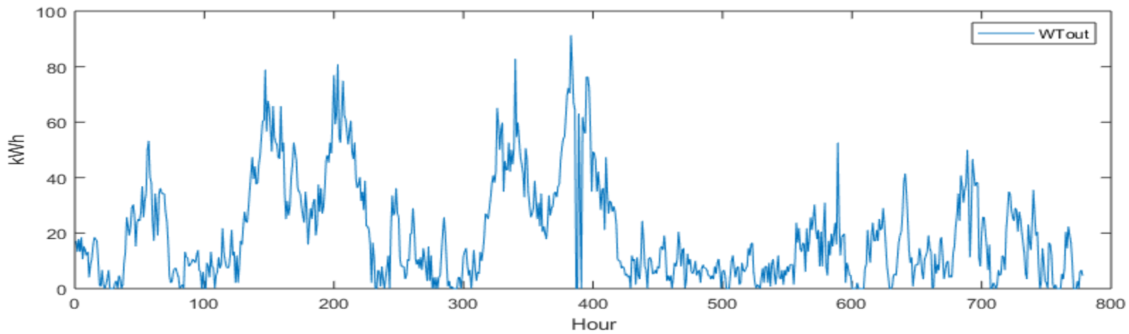


November

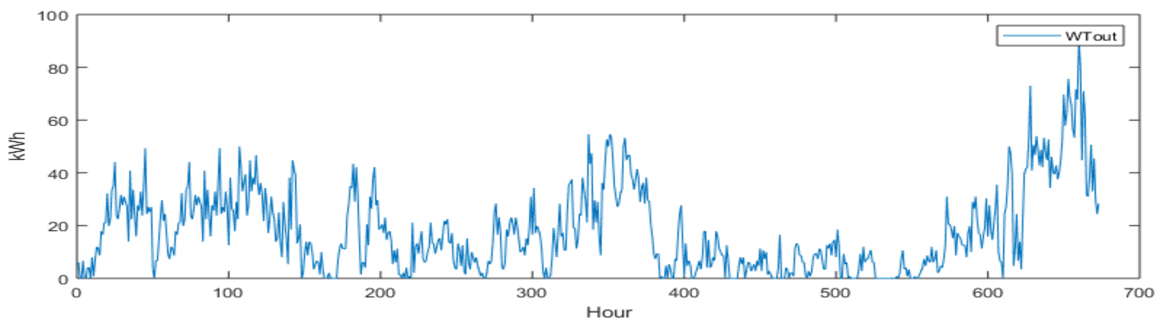


December

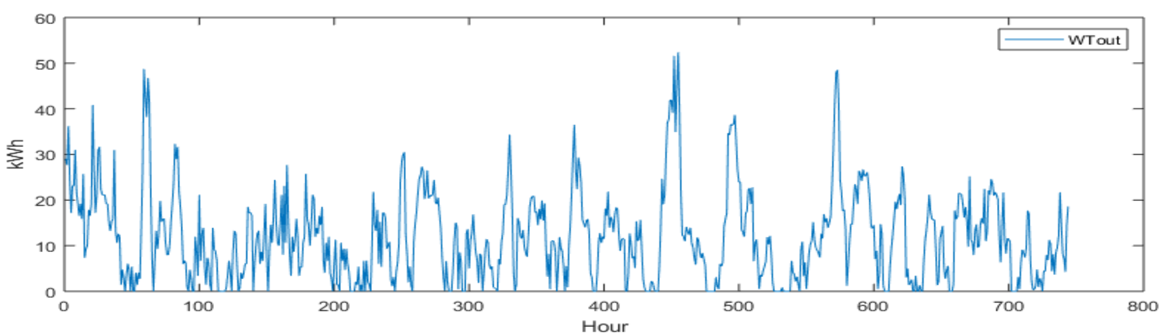
Appendix D: WT generation output for each month



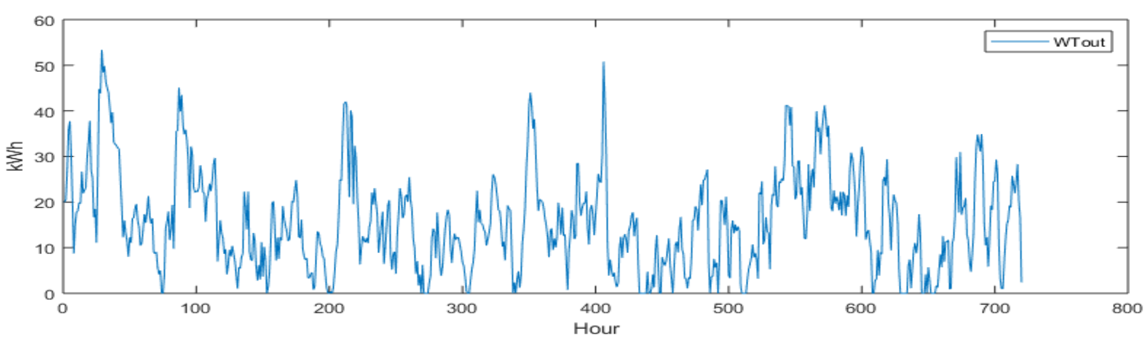
January



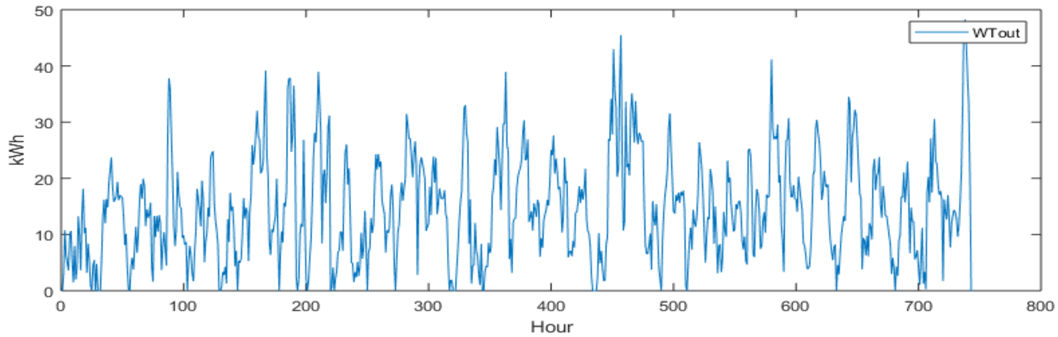
February



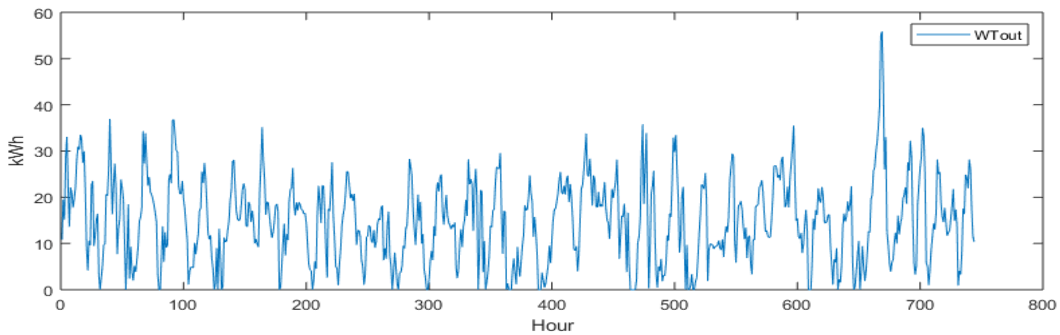
March



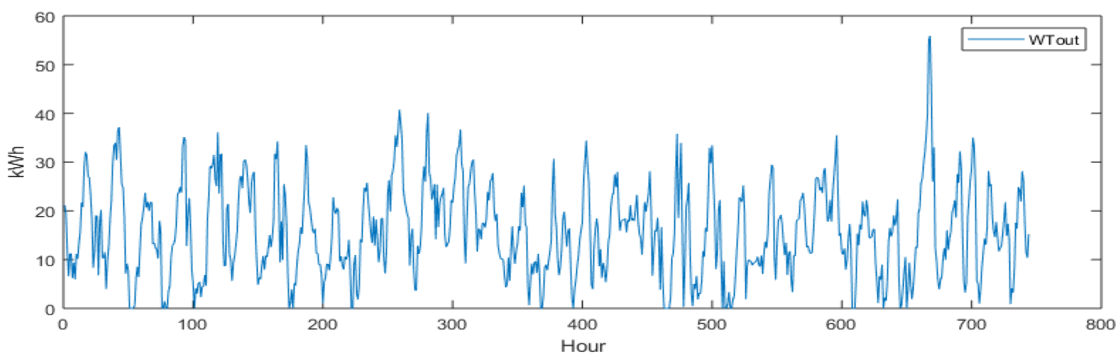
April



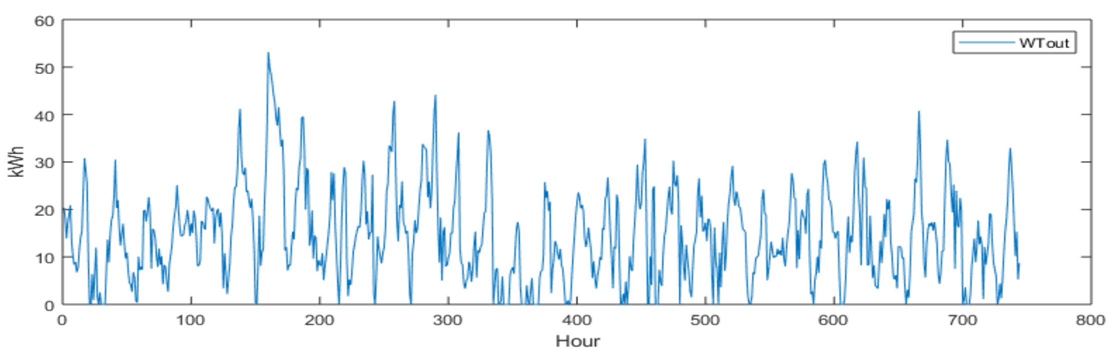
May



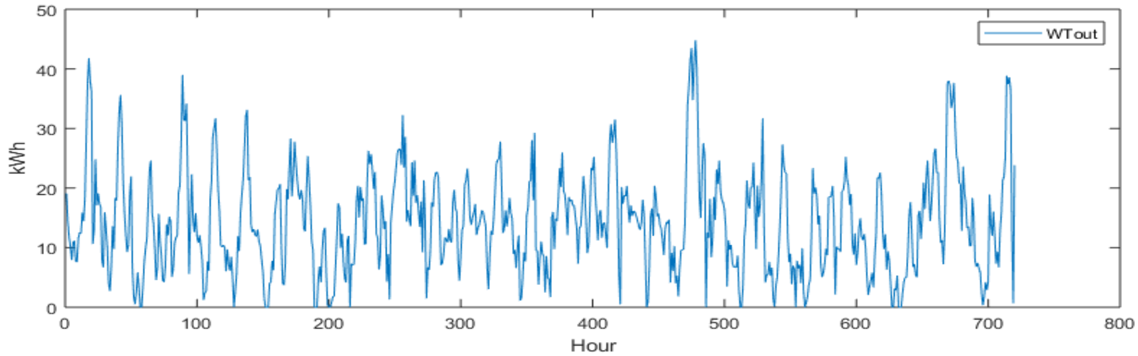
June



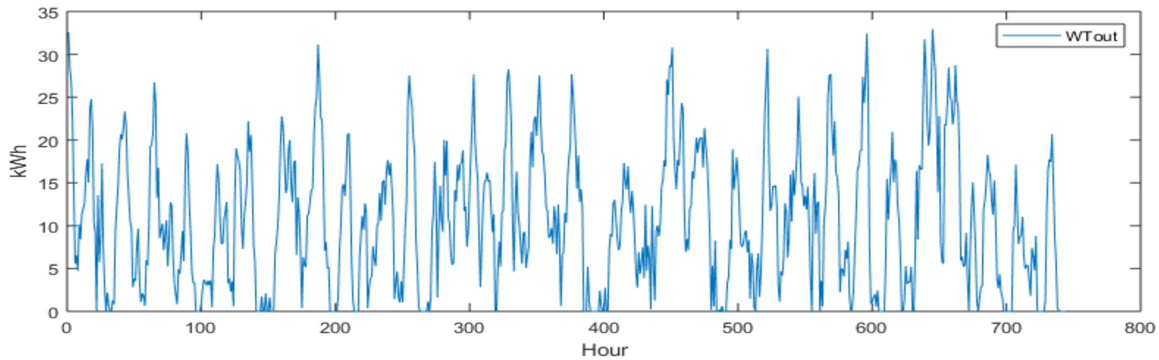
July



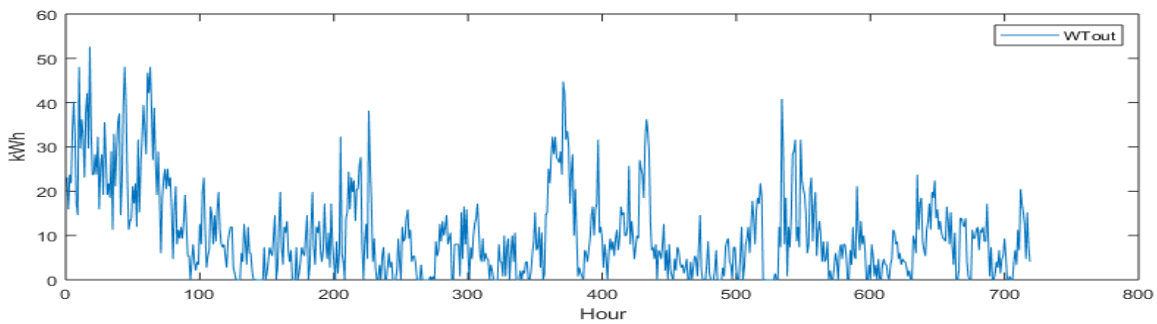
August



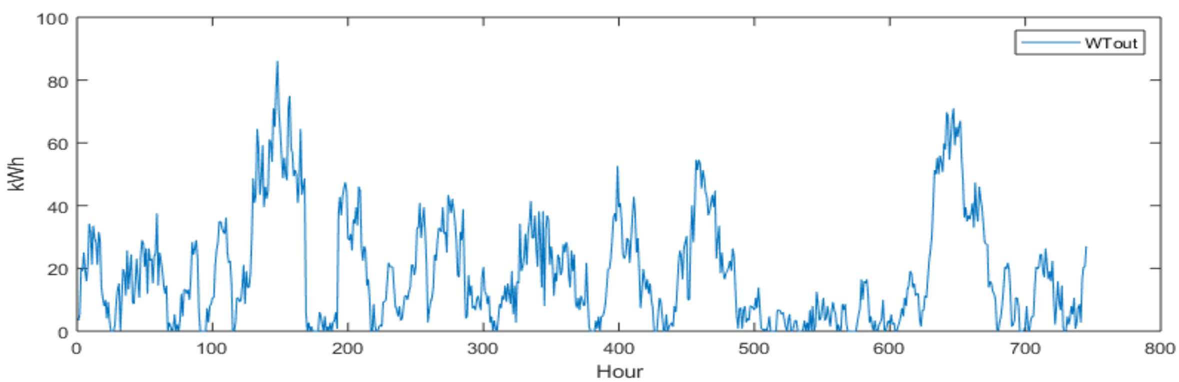
September



October

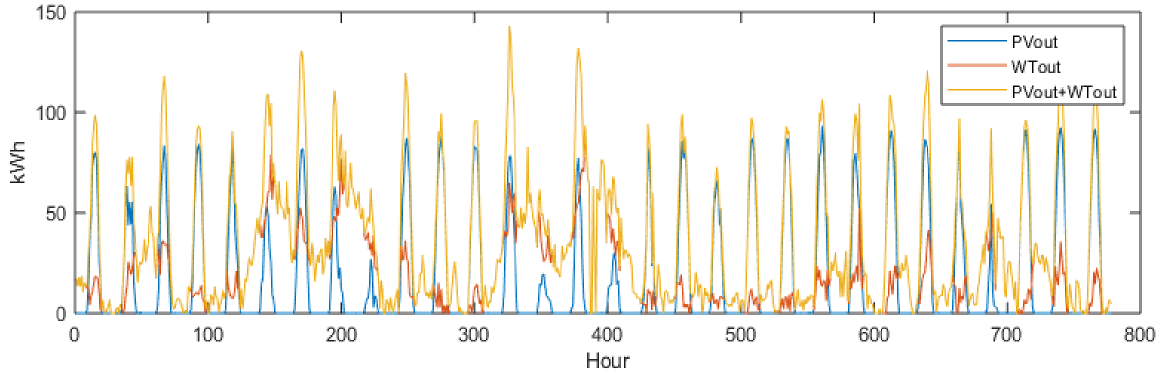


November

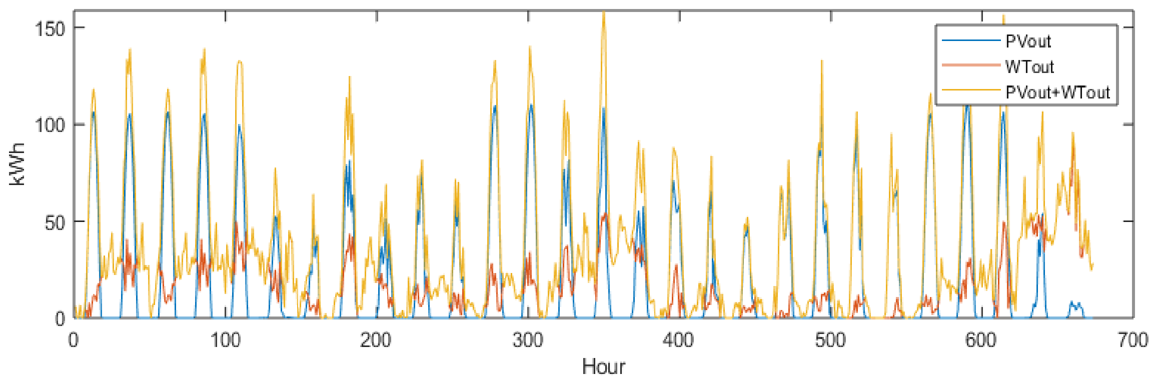


December

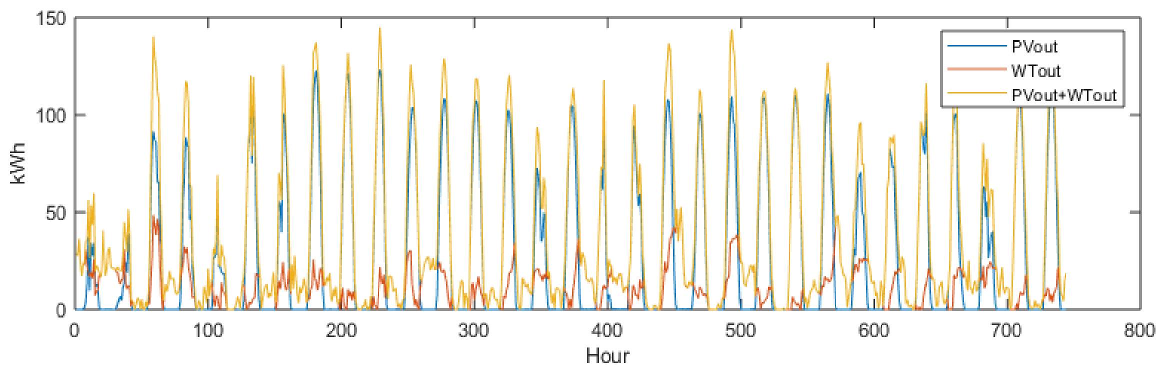
Appendix F: PV-wind HRES output



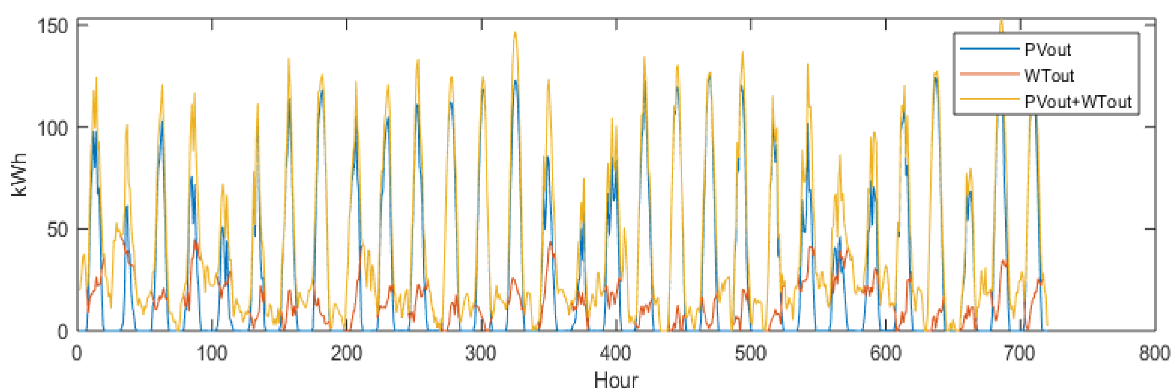
January



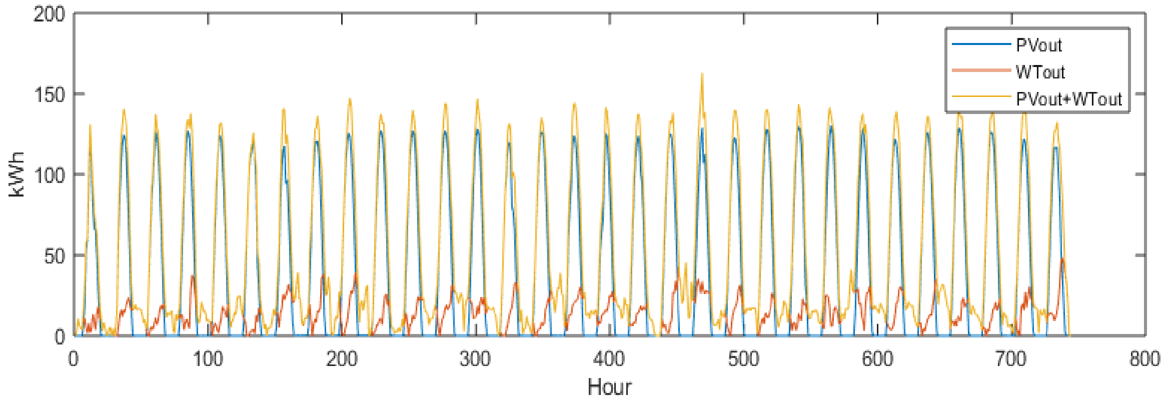
February



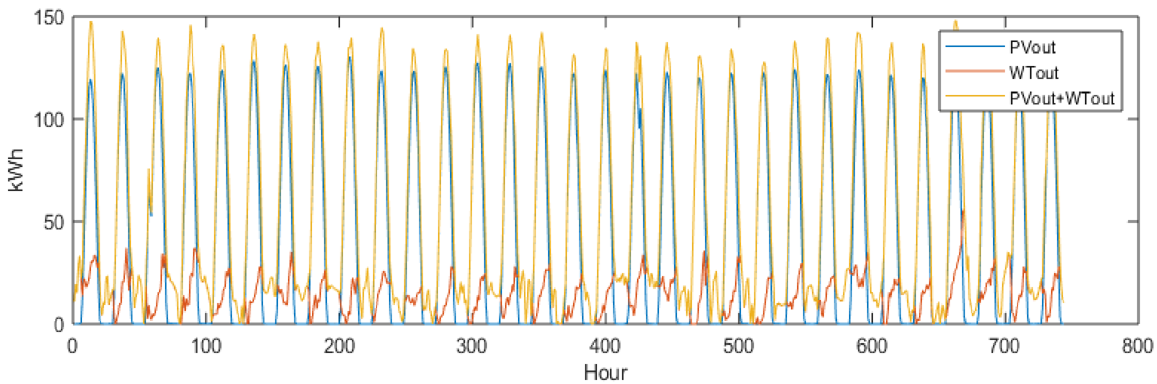
March



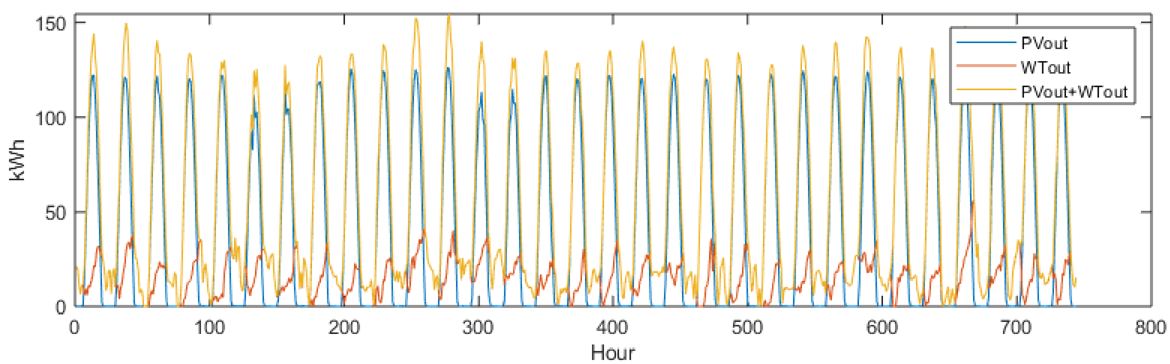
April



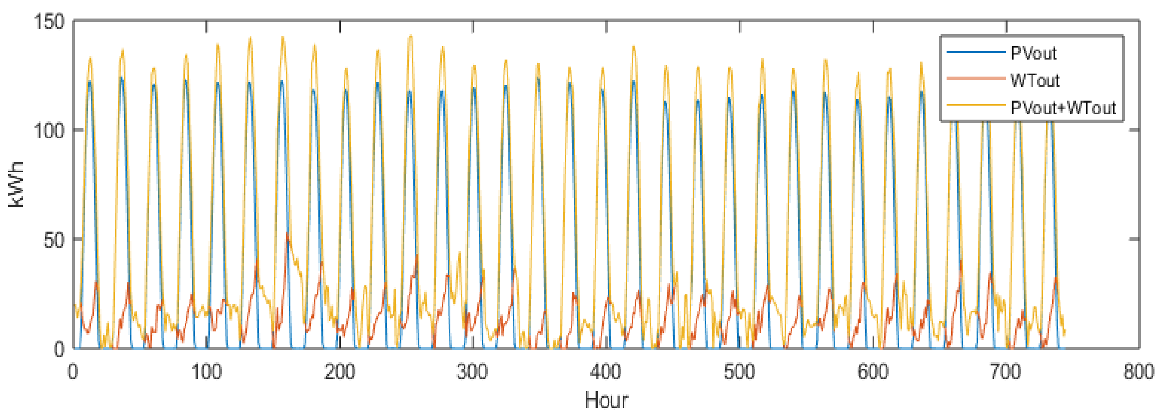
May



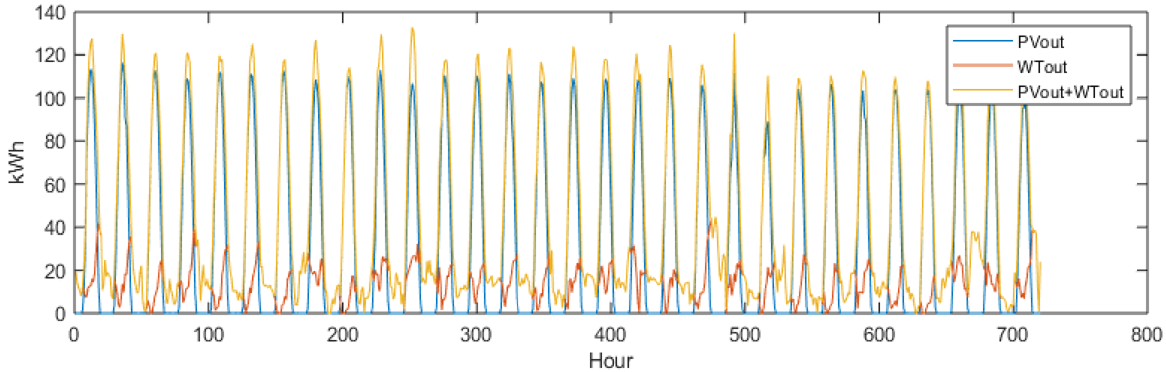
June



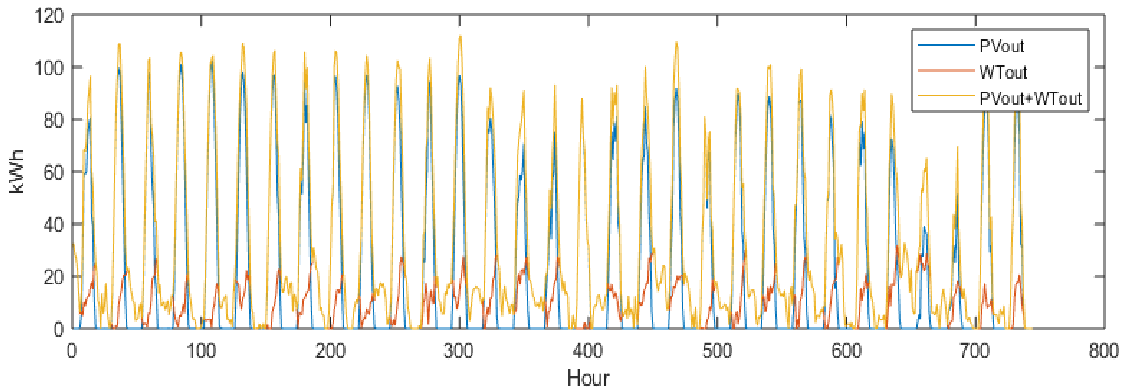
July



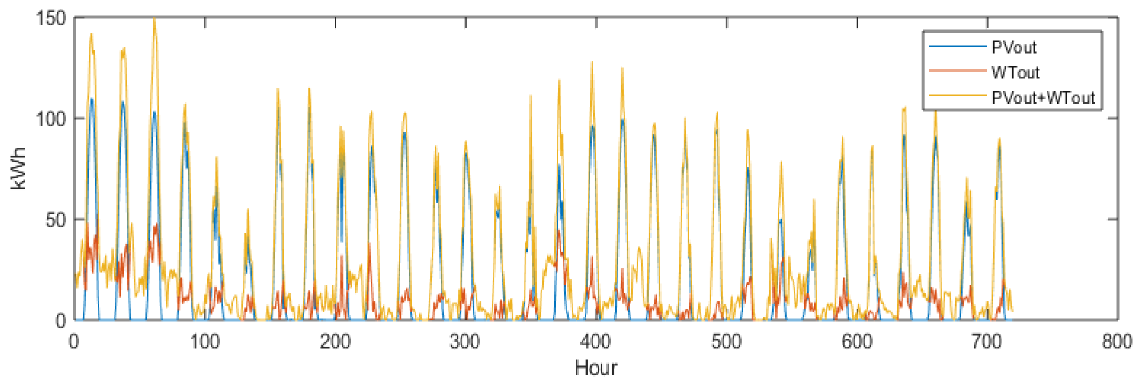
August



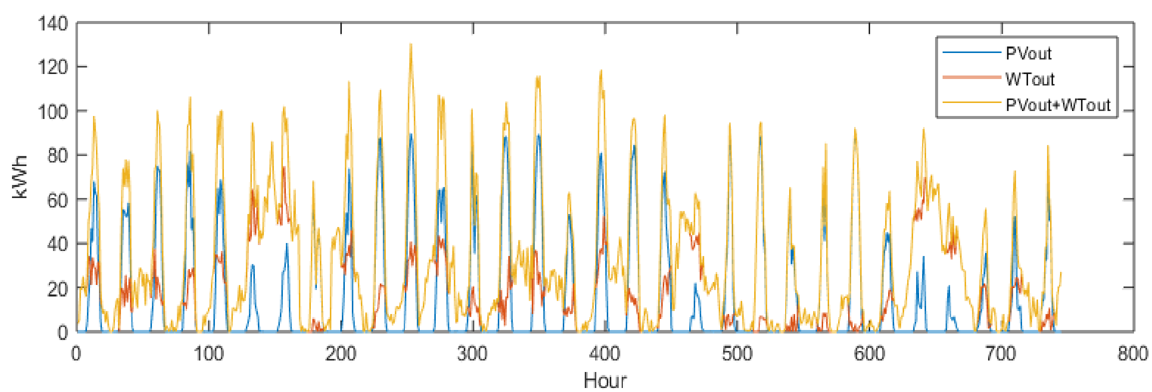
September



October



November



December