Palestine Polytechnic University

College of Engineering

Feasibility Study of a Hybrid PV-Wind Turbine System for Al-Sharif Factory

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الإهداء

إلى ذلك النور الذي يضيء حياتي ، و النبع الذي ارتوي منه حباً و حناناً ، إلى التي سهرت ليالٍ لأصبح على ما أنا عليه الآن ... إليكِ يا أمي أُهدي هذا النجاح

إلى ذلك الجبل الذي لطالما تحمَّلَ كل العقباتِ لأجلنا ، لأجل أن أصل إلى هنا ، إلى ذلك السند إلى قوتي ... إليكَ يا أبي أُهدي هذا النجاح

و لأُخوتي جميعاً ... يا من كنتم خير السند في كل وقتٍ و حين

و لعائلتي أجمع ... إلى من مشيتُ على خُطاهم لأصل إلى هذا النجاح

إلى أصدقائي الذين لطالما كان المُرُّ يزول معهم و كانت الحياةُ أجملَ فيهم

إلى معلماتي اللواتي كُنَّ الشمعاتِ التي تُضيءُ لأجلنا عُتمةَ جهلنا ... إلى اللواتي أوصلوني إلى هذا النور

إلى أساتذةِ كليتي أجمع ... إلى من سَخَّروا لي الطريق لأصل إلى هنا ، أُهديكم هذا النجاح

إلى كليتي ... أقسامها و روادِها ... كلية الهندسة

إلى وطني الحبيب فلسطين ، منتظراً واياه حرية نسعى لبلوغها بالعلم والعمل

شكر وتقدير

قال تعالى:(قل اعملوا فسيرى الله عملكم ورسوله والمؤمنون)

إلهي لا يطيب الليل إلَّا بشكرك ولا يطيب النهار إلا بطاعتك, ولا تطيب اللحظات إلا بذكرك, ولا تطيب الأخرة إلا بعفوك , ولا تطيب الجنة الى برؤيتهِ جل.

لابد لنا ونحن نخطو خطواتنا الأخيرة في الحياة الجامعية من وقفة نعود فيها إلى أعوامٍ قضيناها في رحاب الجامعة مع معلمينا الذين قدموا لنا الكثير باذلين بذلك جهودا كبيرة في بناء جيل الغد. وقبل أن نمضي نقدم أسمى آيات الشكر والامتنان والتقدير والمحبة إلى الذين حملوا أقدس رسالةٍ في الحياة إلى الذين مهَّدوا لنا طريق العلم والمعرفة إلى أساتذتنا الأفاضل الذين نهلنا من علمهم واستفدنا من خبراتهم ونخص بالذكر مشرفنا القدير الدكتور نسيم اقطيط لتعاونه وتشجيعه ولروحه النادرة وفكره المستنير فلهُ منا كل الشكر والتقدير.

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الملخص

في الآونة الأخيرة أصبحت الأنظار أكثر التفاتاً إلى الطاقة البديلة في ضوء ارتفاع أسعار توليد الطاقة من المصادر غير النظيفة مثل الوقود الأحفوري. و في ضوء الواقع الذي تعيشه فلسطين يُعَّد إيجاد مصادر طاقة بديلة أمر في غاية الأهمية.

إن أكثر مصادر الطاقة البديلة توفراً في فلسطين هي الطاقة الشمسية إلى جانب طاقة الرياح. يقدم هذا المشروع دراسة جدوى إقتصادية باستخدام برنامج HOMER Pro لتزويد مصنع الشريف الواقع في مدينة الخليل بنظام طاقة مزدوج يجمع بين الطاقة الشمسية وطاقة الرياح ، تم عمل سيناريوهين كالتالي :

- نظام طاقة شمسية متصل مع شبكة الكهرباء ,عمل على تغطية 31% من مجمل إستهلاك المصنع للطاقة.
- نظام طاقة شمسية متصل مع شبكة الكهرباء بالاضافة الى نظام يحتوي على توربينات رياح ,عمل على تغطية 38% من أحمال المصنع .

Abstract

The Renewable energy becomes popular in the recent days due to the rising of fuel and natural gas prices and due to the desire to have clean sources of energy. The Palestinian energy sector is not independent, so the cost of electricity is too much high than anywhere else in the world.

Solar and Wind are the most available sources in Palestine so they should be used in present project as a Hybrid system.

This project presents an economic feasibility study using the HOMER Pro software to supply **Al-Sharif factory** that located in Hebron city (latitude of $31°31'09.6"\,N$ and longitude of $35°04'11.5"\,E$), with a hybrid energy system that combines between solar and wind energy.

Two scenarios were created as follows:

• A solar energy system connected to the grid. The system covers 31% of the factory's total energy consumption, and the payback period was six years.

• A solar energy system connected to the grid in addition to a system that contains wind turbines. The system covers 38% of the factory's loads, and the payback period was nine years and ten months

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Keywords: Hybrid system, renewable energy, solar power, PV, wind power, HOMER.

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Abbreviations

A	Ampere
COE	The levelized cost of energy
DC	Direct Current
FF	Fill Factor
HAWT	Horizontal axis wind turbine
I-V	current voltage
K	Boltzmann constant (1.38 × 10−23 j/k)
MPP	Maximum Power Point
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
O&M	The Operation and Maintenance
PV	Photovoltaic
SC	Short Circuit
STC	Standard Test Condition
VAWT	Vertical Axis Wind Turbine
WT	Wind Turbines
ac	alternating current
kw	kilowatt
kWh/d	kilowatt hour per day
m/s	meter per second

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Chapter One

Introduction

1.1 **Introduction**

1.2 **Overview**

1.3 **Literature Review**

1.4 **Objectives**

- 1.4.1 **General Objective**
- 1.4.2 **Specific Objective**

1.5 **Challenges**

1.6 **Importance and Motivation**

1.7 **Time Plan**

1.1 Introduction

Renewable energy resources are the most important and expected field to find new energy sources to meet up the large demand in power all over the world especially in developing countries. Solar and wind are the most popular resources between renewable resources because it's easy to access, greatly available and possibility to convert it to electricity.

The hybrid power generation system that consists of more than one source can overcome the interrupts in the supplying power so that keeps the power production at the required levels.

This project aims to study the construction of the optimal hybrid power generation system, it is based on the data of Al-Sharif factory in Hebron with average annual consumption of 377,246 kwh/year. And discuss the price of the parameter and parts of the system. Then simulate the system for power supply analysis, quality, and economic impact. The system is connected to the grid to improve the reliability of supply to the load.

1.2 Overview

The fundamental concept of this project is to study and analyze the load profile of Al-Sharif Factory and collect the results from HOMER Pro software that will be used to decide if the renewable energy sources will be economically feasible or not.

1.3 Literature Review

This project aims to design an economically feasible hybrid PV-wind turbine system for Al-Sharif Factory, the project will be using the data of load profile of the factory, wind data, and solar radiation of the factory's region. The hybrid system of two resources using to enhance the reliability of the system.

A study design of a hybrid solar-wind power plant using optimization focused on designing a model that would allow finding the optimal system design parameters of a hybrid solar-wind system, taking into consideration the number of solar arrays and wind turbines, as well as the wind turbine rotor diameter and height. Karim Mousa, Hamzah AlZu'bi and Ali Diabat meet the load of different applications using our designed hybrid system, while minimizing costs. After the tests were carried out, a complementary relationship between both individual systems was visible. In the summertime, when solar radiation is abundant and there is little wind energy, the solar arrays supply most of the required energy. In wintertime, when wind velocities are higher and there is less solar radiation, it is the wind turbines that supply most of the required energy, thus providing clear evidence of a complementary relationship between the two sources [1].

a E.C. Okonkwo et al simulations in 2017 show that a stand-alone system is adequate and reliable in supplying the load demand of the hotel. Optimization modeling also shows that it is viable to obtain a 100% renewable factor consisting of a 20 kW PV, a 10 kW Bergey XL10 wind turbine system with a 7 kW converter and eight 16 V batteries of the capacity of 1900 Ah. the system is economically viable with SIR greater than 1 [2].

Abdul Razaque Sahito and Sukru Dursun present in their paper the cost analysis of on-grid and off-grid solar PV system for the Institute of Environmental Engineering & Management, in Pakistan. The optimization results show that the grid-connected system is more economically if we compare it with the off-grid solar PV system for the same load with that from the simulation results it is investigated that the NPC (net present cost) of on-grid system is less than off-grid system and the reason is the extra-large battery bank is required for the backup system [3].

Abdel Aleem chose Perhentian Island as a case study area. It is located in Terengganu, far away from grid utilities. This island is exposed to vary season to season wind speed of 2 m/s to 13 m/s. Since the island has high wind potential, it would be advantageous for wind turbine The current average estimation of daily energy consumption of this island is 1253 kW h/day. However, the current technology still costly and emit pollutants. Thus, the idea of proposing a new energy system technology that is cost-effective, environmental friendly is important. HOMER software has been chosen to carry out this article; The optimization results, are presented at the current fuel price of $0.57 per liter, and at scaled annual average wind of 7.78 m/s, and solar of 5.24 kW h/d [4].

Ahmad Rohani and Kazem Mazlumi chose Shiraz (South, Iran, 29◦ 36’ N, 53◦ 40’ E) as case study area This data has been analyzed to assess utilization of hybrid PV/WG/battery/FC power systems to meet the load requirements of a typical remote village (with annual energy demand average of 623 (kWh/d)) , the monthly average daily solar radiation ranges from 3.26 to 7.61 (kWh/m2). In this case using HOMER SIMULATION MODEL In the present work, the selection and sizing of components of the hybrid power system have been done using NREL’s HOMER software. The simulation results indicated that a hybrid power system comprising of 150 (kWpeak) photovoltaic system together with 100 (kW) wind generator system, 25 (kW) fuel cell, and battery storage of 6 hours of autonomy (equivalent to 6 hours of average load), would be a feasible solution for distributed generation of electric power for stand-alone applications at remote locations. The cost of generating energy from the above hybrid PV/WG/FC/battery system has been found to be 0.398 (US$/kWh). The hybrid PV/WG/FC/battery power system offers several benefits such as: utilization rate of PV generation is high; load can be satisfied in the optimal way; reliable power supply; and a reduction in the capacities of PV, FC and battery (while matching the peak loads) can occur. Also it has been found that the unmet load was only 654 (kWh) per year. The environmental friendly nature of the hybrid system can also be depicted from the annual emission of the system [5].

1.4 Objectives

1.4.1 General Objective

To study the feasibility of solar-wind hybrid power systems for Al-Sharif Factory located in Dweirban, Hebron.

1.4.2 Specific Objective

To analyze and evaluate the renewable energy potential mainly for solar and wind resources at the factory.

1.5 Challenges

This study has faced many challenges, main challenges represented as:

1. The access for data and data collection:

- There is no previous information about load profile for Al-Sharif Factory.
- There is no wind data collected for the factory's region.

2. Self-learning of HOMER Pro software and lack of educational materials about it.

1.6 Importance and Motivation

A hybrid power generation system with more than one renewable energy source allows integration of the different energy resources into an optimum combination and can overcome the fluctuation in the power supply. The high-intensity availability of one energy source could overcome the unavailability of the other during a certain period, keeping the power production at required levels.

This research meets the need of AL-Sharif factory to find an alternative source of energy to reduce the payment of electricity bills.

1.7 Time Plan

The following Table1.1 shows the project introduction work divided in fifteen weeks:

Table 1. 1: *Time Table.*

weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Analyze collected data															
Enter data to Homer															
Result extraction															
Analyze results															
Documentation															
Preparing the presentation															

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Chapter Two

HOMER Software

2.1 Introduction of HOMER Software and Analysis of Techno- Economic Parameters

2.2 Techno-Economic Analysis

2.1 Introduction of HOMER Software and Analysis of Techno-Economic Parameters

HOMER software is basically a computer model, a micro power optimization model developed by the United States National Renewable Energy Laboratory (NREL). This program was developed to design power systems and compare power generation technologies. The HOMER software models the physical properties of the hybrid power system and all the total installation and operating costs, with costs over their lifetime. This program allows different power system designs using technical and economic data. It also helps to understand the changes in the data used when modeling the system. HOMER software includes photovoltaic panels, wind turbines, small power hydroelectric power plants, biomass power, piston engine generators, fuel cells, battery and hydrogen storage systems.

This program performs three basic tasks; simulation, optimization, and sensitivity analysis.

In the simulation process, HOMER software models a specific energy system configuration performance, technical feasibility, and life-cycle cost for each hour of the year.

In the optimization process, it simulates many different system configurations to determine a system configuration that meets the technical constraints, taking into account the lowest life cycle cost.

In the sensitivity analysis section, the HOMER software performs a number of optimization operations under several input assumptions to measure the effects of changes in inputs and uncertainties on the system.

The optimization process determines the optimum value of the variables determined by the person designing the system, such as the combination of the elements that make up the system and the size or quantity of each of these elements. Sensitivity analysis helps assess the effects of changes in variables, such as average wind speed or future fuel price, that are not available to the designer [6].

2.2 Techno-Economic Analysis

The economic dimension is included in the simulation stage and in the optimization stage in the HOMER software. In other words, it is included in the calculations. HOMER software works during the simulation process to minimize the total net cost today. In the optimization process, the lowest total sorts of top-down system configurations with today's net cost. At the same time, in the optimization process, HOMER software has to compare the economic aspects of a wide range of system configurations of renewable and conventional energy sources many times. In order to make these comparisons correctly, it is necessary to take into account both capital and operating costs. Life Cycle Cost Analysis also covers all costs incurred during the life of the system.

HOMER software uses the total present net cost value to represent the life cycle cost. NPC is a parameter that summarizes all costs and revenues that have occurred during the life of the project, together with the future cash flows discounted to the present with the use of the discount rate as the amount of money paid in today's dollars. The hybrid power system designer can determine the life and discount rate of the project. The total current net cost includes the initial investment cost, the cost of renewal, maintenance, fuel, and electricity from the grid. Revenues include electricity sold to the grid and the cost of scrap generated as a result of life. Costs are evaluated as positive and revenues as negative.

3

Chapter Three

Description of The System Design

3.1 General Block Diagram

The system will be consisting of PV panels, small scale wind turbines and inverter. The schematic diagram of the hybrid power system is shown in Figure 3.1.

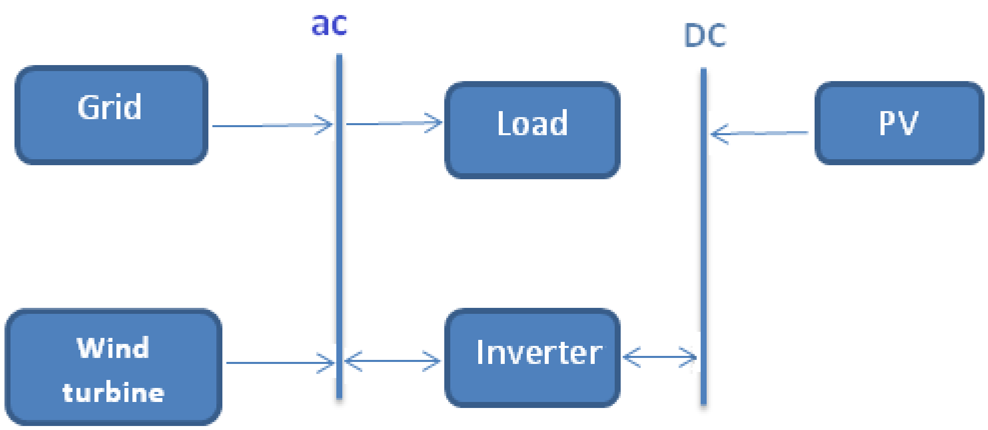

Figure 3. 1: Block diagram of PV-Wind hybrid system.

3.2 Description of Photovoltaic Design

3.2.1 Description and Modeling of Photovoltaic

Energy exists in different forms and can be converted from one form to another. Solar energy, in terms of electromagnetic radiation, can be converted to another form of energy through various routes as solar thermal conversion, photovoltaic conversion, and photochemical conversion. Solar energy can be converted to thermal energy, electrical energy, or chemical energy depending on the kind of interaction between solar radiation and matter. Energy conversion through the photovoltaic route requires an increase in the potential energy of the electrons. For this purpose, the material is required to possess energy levels.

The energy difference between levels should be more than the room temperature energy of electrons. A semiconductor device functions in a similar way. P-N junction diode is essential for the generation of photovoltage. For the collection of the energy of a photon in the form of electrical energy through solar cells required to increase the potential energy of carriers i.e. electrons and holes and the separation of these carriers. Former is done by the collection of photon energy by carriers due to which they remain in higher energy level and the latter is achieved by the asymmetry of P-N which provides built-in electric field at the junction [7]. When this P-N junction is exposed to light, photons are absorbed and an electron-hole pair is formed. These carriers are swept apart under the influence of the internal electric fields of the P-N junction and create a current proportional to the incident radiation.

When a cell is short-circuited, this current flows in the external circuit; when open-circuited, this current is shunted internally by the intrinsic p-n junction diode. Thus, characteristics of PV cells are presented by diode characteristics [8].

3.2.2 Mathematical Modeling of Photovoltaic Cell

An ideal solar cell can be considered as a current source with current produced directly proportional to solar radiation falling on it. The practical behavior of a cell is deviated from ideal due to the optical and electrical losses. The optical loss is represented by the current source itself, where the generated current is proportional to light input. The recombination losses are represented by diode-connected parallel to the current source, but in the reverse direction as recombination current flows in the opposite direction to light generated current[7]. The ohmic losses in the cell occur due to the series and shunt resistance denoted by and respectively. The series resistance is the resistance offered by the solar cell in the path of current flow.

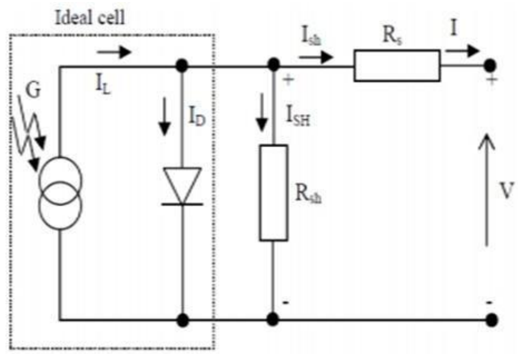

Figure 3. 2: Equivalent circuit of PV cell.[9]

The current (I_c) which flows to the load is the difference between (I_L) and (I_D) and it is reduced by the resistance (R_s) and R_{sh} [9].

Two resistances (R_s) and (R_{sh}), are included to model the contact resistances and the internal PV cell resistance respectively. The value of these two resistances can be obtained from measurements or by using curve fitting methods based on the I-V characteristic of PV. The equivalent electrical circuit for a PV cell or module is illustrated in Figure 3.2.

The current source (I_L) depended on the solar radiation and the ambient temperature. The (I-V) characteristics of a photovoltaic cell can be determined by the following equations. The terminal current of the model (I_L) is given by equation 3.1[10]:

$$I = (I_L) - (I_D) - (I_{sh}) \tag{3.1}$$

Where:

(I_L): photocurrent from a photovoltaic cell (A).

(I_D): is the current passing through none linear diode (A).

(I_{sh}): current through shunt resistance (A).

The photocurrent (I_L) is a function of solar radiation and temperature, it is determined from the equation 3.2 [10] :

$$I_L = [I_{SC} + k_i(T_c - T_r)]\, G/G_n \tag{3.2}$$

Where:

I_{sc}: is the short-circuit of the cell at standard test condition (STC: G_n = 1000 W/m and Tr = 298.15 K) (A).

ki: is the short-circuit temperature coefficient of the cell (A/K).

T_c and T_r: are the working temperatures of the cell and reference temperature respectively (k).

G and G_n: are the working solar radiation and nominal solar radiation respectively (w/m).

The diode saturation current Id of the cell varies with the cell temperature which is expressed in the equation 3.3 [10] :

$$I_d = I_0[e^{q(V_L + I_L R_S) \times A \times k \times T_C}] \tag{3.3}$$

Where:

I_0: reverse saturation current of the diode (A).

q: is the electron charge (1.6021 × 10−19) C.

V_L: output voltage of the photovoltaic cell (V).

R_s: series resistance of cell (ohm).

A: is the ideality constant of diode depend on the PV technology.

k: Boltzmann constant (1.38 × 10−23 j/k).

The shunt current I_p is given by equation 3.4 [10]:

$$I_p = (V_L + I_L + R_s)/R_p \tag{3.4}$$

Where: R_p is parallel resistance (ohm).

3.2.3 Characteristics of Photovoltaic Module

The performance of a photovoltaic module depends on manufacturing technology and operating conditions (solar radiation and temperature). The curve of current-voltage (I-V) which determines the behavior of a photovoltaic cell is represented

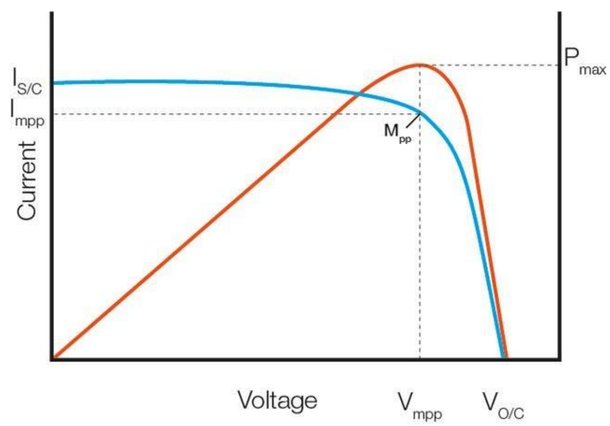

Figure 3. 3: Characteristic of PV module [10].

The main electrical parameters that describe the performance of a Photovoltaic cell are:

1. Short circuit current I_{sc} The value of (I_{sc}) can be obtained by connecting the terminals of a module via an ammeter and measuring the current. The value of (I_{sc}) changes in function of solar radiation and very little of temperature**.**

2. Open circuit voltage (V_{OC}) It's the voltage of a PV module measured at terminals at no load.

3. Maximum power point (MPP) The maximum power point of a photovoltaic is a unique point on the (I-V) or (P-V) Characteristics and the power supplied in this point is maximum, where measured in Watts (W). its value can be calculated by the product Vmax and Imax.

4. Fill Factor (FF) The ratio of output power at maximum power point to the power computed by multiplying I_{sc} by V_{OC} , as illustrated in Figure 3.3.

3.3 Wind Energy Basics

The wind is an abundant, free, clean, sustainable, and environmentally friendly renewable energy source. It has served the human civilization for many centuries by propelling ships and driving windmills to grind grain and pump water, and nowadays also for electrical power production.

Most wind turbines (WT) are machines built to convert the containing power in the wind into electricity. The main classification of those machines is according to the interaction of their blades with the wind by aerodynamic forces - drag or lift or a combination of both; and the orientation of the rotor axis with respect to the ground and to the tower – upwind or downwind.

Among the VAWTs machines, we highlight the Savonius (Figure 3.4 b) mostly used for water pumping and the Darrieus (Figure 3.4 a) WT. They have the advantage of receiving wind from any direction not requiring tracking mechanisms of the wind direction and that the coupling between the rotor and the generator can be made at ground level, allowing easy access for maintenance meaning that smaller towers get reduced costs [11].

Figure 3. 4: Types of rotors according to the orientation of its axis. (a) Darrieus rotor - Vertical Axis (b) H-type rotor - vertical axis, and (C) Upwind horizontals axis rotor [11].

The main disadvantage is that it has no self-starting, high torque fluctuations, and limited options of regulations at high wind speed.

The other type is the HAWT's where the rotors are kept perpendicular to the wind and the rotational driving force is lift and the blades can be in front (upwind) or behind (downwind) of the tower. The HAWTs take advantage of extracting higher wind speeds farther from the ground as the rotors are placed on the top of a tower.

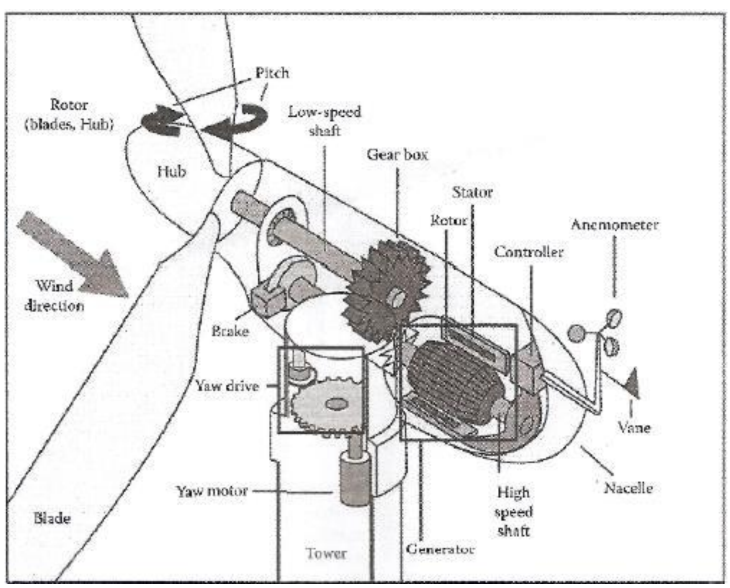

Figure 3. 5: Diagram of parts that constitute a wind turbine [11].

The nacelle contains the main components of the WT such as the electricity generator, gearbox, and the rotor. The generator transforms the rotational mechanical energy delivered by the gears, into electrical energy. The generator may be of asynchronous, synchronous, direct current and alternating current commutated types each having its advantages and disadvantages, the use of one type or the other will depend on the turbine size or the specific application and on the preferences of the manufacturer of the turbine [11].

In the present work, we will focus on the HAWT's with three blades attached to a central hub as it is the most widespread in the wind power industry and in use today. Together, the blades and the hub form the rotor (the main element to capture energy), which are connected to an electrical generator. When the wind blows, the rotor turns and the generator produces alternating current (AC) electricity. WT with multi-blade rotors (20 or more blades) have high starting torque in light wind and are mainly used for mechanical water pumping [11].

The main configuration and components of the HAWT are shown in Figure 3.5, which consists of a tower and nacelle mounted at the top of a tower.

3.4 Solar Inverter

A solar inverter or PV inverter, is a type of electrical converter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. allowing the use of ordinary AC-powered equipment. Solar power inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

4

Chapter Four

Material And Method

4.1 Modeling of Load Profile

4.2 Modeling Of Energy Resources

4.2.1 Modeling of Solar Source

4.2.2 Modeling of Wind Source

4.3 Modeling of Wind Turbines

4.4 Modeling of The Photovoltaic System

4.5 Modeling of The Inverter

4.6 Modeling of The Network

4.7 Determination of Economic Parameters

In this chapter, the various options of power generation system was modeled, also modeling of each component in the system and determining the required parameters for each component, moreover entering the obtained parameters into the HOMER software.

4.1 Modeling of Load Profile

Al-Sharif Factory is one of the factories that producing foodstuffs, it was founded in 1990 and its located in Hebron in the Dweirban district.

The factory produces many products that are classified into winter products such as “Ras Al-Abd” and summer products such like various shapes of pastry, cakes, cupcakes, jellies and juices.

The building of the Factory consists of five floors, which are basement, ground, mezzanine floor, then first and second floors. The total area of the Factory is equal to 6099 square meters and Figure 4.1 shows Al-Sharif Factory’s location.

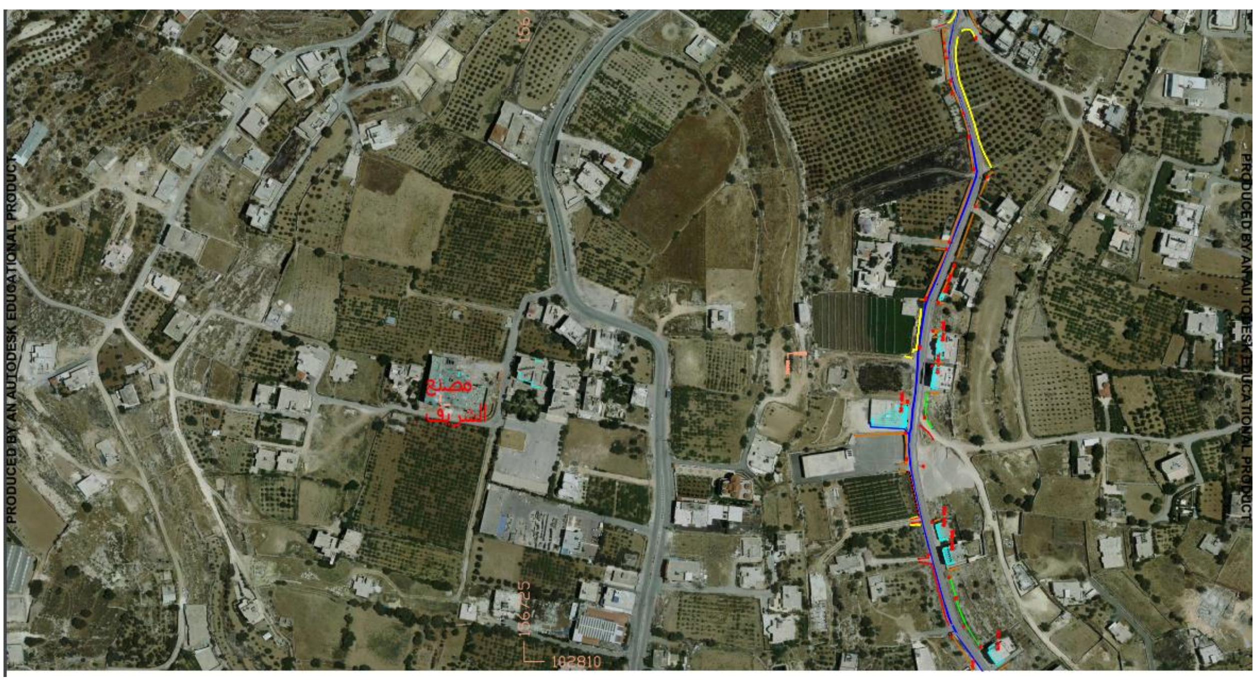

Figure 4.1: Al-Sharif Factory’s location (PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT).

The daily consumption data of the factory for the last year (2019) was obtained from Hebron municipality and this study based on it. The Factory will add production lines for chips during the current year (2020), so the daily load will increase in the future.

The average daily load for Al-Sharif Factory is 740.38 kWh/day. The hourly maximum load is 103.85 kW, while the average hourly load value is 40 kW.

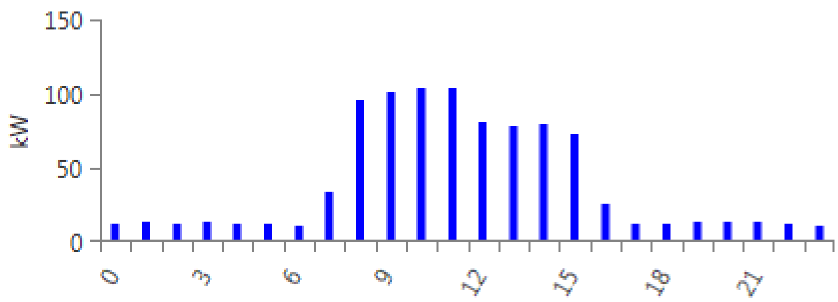

Figure 4. 2: Al-Sharif Factory daily load curve.

And the following figure (Figure 4.3) shows the Daily Load profile for each month.

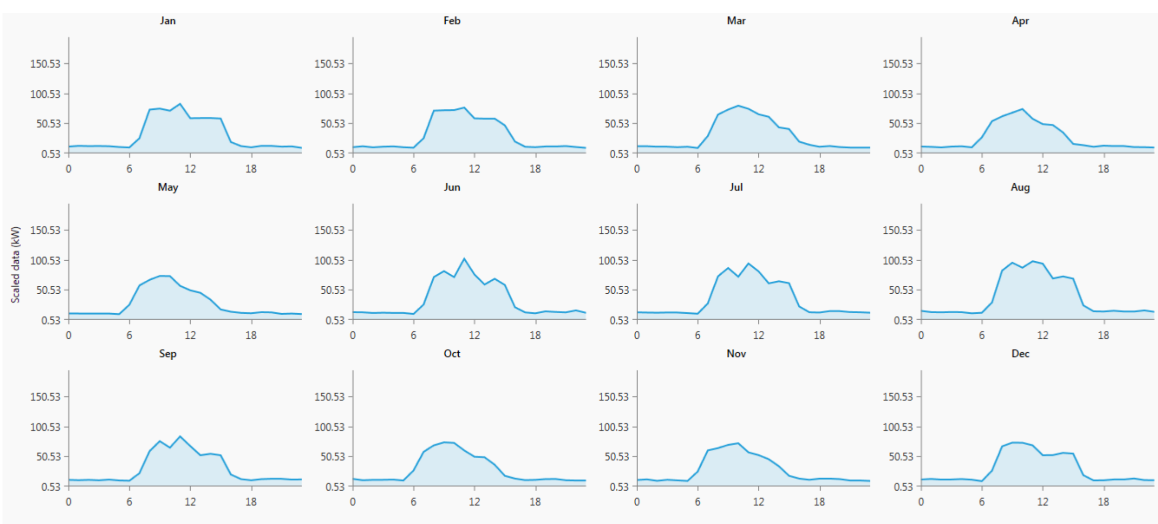

Figure 4. 3: Daily Load profile.

The following figure (Figure 4.4) shows the monthly load profile.

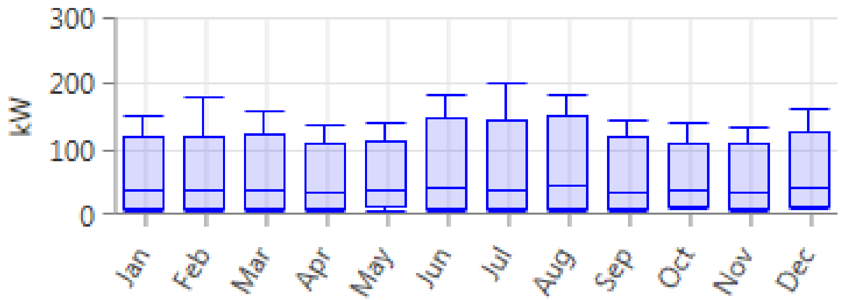

Figure 4. 4: Monthly Load profile.

4.2 Modeling of Energy Resources

In this study, information about modeling of energy resources is represented.

4.2.1 Modeling of Solar Source

The solar radiation values of the region where the hybrid power generation system will be installed are very important in the production of electricity in solar energy.

The coordinates of Al-Sharif Factory are at the latitude of $31°31'09.6"\ N$ and the longitude of $35°04'11.5"\ E$. Using the coordinates of the factory, monthly average solar radiation data was obtained with the help of HOMER software from NASA.

Monthly average solar radiation data is shown in Figure 4.5.

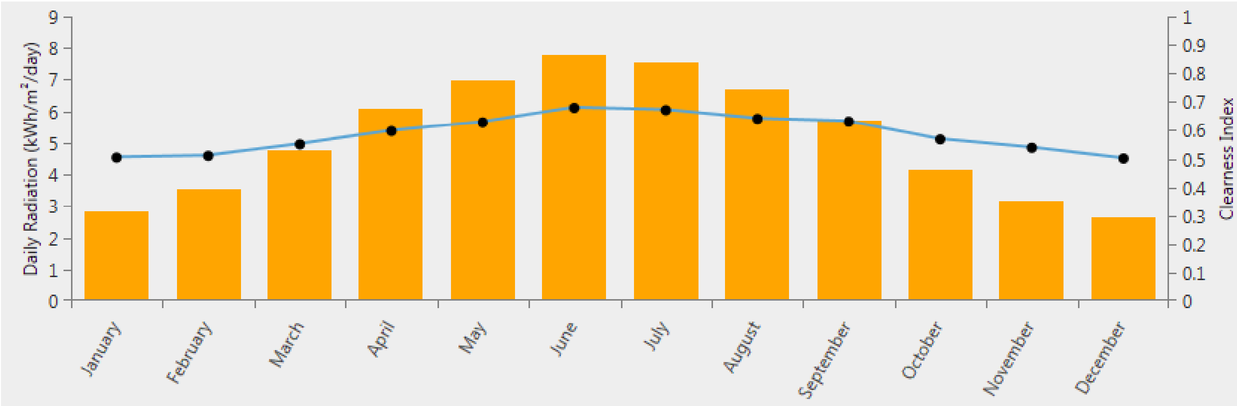

Figure 4. 5: Monthly average solar radiation and cloudlessness index in of Al-Sharif Factory region.

The indicator (clarity index) in Figure 4.5 is a measure of the clarity of the atmosphere. This value is high in clear weather and low in cloudy weather. The average annual radiation is 5.15 kWh/m^2/day.

4.2.2 Modeling of Wind Source

There are two options in the HOMER software for modeling the wind source. Either the average wind speeds of each month of the year can be entered or downloaded the hourly wind speeds of one year by the HOMER software from internet. for this study the Wind speed values have been downloaded from the internet by using HOMER software. Figure 4.6 shows the monthly average wind speed data.

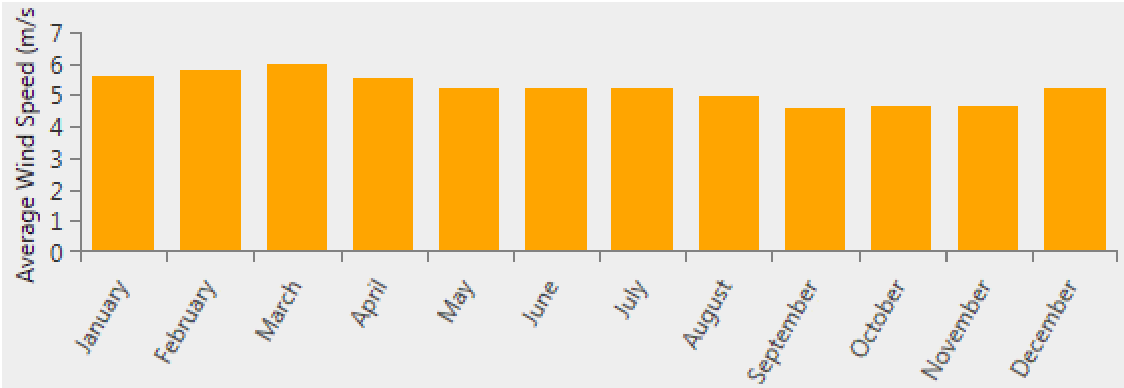

Figure 4. 6: Wind speed data in Al-Sharif Factory's region.

4.3 Modeling of Wind Turbines

The AWS5.1kW wind turbine model will be used in the modeled hybrid renewable power generation system, it has a rated output power equals 5.100 kW.

The rotor diameter of the turbine is 5.24 m. tower height is 12 m. Typical production of 25-75 kWh per day. The power curve of the turbine can be seen in Figure 4.7.

The investment cost for one wind turbine is $8,201.580 and the replacement cost is equal to the initial investment cost. The lifetime of the wind turbine is 20 years.

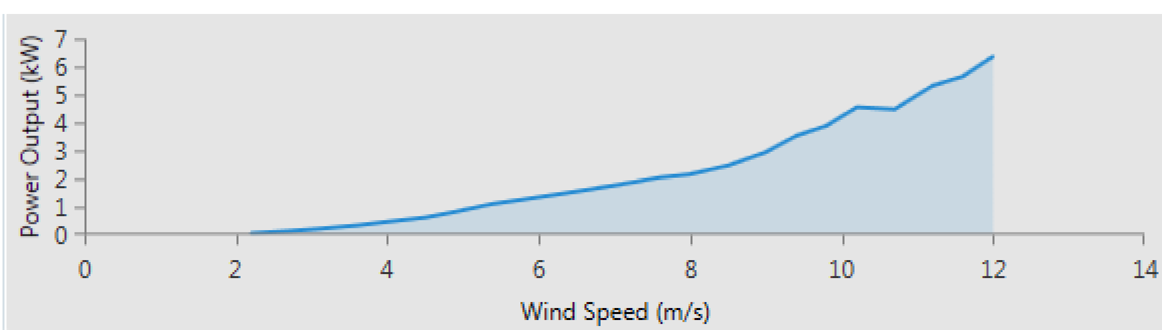

Figure 4. 7: wind turbine power curve.

While creating the optimum system in the study, the wind turbine number has been determined as (1,2,3) to find the most suitable number.

Figure 4. 8: AWS5.1kW wind turbine.

4.4 Modeling of The Photovoltaic System

The photovoltaic array used in modeling the photovoltaic system in the modeled hybrid power generation system. Hanwha Q CELLS 325Q.PLUS L-G5 325pv panel is Selected, with rated power 0.325 kW, and efficiency13%. The initial investment cost is $200 for 1 kW, the replacement cost is $200 and the annual maintenance value is $13. The lifetime of the photovoltaic system is 25 years.

The value that enables the reduction factor, the losses that will occur at the exit of the photovoltaic arrays due to dirt, temperature, shade, snow cover and aging, has been used as 90%.

The slope value is the angle value that indicates the position of the panel, the angle is 30°.

Figure 4. 9: Hanwha Q CELLS 325Q.PLUS L-G5 325pv panel.

4.5 Modeling of The Inverter

The element defined as a converter in HOMER works as an inverter that converts direct current to alternating current ABB27.6 converter is selected, the investment cost for 1 kW converter is $135, the replacement cost is $135 and the operating and maintenance costs are $10 / year.

Figure 4. 10: ABB 27.6 inverter.

4.6 Modeling of The Network

In the HOMER program, the grid is designed in such a way that electricity can be purchased when needed, and electricity can be sold when required. When modeling the grid, if electricity is purchased from the grid, the amount to be paid to the electricity company is $0.2/kWh, and when the electricity that the system sells is a net metering system, then the values in $0.05/kWh are also used to determine the amount to be The electric company paid it.

4.7 Determination of Economic Parameters

- (NPC)

The total net present cost (NPC) of a system is the value of all parts that the system consists over its lifetime minus revenues. It contains capital, replacement, O&M and fuel costs, emissions penalties, and the cost of buying power from the grid [12].

- (COE)

HOMER determines the Levelized cost power (COE) as the average cost per KWh of useful electrical energy produced by the system [13]. To calculate the COE, HOMER divides the annual cost of electricity production (total annual cost minus the cost of the convection service) by the total electrical load of the server.

- Operating costs

The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating the component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime [14].

- O&m

The Operation and Maintenance (O&M) cost of a Component is the cost associated with operating and maintaining that Component [15].

- Capital Cost

The initial capital cost of a component is the total installed cost of that component at the beginning of the project [16].

5

Chapter Five

Discussion and Evaluations

In this chapter, basic assumptions and principles relating to the parameters used during the design of the hybrid power generation system are defined. Designed hybrid power generation system options were examined by taking into account these parameters in details.

5.1 Operating Characteristics for Hybrid Power Generation Systems

The aim of this project is to reduce the Factory's electricity bills by generating electrical energy using solar cells and wind turbines. The rooftop area of the Factory controls the capacity of the hybrid system.

5.2 Evaluation of Hybrid Renewable Power Generation Systems

5.2.1 On-Grid/ Photovoltaic Panel Production System

On-grid/photovoltaic panel System is a system consisting of On-grid system, solar panels, converters, and electrical load (Al-Sharif Factory daily load), it is planned to meet a part of the load demand. Figure 5.1 shows on grid/photovoltaic system.

The system contains

- PV panel type Hanwha Q CELLS325.
- inverters type ABB 27.6.
- On grid system with unlimited power.
- Electrical load.

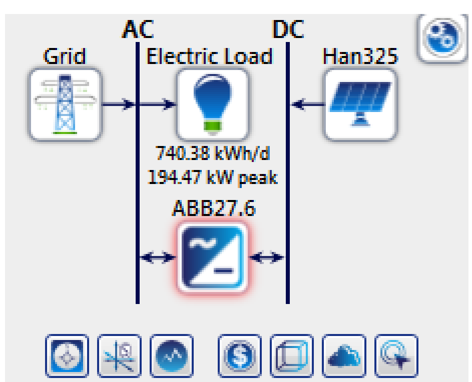

Figure 5. 1: on grid /photovoltaic system.

5.2.1.1 PV Panel Distribution

The system selection

- PV panel type Hanwha Q CELLS325 with total number 228.
- 3 inverters type ABB 27.6.

The PV number selection is based on the available area which is the space above the surface of the second floor, and the available space on the first floor, the total available area is 945 m^2.

PV panels were distributed to the following form

- Inverter #1

MPPT 1 = 3 strings *12 panel

MPPT 2 = 3 strings *12 panel

- Inverter #2

MPPT 1 =3 strings *12 panel

MPPT 2 =3 strings *12 panel

- Inverter #3

MPPT 1 =3 strings *14 panel

MPPT 2 =3 strings *12 panel

The total number is 228 PV panels.

The solar cells were distributed as shown below in Figure5.2.

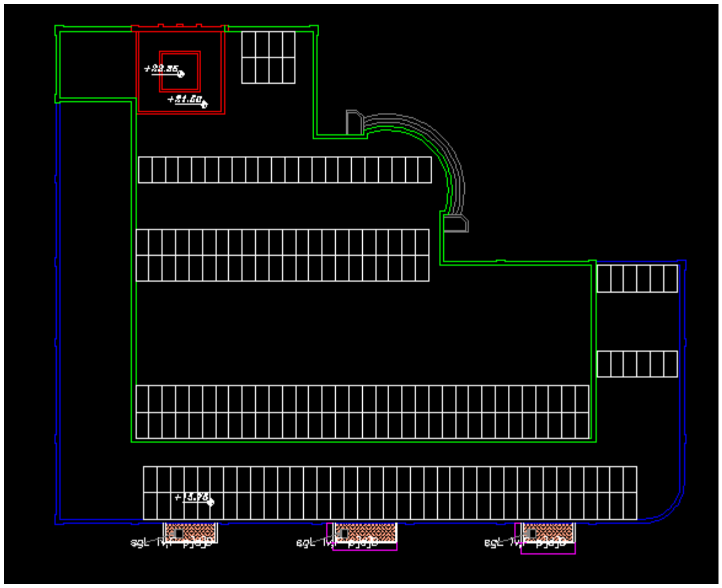

Figure 5. 2: Distribution of photovoltaic cells on the rooftop for Al-Sharif Factory.

5.2.1.2 HOMER Simulation Results

The following Figure 5.3 shows PV output during a year.

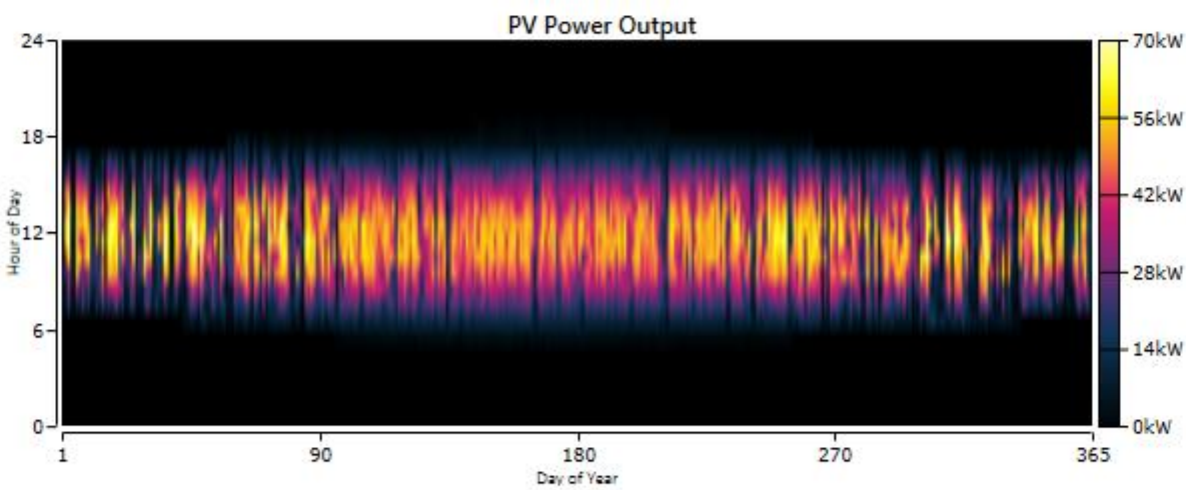

Figure 5. 3: PV output during a year.

And the figure below (Figure 5.4) shows monthly average electricity production.

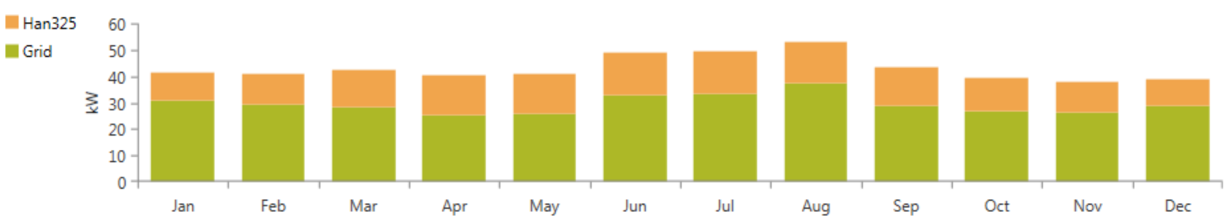

Figure 5. 4: Monthly average electricity production.

The rate of photovoltaic power generation system is shown in Table 5.1, PV panels worked for 4,390 hours. The unit energy cost of the system is 0.0173 $/ kWh.

The simple payback of this investment is six years.

Table 5. 1: *The rate of photovoltaic power generation system.*

production	kWh/year	%
Hanwha Q CELLS325Q.PLUS L-G5 325	118,862	31.5
Grid Purchases	258,385	68.5
Total	377,247	100

Table 5.2 shows the Economic analysis for photovoltaic power generation system.

Table 5. 2: *Economic analysis for photovoltaic power generation system.*

Parameters	Cost $
capital cost	28,278
Operation and maintenance cost	685,276
Levelized COE	0.1867
Total NPC	714,412
Operating cost	53,307

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
January	22,737	1,596	21,141	152	$ 4,467.68	$ 0
February	19,648	1,848	17,800	180	$ 3,837.23	$ 0
March	21,108	2,319	18,788	145	$ 4,105.54	$ 0
April	18,239	2,274	15,966	132	$ 3,534.19	$ 0
May	19,106	2,551	16,554	139	$ 3,693.58	$ 0
June	23,729	2,524	21,205	183	$ 4,619.61	$ 0
July	24,935	2,402	22,533	194	$ 4,866.92	$ 0
August	27,892	2,142	25,750	185	$ 5,471.26	$ 0
September	20,563	2,254	18,310	188	$ 3,999.98	$ 0
October	19,989	1,891	18,098	140	$ 3,903.20	$ 0
November	19,027	2,222	16,805	135	$ 3,694.32	$ 0
December	21,411	1,719	19,692	162	$ 4,196.28	$ 0
Annual	258,385	25,742	232,643	194	$ 50,389.8	$ 0

Figure 5. 5: Monthly cost of energy sold and purchased.

5.2.2 On-Grid / Wind-PV Hybrid Power Generation System

ON-grid / wind-photovoltaic hybrid renewable power generation system is a system consisting of a photovoltaic panel, wind turbine and converter. With this hybrid renewable system, it is planned to meet a part of the load demand of Al-Sharif Factory. Figure 5.6 shows the on-grid/ wind-photovoltaic hybrid power generation system.

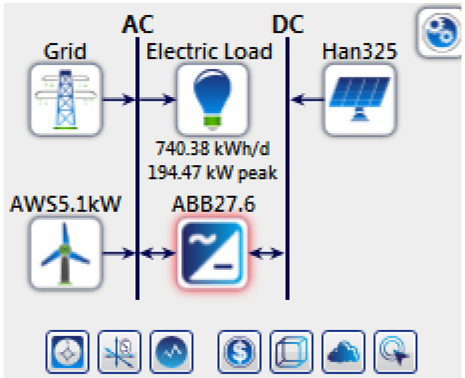

Figure 5. 6: On-grid wind-photovoltaic hybrid renewable power generation system.

The optimum number of components used in the wind / photovoltaic hybrid renewable power generation system, as well as the initial investment and operating costs, total net present cost and unit cost of energy were calculated. Wind speed is 5.22 m/s, and solar radiation value is 5.15 kWh/m^2/day.

The optimum values of each component in wind/photovoltaic hybrid renewable power generation system that will meet a part of the energy needs of Al-Sharif Factory are:

- PV panel type Hanwha Q CELLS325 with total number 228.
- 3 inverters type ABB 27.6.
- 3 wind turbines type AWS HC 5.1kW.

Wind turbines need an unchanging and uninterrupted flow or air to work effectively, which means there must be no obstructions nearby. A wind turbine is most effective when it operates in a steady, smooth, unchanging and uninterrupted flow of air. That never happens in the real world, but when planning where to install a wind turbine the locations has to be as close as possible to the ideal. For residential systems this isn't so much a question of how much area the wind turbine needs but of how much distance is required between the wind turbine and other obstructions.

5.2.2.1 The Distribution of Wind/Photovoltaic Hybrid Renewable Power Generation System

The following figure (Figure 5.7) show the distribution of wind- PV hybrid system on the rooftop for Al-Sharif Factory.

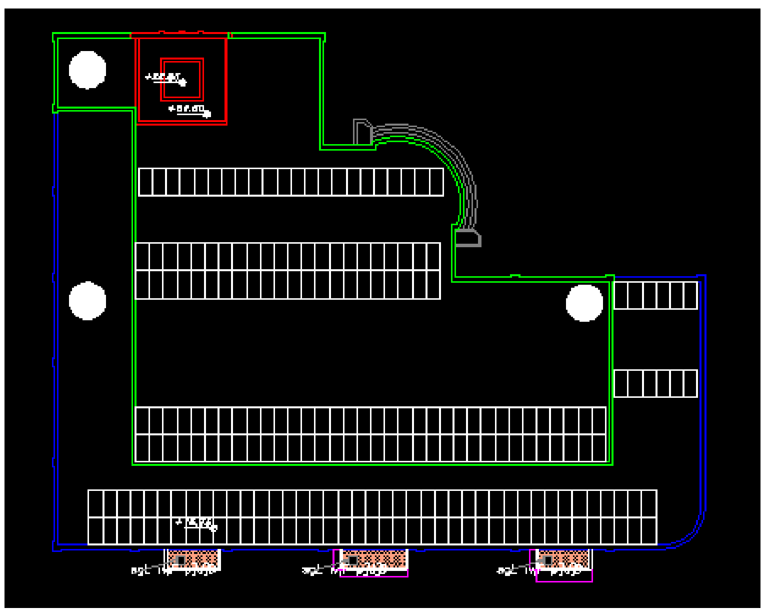

Figure 5. 7: Distribution of wind- PV hybrid system on the rooftop for Al-Sharif Factory.

5.2.2.2 HOMER Simulation Result

Renewable energy rate of wind-PV hybrid renewable power generation system shown in Table 5.3.

Table 5. 3: *Renewable energy rate of wind-PV hybrid renewable power generation system.*

production	kWh/year	%
Hanwha Q CELLS325Q.PLUS L-G5 325	118,862	31.4
AWS HC 5.1kW Wind Turbine	20,891	5.52
Grid Purchases	238,891	63.1

Figure 5.8 show the monthly average electric production for wind/photovoltaic hybrid renewable power generation system.

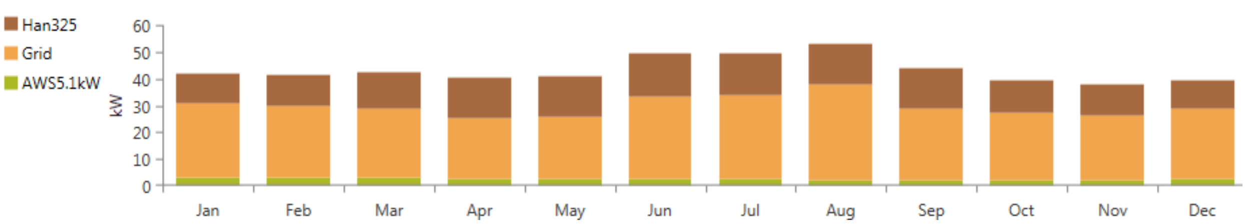

Figure 5. 8: Monthly average electric production.

The figure below (Figure 5.9) shows PV output during a year.

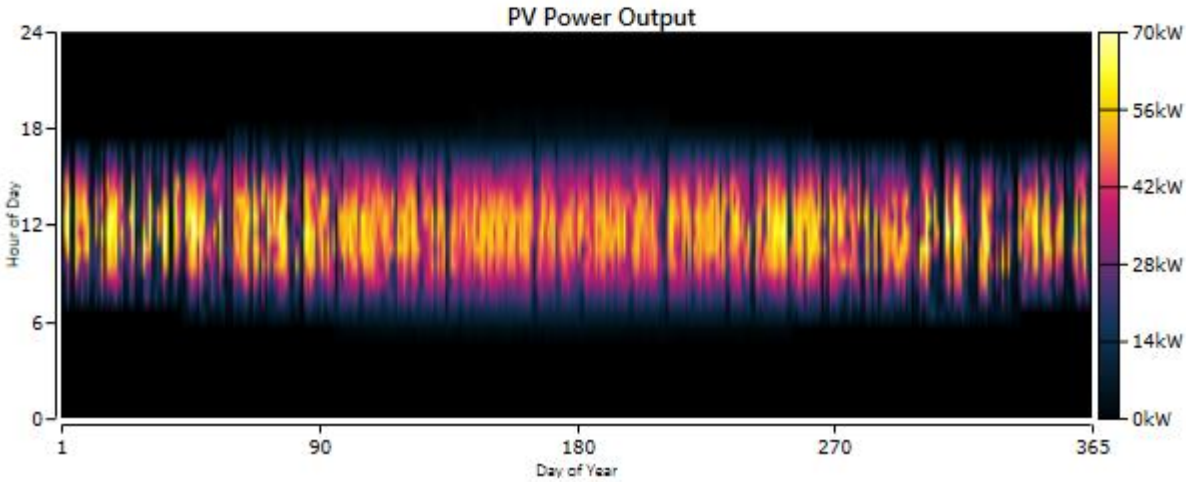

Figure 5. 9: PV output during a year.

And the figure below (Figure 5.10) shows wind turbine output during a year.

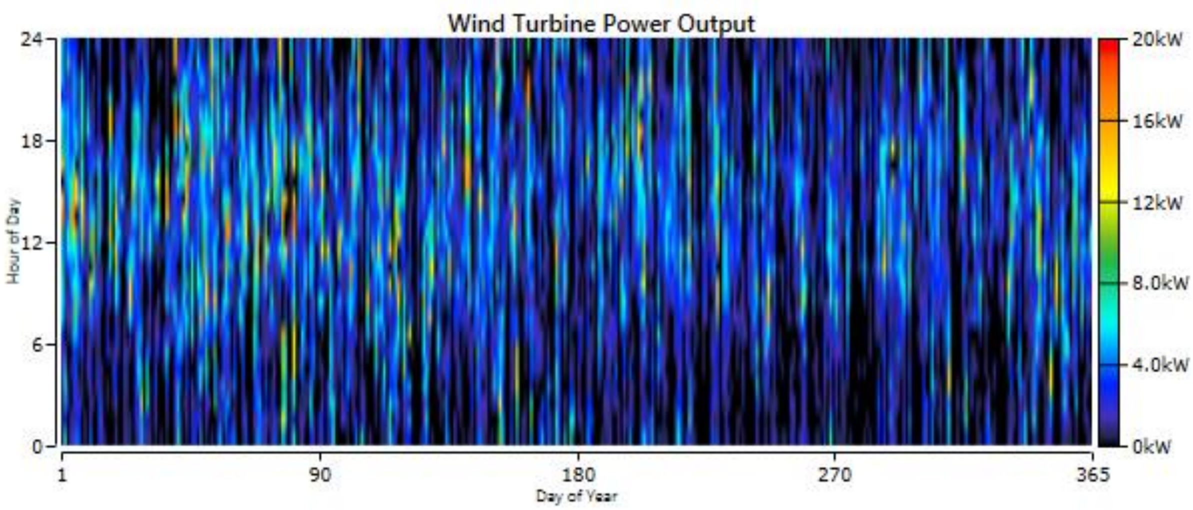

Figure 5. 10: wind turbine output during a year.

The figure below (Figure 5.11) shows Monthly costs of energy sold and purchased.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
January	20,854	1,961	18,893	152	$ 4,072.76	$ 0
February	17,811	2,202	15,609	175	$ 3,452.15	$ 0
March	18,998	2,867	16,132	138	$ 3,656.34	$ 0
April	16,233	2,767	13,466	129	$ 3,108.22	$ 0
May	17,408	2,884	14,524	136	$ 3,337.44	$ 0
June	22,237	2,844	19,393	182	$ 4,305.12	$ 0
July	23,250	2,627	20,623	194	$ 4,518.58	$ 0
August	26,494	2,405	24,089	182	$ 5,178.58	$ 0
September	19,462	2,545	16,917	188	$ 3,765.19	$ 0
October	18,752	2,182	16,571	127	$ 3,641.37	$ 0
November	17,675	2,401	15,274	134	$ 3,414.98	$ 0
December	19,716	1,949	17,767	161	$ 3,845.75	$ 0
Annual	238,891	29,633	209,258	194	$ 46,296.5	$ 0

Figure 5. 11: Monthly costs of energy sold and purchased.

The simple payback of this investment is nine years and ten months.

Table 5.4 show the Economic analysis for wind / photovoltaic hybrid system.

Table 5. 4: *Economic analysis for wind / photovoltaic hybrid system.*

Parameters	Cost $
capital cost	49,883 $
Operation and maintenance cost	633,135 $
Levelized COE	0.178 $
Total NPC	690,300$
Operating cost	49,540 $

6

Chapter Six

Summary

6.1 Summary

6.2 Recommendations

6.1 Summary

The on grid/wind-photovoltaic hybrid renewable power generation system. Is the optimum system configuration to meet a part of the energy needs of Al-Sharif Factory, 3 wind turbines of 5.1 kW AWS model, 74 kW PV panel and 3 converters of 30 kW. The initial investment, operation and total net present cost of the optimum renewable power generation system is $49,883, $49,540 and 690,300$ respectively. The simple payback of this investment is nine years and ten months. The output energy rate of wind and photovoltaic hybrid renewable power generation system of the demand is 5.52% , 31.5 % respectively.

Photovoltaic renewable power generation system. The model consists of 228 PV panels and 3 inverters with a power of 30 kw. The initial investment, operation and total net present cost of the optimum renewable power generation system is $28,278, $53,307 and $714,412 respectively. The unit energy cost of the renewable power generation system equals 0.0174$ /kWh. The simple payback of this investment is six years . The output energy rate of photovoltaic renewable power generation system of the demand is 31.5 %.

6.2 Recommendations

- In this project, the load analysis is the predicted value. If the power suppliers can provide the real load data, the project will be more accuracy.

- In the simulation section, the statistical solar and wind speed data is used. If the real time weather data is used to make the simulation, the results will have better persuasion.

- Consideration must be given to the locations of solar cells and wind turbines so more than one scenario should be taken to get the optimized solution.

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Appendix A Datasheet for The PV Panel

Q.POWER L-G5 315-335

POLYCRYSTALLINE SOLAR MODULE

The new Q.POWER L-G5 is the result of the continued evolution of our polycrystalline solar modules. Thanks to improved power yield, excellent reliability and high-level operational safety, the new Q.POWER L-G5 generates electricity at a low cost (LCOE) and is suitable for a wide range of applications.

SUPERIOR YIELD
High power output thanks to advanced 6-busbar technology and outstanding performance under real-life conditions.

LOW LEVELISED COST OF ELECTRICITY
Higher yield per surface area, lower BOS costs, higher power classes and an efficiency rate of up to 17.5%.

INNOVATIVE ALL-WEATHER TECHNOLOGY
Optimal yields, whatever the weather with excellent low-light and temperature behaviour.

EXTREME WEATHER RATING
High-tech aluminium alloy frame, certified for high snow (5400 Pa) and wind loads (2400 Pa).

MAXIMUM COST REDUCTIONS
Lower logistics costs due to higher module capacity per box.

A RELIABLE INVESTMENT
Inclusive 12-year product warranty and 25-year linear performance warranty[1].

[1] See data sheet on rear for further information.

THE IDEAL SOLUTION FOR:

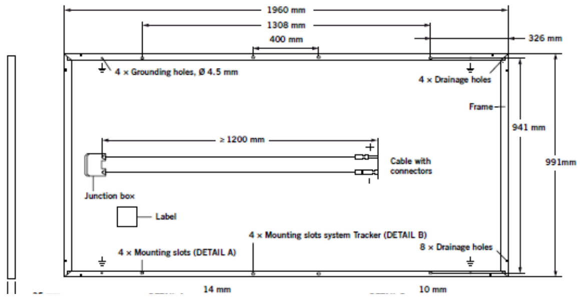
Ground-mounted solar power plants

Engineered in **Germany**

Q CELLS

MECHANICAL SPECIFICATION

Format	1960 mm × 991 mm × 35 mm (including frame)
Weight	22.5 kg ±5%
Front Cover	3.2 mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Multi-layer composite sheet
Frame	Anodised aluminium
Cell	6 × 12 polycrystalline solar cells
Junction box	Protection class IP67 or IP68, with bypass diodes
Cable	4 mm² Solar cable; (+) ≥1200 mm, (-) ≥1200 mm
Connector	Intermateable connector with H4, MC4

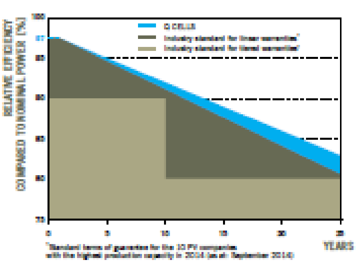


ELECTRICAL CHARACTERISTICS

POWER CLASS				315	320	325	330	335
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / -0 W)								
Minimum	Power at MPP[2]	P_{MPP}	[W]	315	320	325	330	335
	Short Circuit Current*	I_{SC}	[A]	9.11	9.15	9.20	9.30	9.40
	Open Circuit Voltage*	V_{OC}	[V]	45.7	45.8	46.0	46.1	46.3
	Current at MPP*	I_{MPP}	[A]	8.50	8.61	8.67	8.76	8.87
	Voltage at MPP*	V_{MPP}	[V]	37.1	37.2	37.5	37.7	37.8
	Efficiency[2]	η	[%]	≥16.2	≥16.4	≥16.7	≥16.9	≥17.2
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NOC[3]								
Minimum	Power at MPP[2]	P_{MPP}	[W]	232	235	239	243	247
	Short Circuit Current*	I_{SC}	[A]	7.37	7.40	7.44	7.52	7.60
	Open Circuit Voltage*	V_{OC}	[V]	42.9	43.0	43.1	43.2	43.4
	Current at MPP*	I_{MPP}	[A]	6.79	6.88	6.93	7.00	7.09
	Voltage at MPP*	V_{MPP}	[V]	34.1	34.2	34.5	34.7	34.8

[1] 1000 W/m², 25 °C, spectrum AM 1.5G   [2] Measurement tolerances STC ±3%; NOC ±5%   [3] 800 W/m², NOCT, spectrum AM 1.5G   * typical values, actual values may differ

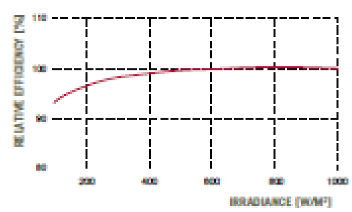
Q CELLS PERFORMANCE WARRANTY



At least 97% of nominal power during first year. Thereafter max. 0.6% degradation per year.
At least 91.6% of nominal power up to 10 years.
At least 83.0% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organization of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[%/K]	+0.05	Temperature Coefficient of V_{OC}	β	[%/K]	-0.31
Temperature Coefficient of P_{MPP}	γ	[%/K]	-0.40	Normal Operating Cell Temperature	NOCT	[°C]	45±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1000 (IEC), 1500 (IEC)	Safety Class	II
Maximum Reverse Current	I_R	[A]	20	Fire Rating	C
Push/Pull Load (Test-load in accordance with IEC 61215)		[Pa]	5400/2400	Permitted Module Temperature On Continuous Duty	-40 °C up to +85 °C

QUALIFICATIONS AND CERTIFICATES

IEC 61215, IEC 61730, Conformity to CE, Application Class A

PARTNER

NOTE: Installation instructions must be followed. See the installation and operating manual or contact our technical service department for further information on approved installation and use of this product.

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Engineered in **Germany**

Appendix B Datasheet for The Inverter

Solar inverters

ABB string inverters
TRIO-27.6-TL-OUTD-S2X-400/JP
27.6 kW

The three-phase commercial inverter offers more flexibility and control to installers who have large installations with varying aspects or orientations.

The dual input section containing two, independent Maximum Power Point Tracking (MPPT), allows optimal energy harvesting from two sub-arrays oriented in different directions.

The TRIO features a high speed and precise MPPT algorithm for real power tracking and improved energy harvesting.

High efficiency at all output levels

Flat efficiency curves ensure high efficiency at all output levels ensuring consistent and stable performance across the entire input voltage and output power range.

This device has an efficiency rating of up to 98.2%.

The very wide input voltage range makes the inverter suitable for installations with reduced string size.

In addition to its new look, this inverter has new features including a special built-in heat sink compartment and front panel display system. The unit is free of electrolytic capacitors, leading to a longer product lifetime.

Highlights of the improved design – first time shown at Intersolar 2014

- True three-phase bridge topology for DC/AC output converter
- Transformerless topology
- Each inverter is set on specific grid codes which can be selected in the field
- Detachable wiring box to allow an easy installation
- Wide input range
- 'Electrolyte-free' power converter to further increase the life expectancy and long term reliability

Power and productivity
for a better world™

ABB string inverters

Additional highlights

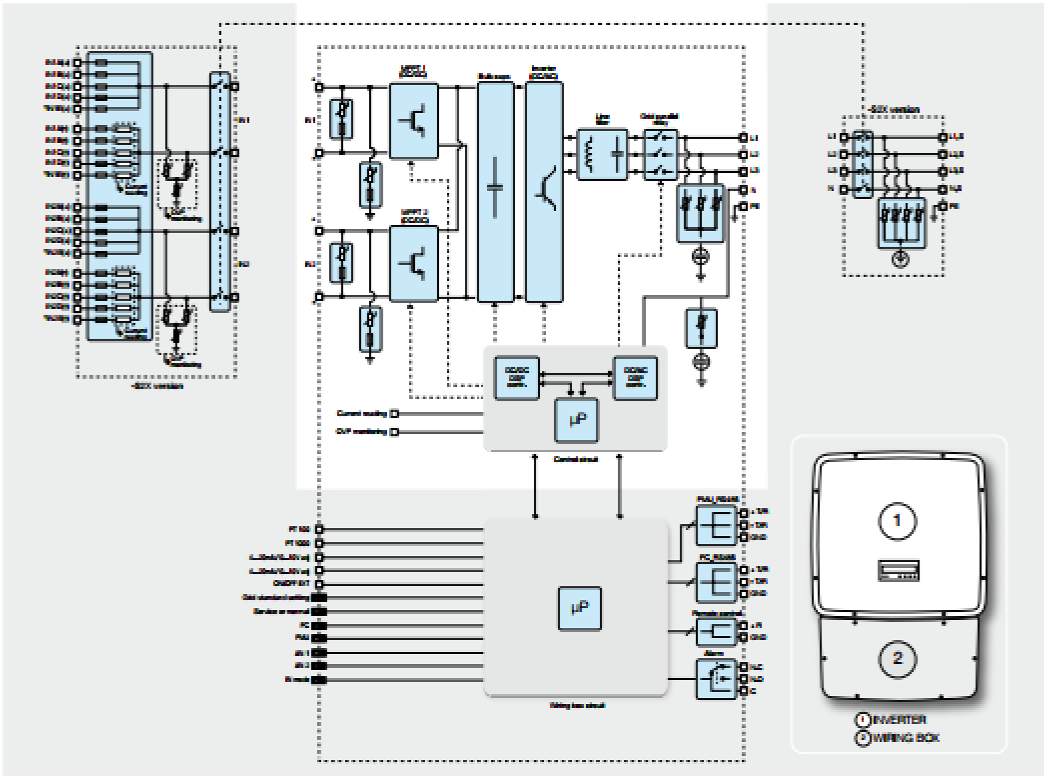
- Integrated string combiner with different options of configuration which include DC and AC disconnect switch in compliance with international standards
- Natural convection cooling for maximum reliability
- Outdoor enclosure for unrestricted use under any environmental conditions
- Capability to connect external sensors for monitoring environmental conditions
- Availability of auxiliary DC output voltage (24V, 300mA)

Technical data and types

Type code	TRIO-27.6-TL-OUTD-S2X-400/JP
Input side	
Absolute maximum DC input voltage ($V_{max,abs}$)	1000 V
Start-up DC input voltage (V_{start})	430 V (adj. 250…500 V)
Operating DC input voltage range ($V_{dcmin}…V_{dcmax}$)	0.7 x V_{start}…950 V
Rated DC input voltage (V_{dcr})	620 V
Rated DC input power (P_{dcr})	28600 W
Number of independent MPPT	2
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	16000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	500…800 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [800V≤V_{MPPT}≤950V]
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr} , max unbalance example	16000 W [500V≤V_{MPPT}≤800V] the other channel: P_{dcr}-16000W [400V≤V_{MPPT}≤800V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	64.0 A / 32.0 A
Maximum input short circuit current for each MPPT	40.0 A
Number of DC inputs pairs for each MPPT	5
DC connection type	Tool Free PV connector WM / MC4
Input protection	
Reverse polarity protection	Protection for inverter only, from current limited source, with max 2 string connected
Input over voltage protection for each MPPT - varistor	2
Input over voltage protection for each MPPT - plug in modular surge arrester (-S2X version)	3 (Class II)
DC switch rating for each MPPT (version with DC switch)	40 A / 1000 V
Fuse rating (versions with fuses)	15 A / 1000 V

Output side	
AC grid connection type	Three Phase 3W+PE or Three phase 3W+N+PE
Rated AC power (P_{acr} @cosϕ=1)	27600 W
Maximum AC output power (P_{acmax} @cosϕ=1)	27600 W
Maximum apparent power (S_{max})	30000 VA
Rated AC grid voltage ($V_{ac,r}$)	400 V
AC voltage range	320…480 V
Maximum AC output current ($I_{ac,max}$)	45.0 A
Contributory fault current	46.0 A
Rated output frequency (f_r)	50 Hz / 60 Hz
Output frequency range ($f_{min}…f_{max}$)	47…53 Hz / 57…63 Hz
Nominal power factor and adjustable range	>0.995 Adj ± 0.8 with max 30kVA
Harmonic Distortion of Current	each <3%, total<5%
AC connection type	Screw terminal block, cable gland PG36

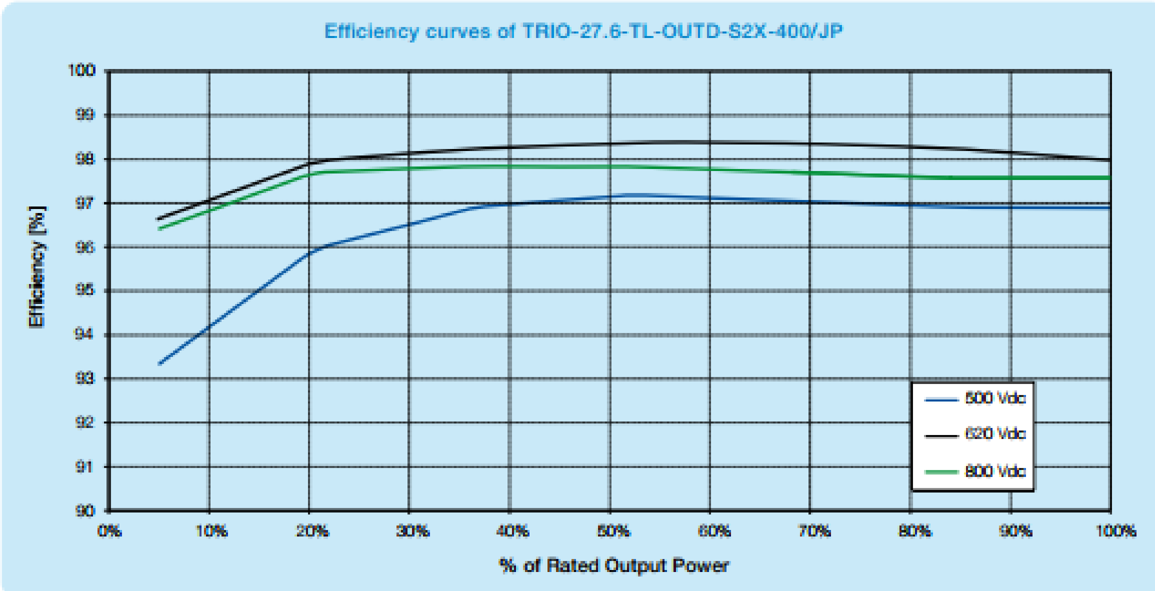
Block diagram of TRIO-27.6-TL-OUTD-S2X-400/JP



Technical data and types

Type code	TRIO-27.6-TL-OUTD-S2X-400/JP
Output protection	
Anti-islanding protection	Passive, Active
Maximum AC overcurrent protection	46.0 A
Output overvoltage protection - varistor	4
Output overvoltage protection - plug in modular surge arrester (-S2X version)	4 (Class II)
Operating performance	
Maximum efficiency (η_{max})	98.2%
Weighted efficiency (EURO/CEC)	98.0% / 98.0%
Feed in power threshold	40 W
Stand-by consumption	< 8W
Communication	
Wired local monitoring	PVI-USB-RS232_485 (opt.)
Remote monitoring	VSN700 Data Logger (opt.)
User interface	Graphic display
Environmental	
Ambient temperature range	-25...+60°C /-13...140°F with derating above 45°C/113°F
Relative humidity	0...100% condensing
Sound Power Level in accordance with ISO3741	<53 dB(A)
Maximum operating altitude without derating	2000 m / 6560 ft
Physical	
Environmental protection rating	IP 65
Cooling	Natural
Dimension (H x W x D)	1061 mm x 702 mm x 292 mm
Weight	65 kg inverter + 15 Kg wiring box
Mounting system	Wall bracket
Safety	
Isolation level	Transformerless

Remark. Features not specifically listed in the present data sheet are not included in the product



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Support and service
ABB supports its customers with dedicated, global service organization in more than 60 countries and strong regional and national technical partner networks providing complete range of life cycle services.

For more information please contact your local ABB representative or visit:

www.abb.com/solarinverters

www.abb.com

Appendix C Datasheet for The Wind Turbine

AWS™ AUSTRALIAN WIND AND SOLAR

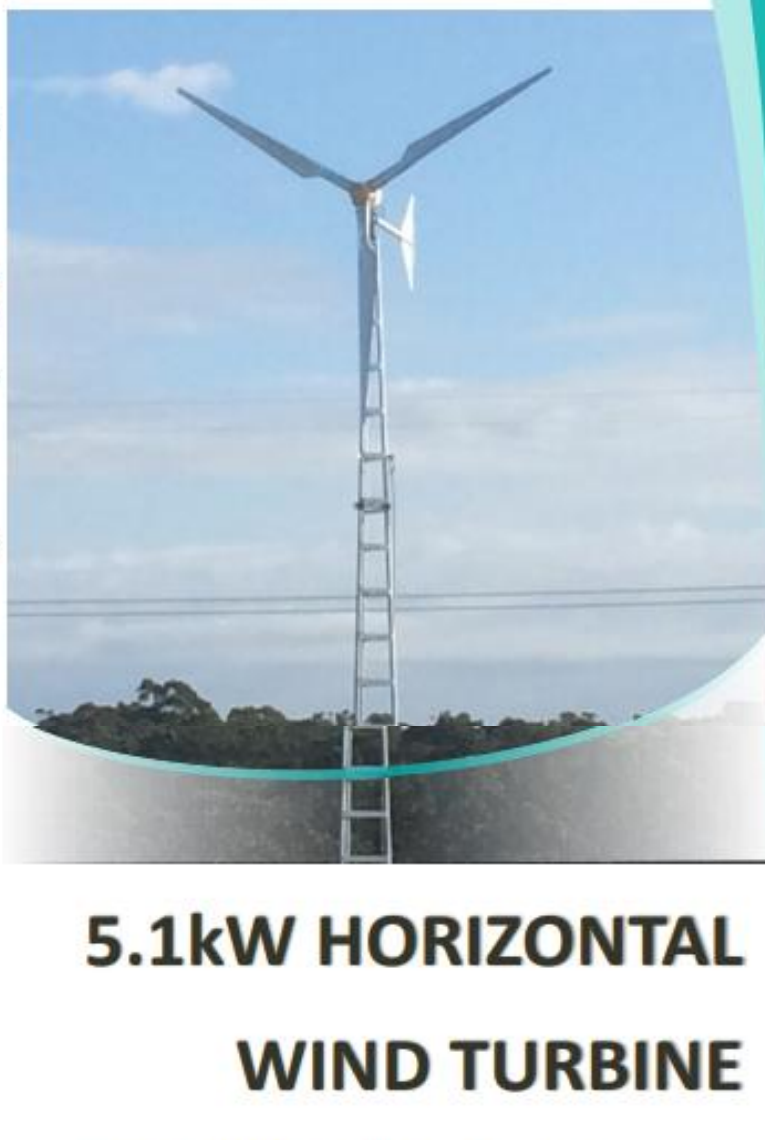
Your best solution for all your power needs

AWS - HC 5.1kW

AWS HC are the next evolution in Horizontal Wind Turbines. AWS HC Wind Turbines have the lowest start -up speed in their class, highest efficiency, superior build quality, including cast body, carbon-fibre blades and revolutionary full body passive pitch control. AWS HC Wind Turbines can operate at full capacity in all wind conditions whilst protecting itself in extreme weather conditions. AWS HC Wind Turbines have a minimum 20 year life expectancy.

AWS HC Wind Controller is available in 12V, 24V, 48V or Grid Connect. It offers superior performance with absolute Wind Turbine protection. It includes power smoothing and surge protection.

There are a range of sizes available: 650W, 1.5kW, 1.8kW, 3.3kW, 4.2kW, 5.1kW.



5.1kW HORIZONTAL WIND TURBINE

www.australianwindandsolar.com

MODEL	AWS—HC 5.1kW
RATED OUTPUT	5100W
RATED WIND SPEED m/s / mph	11 / 25
PEAK OUTPUT	5700W
CUT IN m/s / mph	2.7 / 6
YAW SYSTEM	Passive by tail Vane
YAW / TOWER CABLE	N x 360^{0} Freedom
GENERATOR	PM 3 phase alternator (variable speed)
INSULATION CLASS & EFFICIENCY	Class "H" > 87%
STATOR SKEW	1 slot pitch
MAX STATOR CORE TEMPERATURE	180°C
POLES	16
RPM—50hz/60hz	375 / 450
OVER SPEED LIMIT RPM / Hz	525 / 70
MONTHLY KWH 10mph / 4.5 m/s PLF %	500 kWh (18%)
MONTHLY KWH 12mph / 5.4 m/s PLF (%)	900 kWh (25%)
ROTOR DIAMETER	5.24m / 17.20ft
NUMBER OF BLADES	3
BLADE MATERIAL & COMPOSITION	Carbon fibre composite ~ 0.37
SWEPT AREA	21.4 sq.m / 230 sq.feet
MINIMUM TIP CLEARANCE cm / in	36 / 14
TIP SPEED RATIO (TSR)	8.5
LATERAL THRUST (MAX)	4200 nts
GOVERNOR / OVER SPEED LIMIT	Uptilt tilt (Hydraulic assisted)
GOVERN SPEED	27mph
GOV. SHUT-DOWN / OPTIONAL STOP	Electro-dynamic Switch
UNIT WEIGHT (TOWER TOP)	99Kg
TOWER TOP PIPE / YAW ADAPTOR	P 2.5" Shd 40
VOLTAGE OPTIONS	48 LV / 60—240 HV / 380—440 EHV
ELECTRONIC CONTROLLER	Incl. but separate
WARRANTY	2 years
OPERATING LIFE	20 years
SURVIVAL WIND SPEED	55 m/s
SUGGESTED ROUTINE MAINTENANCE	Annual inspection

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ND AND SOLAR

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