

**T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES**



DESIGN OF HIGHLY EFFICIENT PV SYSTEM IN THE UAE

MASTER'S THESIS

Dana NASSER EDDIN

**Department of Energy Technologies
Energy Technologies Program**

AUGUST, 2023

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AUGUST, 2023

ONAY FORMU



DECLARATION

I hereby declare with the respect that the study “Design of highly efficient PV system in the UAE”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References. (14/08/2023)

Dana NASSER EDDIN

FOREWORD

Firstly, all my appreciation to my supervisor and guide throughout my study years, Prof. Dr. Murtaza FARSADI, and the Graduate studies institute of Istanbul Aydin University, Department of Energy Technology. Secondly, with so much love and respect to my parents and forever biggest supporters, I'm finishing this work with gratitude in hopes of making you proud. Finally, thank you to my siblings who stood by my side all the way, please accept my hard work as a gift for your endless kindness.

August, 2023

Dana NASSER EDDIN

DESIGN OF HIGHLY EFFICIENT PV SYSTEM IN THE UAE

ABSTRACT

This is an attempt to design an efficient PV system with 1 MW capacity in the UAE using SAM software provided by National Renewable Energy Laboratory (NREL). The project took place in three different cities in the country to analyze the geological factors and impacts affecting the PV system efficiency and overall performance. In the same token, the project compared three other different conditions within each city. The comparison investigated the mechanical and electrical aspects of the power plant, noting that the type of PV panels, capacity, and inverter type were fixed values to simplify the financial analysis.

Keywords: PV system, inverter, NREL, solar energy

SOLAR APLİKASYONLAR İÇİN YÜKSEK KAZANIMLI DA/DA ÇEVİRİCİ TASARLANMASI

ÖZET

Bu, Ulusal Yenilenebilir Enerji Laboratuvarı (NREL) tarafından sağlanan SAM yazılımını kullanarak BAE’de 1 MW kapasiteli verimli bir PV sistemi tasarlama girişimidir. Proje, PV sistem verimliliğini ve genel performansı etkileyen jeolojik faktörleri ve etkileri analiz etmek için ülkedeki üç farklı şehirde gerçekleştirildi. Aynı şekilde proje, her şehirdeki diğer üç farklı koşulu karşılaştırdı. Karşılaştırma, PV panel tipi, kapasite ve inverter tipinin finansal analizi basitleştirmek için sabit değerler olduğuna dikkat çekerek, santralin mekanik ve elektriksel yönlerini araştırdı.

Anahtar Kelimeler: PV sistemi, çevirici, NREL, Güneş enerjisi

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ABBREVIATIONS

DC : Direct Current

kW : Kilowatt

MPPT : Maximum Power Point Tracker

PV : Photovoltaic

AC : Alternating current



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I. INTRODUCTION

A. Statement of the Case

The constant global population growth obligates energy production to increase its supply to meet the global energy demand. Thus, the energy production process is going more reliable, cost-efficient, and sustainable for a stable future. Therefore, solar energy, as renewable energy, is considered an auspicious and attractive energy source for electricity production as it offers an unlimited source of energy to avoid any global energy crisis. Moreover, solar energy systems came as an alternative to conventional energy production, such as fossil-fueled plants (Kannan & Vakeesan, 2016).

Using renewable energy has many positive effects on the economy and environment. However, unfortunately, conventional energy production systems are the primary source of pollution, as conventional power plants release greenhouse emissions into the atmosphere and the surrounding environment, causing severe consequences that cost lives and money. Therefore, eco-friendly practices are highly encouraged in the energy sector to provide a green and sustainable for future generations. Thus, many countries established PV power plants ranging from a few kW to MW (Kannan & Vakeesan, 2016).

Solar energy systems suit the world's demand for energy for many reasons. First, it is the most abundant energy source on Earth, as the sun emits 3.8×10^{23} kW of radiation, where the Earth intercepts 1.8×10^{14} kW of it, shown in Figure 1, the global horizontal irradiation. Second, solar energy hits the Earth in heat and light forms, giving more options for electricity production procedure and its constant increment in efficiency, allowing for stability in production with constant advancement (Kannan & Vakeesan, 2016).

Solar PV power plants are the most commonly used production systems. This type of technology converts sunlight into electricity directly by producing DC. Not needing a medium for energy conversion makes it very convenient and easy to use. In addition, PV systems can produce a massive amount of electricity from a relatively

small input, making the input-output ratio very attractive. This quality of PV systems has helped develop and utilize the technology in many practical applications (Kannan & Vakeesan, 2016).

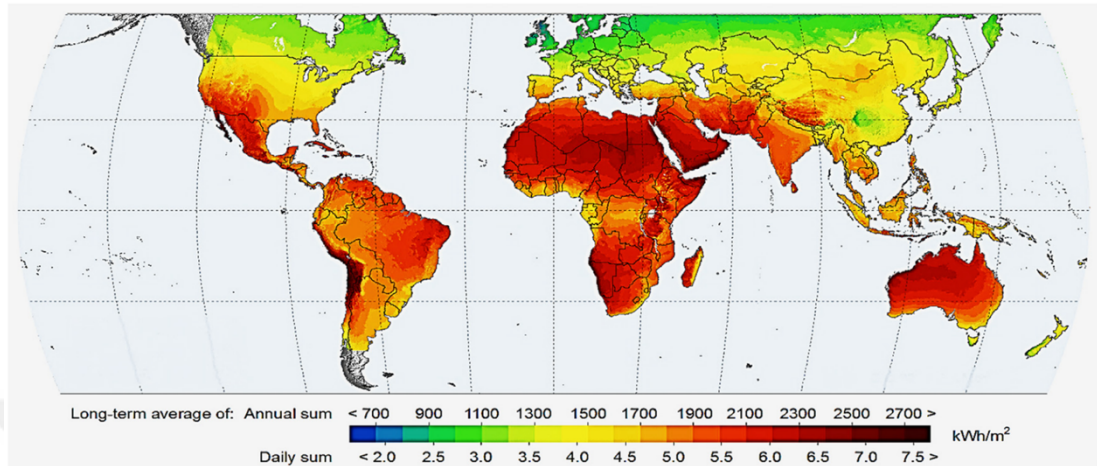


Figure 1 Global Horizontal Irradiation (Kannan & Vakeesan, 2016)

Furthermore, United Arab Emirates is one of the countries with the highest carbon emissions rate in the world, ranking the 4th in years 2006, 2008, and 2010 (Mokri et al., 2013). The numbers of carbon emissions indicate the high demand of energy per capita in the country as well as the type of typical energy generation power plants being conventional. The average consumption of electricity in the UAE is 4.5 times the world's average, in Figure 2, the amounts of CO₂ emissions of the UAE vs. the world are shown.

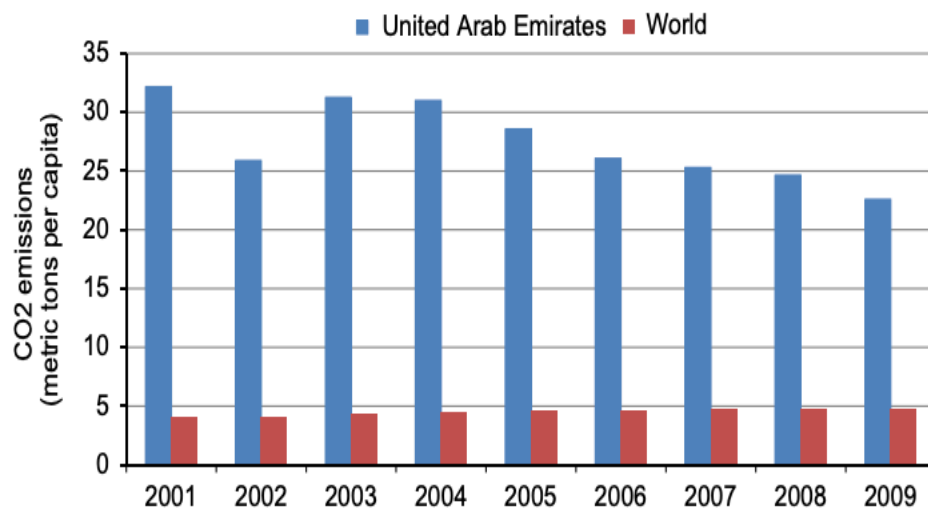


Figure 2 Carbon emission of the UAE vs. the world (Mokri et al., 2013)

According to (Jamil et al., 2016), PV power plants already take a significant place in the energy generation field in the UAE. The total installed capacity of PV power plants is reported to be 22.5 MW and is the most promising type of renewable energy in the county. However, it is stated by (Jamil et al. 2016: 5) that the average efficiency of a typical PV system is 4.82%, with a 30% drop in efficiency of the system that is referred to as Staebler Wronski effect. (Ramachandran et al., 2022) stated that the UAE's government has developed policies and strategies to increase the dependency on renewable energy resources rather than conventional power plants for energy generation. It is reported that by 2030, the PV solar system will grow reaching more than 400 MW of installed capacity.

B. Main Purpose of the Study, Aim of Study

Solar PV systems play a vital role in the energy production sector. As the population is proliferating, the need for energy is constantly rising too. Utilizing PV systems for energy production can spare the world many of the negative impacts caused by conventional energy production systems such as fossil fuels. Moreover, electricity production capacity mainly depends on the amount and the quality of solar radiation absorbed during the day, as well as the efficiency and cost of the solar panels. However, this would not be an issue in the Middle East, especially the United Arab Emirates, considering its long hot days. Furthermore, the UAE is in the Arabian Gulf, with a total annual solar radiation of 2285 kWh/m² (Al-Shamisi et al., 2013). Therefore, the UAE's location is good for establishing an effective PV system to produce sufficient electricity to feed the local demand.

The project aims to design an efficient PV system in the UAE to enhance the country's energy production industry, which will support the UAE's ambitious goals to go green and adopt sustainable practices to feed the local energy market. The design process will depend on the following:

- Location comparison for an optimal solution.
- Variation of inputs.

The thesis mainly focuses on the energy output after running the designed simulation. Considering constant variables such as PV panel type and system capacity, the desired result is a maximum power output in each simulation run in different cities in the UAE. The project considers the economic aspect less than the technical and mechanical ones due to the limited sources and database of the simulation software.

Initially, the work started with studying and investigating regular and advanced PV systems worldwide. With the focus on the PV system components, the MPPT mechanism, inverter, and PV cells are the most highlighted instruments in the scope of the study. The design simulation runs using SAM software provided by the NREL as an open source.



II. LITERATURE REVIEW

A. Overview

All societies around the world have been relying on energy for a very long time, which enabled us to get to the level of advancement we currently live in; to keep our societies growing, we had to keep increasing our energy consumption year by year reaching an increase of 2.1% in 2011-2012 which later approximately doubled, the increase in energy consumption does not stop there and is expected to increase much more by 2040 (Aman et al., 2015). The most exploited source of energy has been fossil fuels that include coal, oil, and natural gas. Due to this high energy demand, the use of fossil fuels has created much bigger problems than meeting the market demand including climate change (Johnsson et al., 2018), emissions of carbon dioxide, methane, nitrous oxide, and other environmental pollutions and threats (Dell & Rand, 2004). On the other hand, fossil fuels are not the only problematic sources of energy, one of the oldest used sources of fuels was wood even before fossil fuels were getting exploited, and it is still being used domestically for multiple purposes (Dell & Rand, 2004). Therefore, an alternative source of energy was deemed necessary, and this brought different types of renewable energy to light.

Clean, renewable forms of energy include solar, wind, biomass, tidal, and geothermal energy, each is used in different regions of the world, for different reasons, and at different circumstances (Alrikabi, 2014:2). One of the cleanest forms of renewable energy that comes with a lot of advantages is solar energy (Aman et al., 2015), some of the reasons that made this specific form of renewable energy so popular are its low costs, abundance, and usability in a variety of applications (Rabaia et al., 2021). However, solar energy is not as simple and straightforward as it sounds, in other words, it is not the simple transformation of the radiation coming from the sun to electricity; solar energy includes a variety of different technologies and approaches

through which this energy is extracted, stored, later used, and a bunch of things in-between (Aman et al., 2015).

B. PV System Components

1. PV Panel

One of the most promising and common ways of converting solar radiation so it could generate electricity is using photovoltaic panels as they have seen great success in the market with its equipment being installed over 20 times more in 2009 compared to 8 years prior to that (Tiberiu Tudorache et al., 2012), one of the reasons that explain this incredible success of PV systems is their ability to convert the absorbed solar radiation into electricity instantaneously and without a high mechanical complexity (Yilmaz et al., 2015). The simplest way of explaining what exactly PV panels do is that they are a collection of photovoltaic cells that are assembled together and organized in frames to create a bigger system called the photovoltaic system, the solar radiation absorbed by that system would later be converted into electricity and heat (Van Helden et al., 2004). However, those panels do not absorb a 100% of the solar radiation, and the radiation that was indeed absorbed would not all be converted into electricity. An important concept that should be in mind when trying to understand the mechanism and levels of efficiency of PV panels is the bandgap, and the way to understand the bandgap could be by thinking of it as a threshold for absorption; just like how, for example, the membrane potential needs to increase from -70mV to at least around -55mV in order for the neurons to fire an action potential(Barnett &

Larkman, 2007: 3), the photons need to have higher energy than the bandgap in order for them to be absorbed (Van Helden et al., 2004).

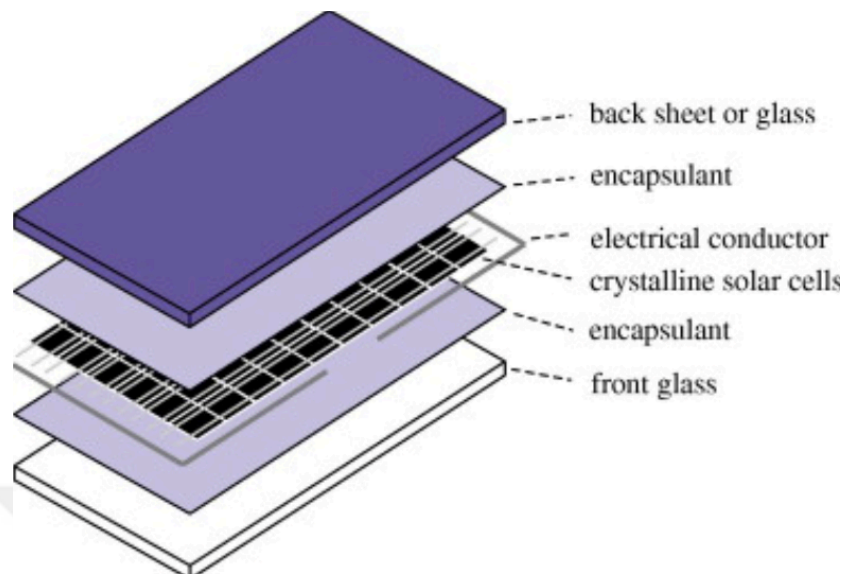


Figure 3 Components of crystalline solar modules (Van Helden et al., 2004)

2. PV Cell Mechanism

As discussed in section B.1, PV panels consist of many solar cells that work together to absorb solar radiation so that it can produce electricity. With the development of solar energy technologies, modern ones are now adopting a “electron hole creation” as the main approach in solar cells. The mechanism of this approach relies on a junction that consists of two layers called p-type and n-type that make up the panel’s semiconductor, if the photon coming from the solar radiation meets the bandgap (see section B.1) and hits the junction, that hit produces energy that pushes out an electron from the first layer to the next. This process is what creates the electron hole that is eventually responsible for the production of electricity (Sharma et al., 2015). Moreover, adding external voltage to this junction is referred to as biasing, and this bias can either be forward or reverse depending on which side of the battery terminal the p-side of the junction is connected to; if the latter is connected to the positive terminal, the hole as well as the electrons will start to move in each other’s direction, in other words, the electron current will be allowed to flow, this is called a forward bias. On the other hand, if the n-side of the junction is connected to the positive terminal of the battery while the p-side is connected to the negative terminal, the electrons and the holes will start to move farther away from each other and will not be

able to intermingle, which does not allow an electron current to flow which is called a reverse bias (Uhlir, 1958), see Figure 4 and Figure 5.

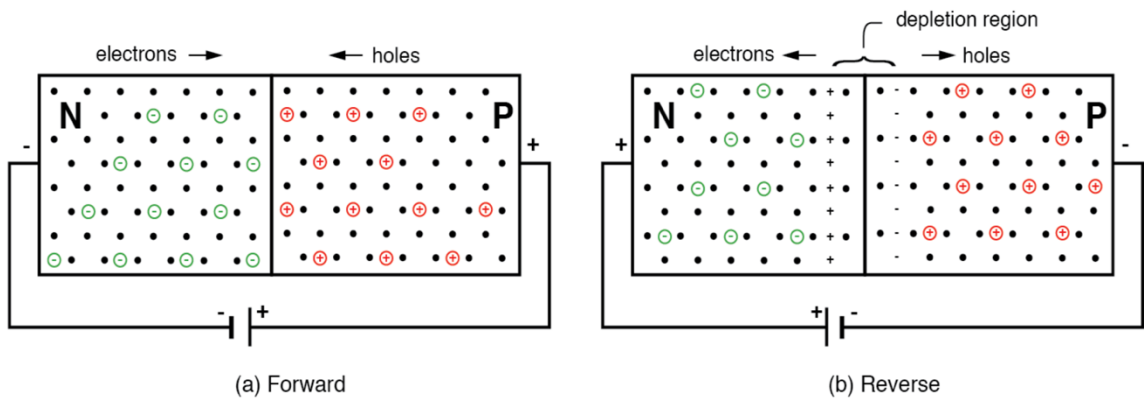


Figure 4 Forward vs. reverse P-N junction bias (Thar et al., 2020)

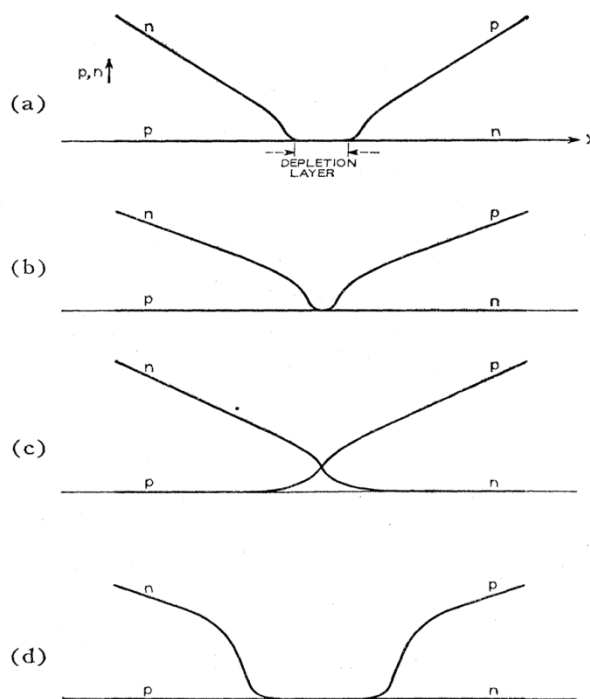


Figure 5 P-N junction at "(a) zero bias, (b) small forward, (c) large forward bias, (d) reverse bias." (Kumar et al., 2018)

3. Inverter

After understanding how different types of PV panels are manufactured, how efficient each is, and why would we choose one over the other, it's time to understand in further detail how a PV system operates when an assembly of panels are in place. After PV panels absorb solar radiation and this radiation is later converted into

electricity, which could be either of alternating current (AC) or of a direct current (DC) depending on which application it is needed for. Alternating current is a form of electricity that flows multi-directionally, to be more specific, it reverses its direction continuously as well as the magnitude of which these current flows and it cannot be stored (Bhargava et al., 2013:8–11). On the other hand, direct current (DC) is one-directional and storable. To convert alternating current into storable, one-directional direct current, we would need a converter (Siebert et al., 2002), and to convert direct current to alternating current, we would need an inverter (Kjaer et al., 2002). Alternating current is mostly used in businesses and residences for, for example, telecommunication tools, wall sockets, and other universal compatibilities, which is why inverters are of common use (schneider-electric.com, 2022).

As there are multiple types or versions of inverters, (Kjaer et al., 2002) categorized them into three distinct categories based on the point in timeline at which each was dominant or used. Starting with the past, (Kjaer et al., 2002) discussed the early type of inverter that was relied on which was centralized and linked to multiple connected modules making up a string. However, that technology was not close to being perfect, it had some downsides such as power losses and its need of direct current cables of very high voltage to connect the inverter to its modules as well as risk of hot spots if a PV cell got fully shadowed hence increasing the temperature inside that cell. On the other hand, the current inverter technologies used include string-inverters and AC-modules, the first solves the issues of power losses that were present in centralized inverters through single string per module and a single maximum power point tracking per string but does not contribute to a solution for the hot-spots risk. The latter, however, eliminates the risk of hot-spots as well as solves a different issue of centralized inverters which was the mismatch of modules and string diodes, increasing this technology's efficiency. Lastly, (Kjaer et al., 2002) suggest that a future technology using AC-cells that integrate the inverter to a great PV-cell could highly increase inverter efficiency.

Furthermore, inverters could work either on two-levels or on multilevel, each with its respective application. The main factor that determines whether a two-levels or a multilevel inverter is needed is the scale size of the industry in which an inverter is to be used, for industries of smaller scales, a two-levels inverter is enough for the

relatively low-power application in question. On the other hand, when the industry is that of high-power applications, a two-levels inverter could be of very low efficiency due to the high voltage stress it puts that increases the temperature to undesirable levels. In these cases, a multilevel inverter is the much more suitable option as it doesn't only work with higher efficiencies in these larger-scale industries applications but is also of low maintenance, these multilevel inverters work very well with renewable energy systems including solar energy systems (Mohd.Ali & Krishnaswamy, 2018), see Figure 6.

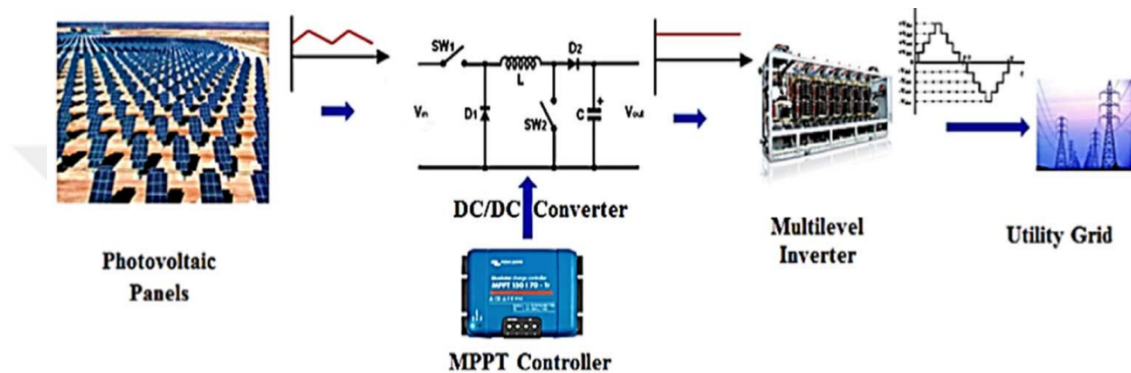


Figure 6 The use of a multilevel inverter in a solar system using PV panels (Thopil et al., 2020)

4. MPPT

In line with what has been discussed before, increasing efficiency and lifetime of the PV system rank very high-up in the priority list; some of the ways that have been discussed so far often used in increasing the technology's efficiency include using certain types of PV panels and certain types of power inverters. Furthermore, another way of doing so is by maximum power point tracking (MPPT) (Podder et al., 2019). Since, as mentioned earlier, different factors such as temperature and the climate could result in inconsistencies and shifts in the amount of irradiance the PV system is being exposed to, this is where the various MPPT methods come into play as they work to keep the system at a maximum power point (FARANDA & SONIA, 2008). One of the features of MPPT systems making them desirable and commonly used is their variability, more importantly is that most of these various types are work in both off-grid and on-grid PV systems (Podder et al., 2019).

C. Types of PV Panels

1. Monocrystalline PV Panels

Monocrystalline panels, the most commonly used type taking up around 80% of the market, use p–n junctions and are manufactured to reach a diameter of around 10-15cm using a method known as Czochralski through which a single crystal ingot is planted. After the ingot is complete, it is then cut into smaller pieces creating multiple highly thin wafers that will eventually make up the solar cell of 0.55 V. Even though monocrystalline panels could, in some cases, heat up which decreases their efficiency, they are still considered highly efficient overall as the highest efficiency level recorded while using this type of panels was 24.7%. A couple of other advantageous features of monocrystalline panels are their high life-expectancy and competitive prices (El Chaar et al., 2011).

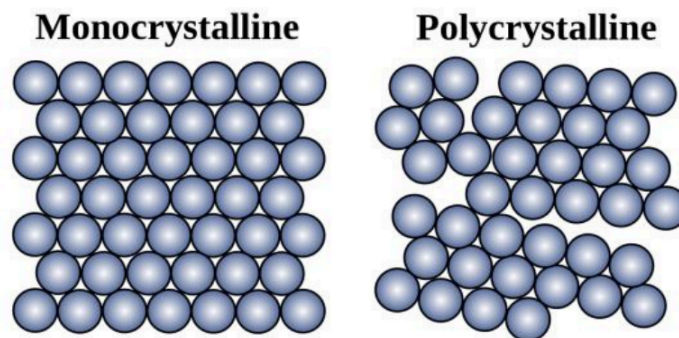


Figure 7 Crystal structure of monocrystalline panels vs. polycrystalline panels
(Green, 2000)

2. Polycrystalline PV Panels

On the other hand, polycrystalline panels also have a promising potential. This type of silicon-based panels is considered the cheaper option compared to monocrystalline panels, though their efficiency doesn't reach that of monocrystalline panels'. However, the main purpose of converting from mono- to polycrystalline panels is not their low costs but their ability to limit down the flaws observed in monocrystalline panels such as metal contamination. The main difference between the manufacturing of monocrystalline panels and the latter is that the ingot is created through melting and re-solidifying the silicon so that the crystals all face the same direction in a rectangular shape. Once the ingot is ready, it is made into wafers through

slicing it into blocks (El Chaar et al., 2011). Figure 6 shows the crystal structure distinction between mono- and polycrystalline panels.

3. Thin Film PV Panels

Lastly, thin film panels are considered the least efficient of around 10-14.5% but least expensive type of PV panels but the most environmental-friendly and sustainable in its production. Furthermore, one of the main reasons for choosing to use thin film technology is its high heat durability, this suitability for areas of extreme heat is due to its low temperature coefficient. On the other hand, and due to its different way of absorbing solar radiation compared to crystalline panels, thin film panels have the capability of producing more energy in areas that are not well exposed to sunlight or areas that are shadowed/partially shadowed compared to crystalline technologies (Thopil et al., 2020). Unlike the previously discussed types of PV panels, thin film panels are manufactured through a continuous process of extremely thin layers (hundreds of microns thinner than that of crystalline wafers') deposition via sputtering tools on top of either glass or stainless steel, and that thinness of the layers used in thin film panels is the reason behind its low efficiency compared to crystalline panels as thinner layers absorb less solar radiation. However, because those layers in thin film panels could be manufactured using different materials, it is still possible to increase the technology's efficiency (El Chaar et al., 2011).

D. Types of PV Systems

1. On-grid vs. Off-grid Systems

PV systems can be classified into 3 distinct types including on-grid, off-grid, and hybrid systems (Hassan, 2021:4). On-grid systems are the ones connected to a power grid from which electricity could reach consumers all over the surrounding area that is connected to that grid (Hassan, 2021:4) and account to approximately 99% of all PV systems installed and used around the world, this type of PV systems also have a relatively high efficiency as its performance ratio could reach up to 80% (Jinkala et al., 2016:1). By connecting the PV system to a grid, it eliminates the need of a battery

and makes this type of system cost-effective and of lower need of maintenance (Jinkala et al., 2016:1). In general, on-grid PV systems involve six main components, first, the PV module (made of any of the three main cell types which are monocrystalline, polycrystalline, and Si-amorph), junction box, on-grid inverter, AC disconnect and main panel, net meter, and electrical grid (Kumar et al., 2018).

Even though on-grid PV systems have high efficiency, cost-effectiveness, and low required maintenance, they still have undesirable potential impacts. One possible impact of using on-grid systems is reducing the lifetime of the supply system and potential malfunctions due to the used inverters' capability of causing harmonics, hence causing voltage drops. Another impact is of direct effect on the workers who might be working on the utility maintenance; in this type of system, the PV system does not necessarily always shut down when the grid power is off resulting in what's called "Islanding" that the workers may not always be aware of and thus pursue their work on an energized circuit (Jinkala et al., 2016).

On the other hand, off-grid systems or as they are sometimes called, stand-alone systems, are independent of power grids where the energy is produced, stored, and used in the same place, it is mostly used for isolated areas that are not connected to a power network that could distribute to them (Karthikeyan et al., 2017:3). For those areas that lack AC, off-grid PV systems behave as the source to provide AC to its users, and that AC's voltage level in these systems is around 220-250V. However, off-grid systems can also be of domestic use such as private devices including refrigerators, TV, lamps, and other household electronics (Akinsipe et al., 2020:25). The main distinction of this type of system is its use of a battery that stores the energy produced by the PV array so it can later be used, and the capacity of this battery bank is determined based on multiple factors such as the estimated load (ISHAQ et al., 2013:3), see Figure 8 in the appendix for the layout and components of the system.

2. Hybrid Systems

The third classification of PV systems is a combination of the previously discussed two systems; just like how an on-grid PV system produces electricity and delivers it to a grid that it is connected to, and an off-grid system keeps that electricity stored in a battery, a hybrid system combines the two and is connected to a grid and a

battery simultaneously (Thar et al., 2020:2), see Figure 9 in the appendix. One of the reasons behind using a hybrid system of the other two systems is often for maximum convenience, when the grid-connected part of the system produces electricity that can be used during the day, the off-grid part has a battery bank that can be used during the night, this helps when the provided energy is not sufficient (Khare & Rangnekar, 2013).

E. Efficiency Boosters

PV systems' efficiency has been mentioned multiple times throughout the previous sections, and as can be seen, there are many different factors that influence efficiency including the components from which the panel was structured, MPPT methods, and external variables (e.g., location, season, dust, sand, etc.) (Melis et al., 2014). When solar energy technologies' efficiency is discussed, it mostly means how much solar radiation is absorbed by the solar cells in relation to how much electricity can be produced by it (Stropnik & Stritih, 2016:3).

One of the main and most common reasons for efficiency drops in PV systems is the increase of the solar cells' temperature in the panel, this mainly happens due to most of the radiation being wasted in the form of heat with very little being converted into electricity; this overheating of the panel decreases its efficiency. However, PV panels can be cooled down either actively using fans directed at the panels or pumping water on them to absorb the heat, or passively by using certain types of metal on the surface like aluminum that can transfer the heat to the ambient (Stropnik & Stritih, 2016:4).

Some of the other factors that influence efficiency are concerned with the angle at which the panel is facing the sun depending on the ground level (Melis et al., 2014) and their arrangement (Kumar Behura et al., 2021), tilting the panel to the correct angle is crucial to ensure the right amount of sunlight is falling onto the surface of the panel which highly influences how much efficiency can be reached, see Fig 2.10. (Melis et al., 2014). On the other hand, one of the things to keep in mind when arranging PV panels is the row spacing, inadequate spacing include very small spacing that doesn't allow enough airflow to help with heat reduction and very big spacing that doesn't utilize the area efficiently (Kumar Behura et al., 2021:4). Therefore, if the panels are

arranged in a proper manner and tilted in the right angle, it can cut the energy losses and greatly boost the PV panels' efficiency.

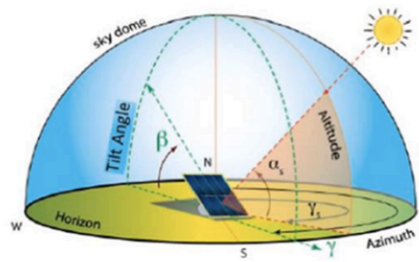


Figure 8 "Orientation of solar tilt and azimuth angle" (Kumar Behura et al., 2021:4).



III. METHODOLOGY

A. Introduction

Chapter III will discuss the method of the conducted project as well as the software and all extra accessories used. The project was carried out using SAM software. The software provides many feature for PV project simulations, the results can contain economic analysis, losses analysis, shading analysis, and many other features. However, in this project only the losses analysis was considered beside the default setting of the software. In the next section, SAM software will be more explained.

B. Proposed PV System

The project is simulated using SAM software provided online by NREL. The software offers many variables and parameters to meet the desired aims and objectives of the PV system. However, the subjected parameters and conditions in this paper are shown in the table 1 below.

Table 1 PV System Simulation Sarameters.

Project system specifications	Conditions
Location (coordinates)	Module name
Average wind speed	Module specification

Average temperature	Module surface area
Global horizontal	Number of cells per module
Direct normal (beam)	Module output power
Diffuse horizontal	Inverter model
System size	Inverter capacity
	DC-AC ratio
	Angle
	Tilt angle
	Ground coverage ratio

The simulation is run in three different stages in three different cities for location optimization. The first stage is conducted under normal conditions such as normal temperatures and global horizontal. Whereas the second stage is run under modified conditions for comparison in ideal conditions of the project. Lastly, the last stage is run with adjustments to the electrical parts of the system such as number of MPPT.

C. Input Data For Phase 1

1. Location 1: Ras Al Khaimah (RAK)

Table 2 System Specifications – RAK.

Parameter	Value
Location (coordinates)	Ras Al Khaimah, United Arab Emirates 25.8007° N, 55.9762° E

Average wind speed	2.9 m/s
Average temperature	30.1 °C
Global horizontal	5.55 kWh/m ² /day
Direct normal (beam)	4.44 kWh/m ² /day
Diffuse horizontal	2.49 kWh/m ² /day
System size	1 MW

Table 11 in the appendix is showing the characteristics of the system under normal or first conditions.

2. Location 2: Dubai

Table 3 System Specifications- Dubai.

Parameter	Value
Location (coordinates)	Dubai, United Arab Emirates 25.2048° N, 55.2708° E
Average wind speed	3.1 m/s
Average temperature	29.0 °C
Global horizontal	5.85 kWh/m ² /day
Direct normal (beam)	5.11 kWh/m ² /day
Diffuse horizontal	2.39 kWh/m ² /day
System size	1 MW

Table 12 in the appendix is showing the characteristics of the system under normal or first conditions for Dubai city.

3. Location 3: Abu Dhabi (The Capital City)

Table 4 System Specifications- Abu Dhabi.

Parameter	Value
Location (coordinates)	Abu Dhabi, United Arab Emirates 24.4539° N, 54.3773° E
Average wind speed	3.2 m/s
Average temperature	28.5 °C
Global horizontal	5.88 kWh/m ² /day
Direct normal (beam)	5.12 kWh/m ² /day
Diffuse horizontal	2.40 kWh/m ² /day
System size	1 MW

See Table 13 in the appendix for phase 1 system characteristics of Abu Dhabi.

D. Input Data For Phase 2

For phase II, the changes are only made to the system specifications while the conditions remain unchanged except for tilt angle. The tilt angle changes from 20 degrees to 10.77 in all cities as the software suggested.

Table 5 Modified System Specifications- RAK.

Parameter	Value
Average temperature	29.9 °C

Global horizontal	5.73 kWh/m ² /day
Diffuse horizontal	2.40 kWh/m ² /day

Table 6 Modified Systems Specifications- Dubai.

Parameter	Value
Global horizontal	5.80 kWh/m ² /day
Direct normal (beam)	5.0 kWh/m ² /day

Table 7 Modified System Specifications- Abu Dhabi.

Parameter	Value
Global horizontal	5.02 kWh/m ² /day
Direct normal (beam)	3.20 kWh/m ² /day
Diffuse horizontal	2.76 kWh/m ² /day

E. Input Data For Phase 3

In phase III, the electrical system is modified and adjusted for further investigation for each city chosen in the United Arab Emirates. The number of MPPT is essential for accuracy and controlling the DC-DC optimized matched power between the system and the utility grid. However, for optimal power output, one more MPPT was added unlike the previous phases where only one MPPT is implemented.

IV. RESULTS AND DISCUSSION

In the three phases of the project for the city of Ras Al Khaimah (RAK), the 1 MW capacity PV solar system showed promising results in terms of energy generation and efficiency. Table 8 below shows the three different results for annual AC energy production in the first year as well as the energy yield. The results are very similar; however, the optimum choice is the setting of phase III in which the system has two MPPT and Table 5 parameters.

Table 8 Results of PV System Outcomes in The Three Phases For RAK City.

Phase number	Phase I	Phase II	Phase III
Annual AC energy production (kWh)	1,920,724	1,871,312	1,923,500
Energy yield (kWh/kW)	1,920	1,870	1,922

Moreover, the simulation in the three phases for RAK city showed a different monthly energy generated during the first year of the total time expected of the simulation which is set to be 10 years. It is worth mentioning that June has the highest energy generated amount of all months in all phases as shown in Figure 14, Figure 15, and Figure 16 in the appendix. Furthermore, it is convenient to choose RAK as a project location.

Nonetheless, the city of Dubai showed a higher annual AC energy in year 1 with a total of 2,076,210 kWh and DC capacity factor of 23%. All results for Dubai

city are shown in Table 9 below. Higher AC energy generation makes Dubai more of an attractive project site than RAK city.

Table 9 Results of PV System Outcomes in the Three Phases for RAK City.

Phase number	Phase I	Phase II	Phase III
Annual AC energy production (kWh)	2,076,210	1,901,367	2,080,730
Energy yield (kWh/kW)	2,075	1,900	2,080

The results of the monthly energy generated in the first year in Dubai city showed similar numbers too in all three phases while phases I and III are the most alike, this in fact, leaves the comparison in which phase conditions to choose to the higher total energy production. In all phases, June has the highest energy production, whereas February and March recorded the lowest as shown in Figure 17, Figure 18, and Figure 19 in the appendix. To this end, Dubai is a better location for a 1 MW PV power plant than RAK city.

Lastly, the city of Abu Dhabi. According to the findings of the simulation, the second phase is not as good as desired. The resulted energy generated is very low compared to phase I and II. This directly affect the decision for choosing Abu Dhabi as the primary project location, however, it is possible to consider phase III of this simulation for Abu Dhabi to establish the power plant as it has a high energy production rate out of all simulation run in the other two cities. Table 10. below shows the three phases' results regarding energy production and energy yield with a DC capacity factor of 23.8%.

Table 10 Results of PV System Outcomes in the Three Phases for Abu Dhabi.

Phase number	Phase I	Phase II	Phase III
Annual AC energy production (kWh)	2,084,765	1,602,019	2,089,507
Energy yield (kWh/kW)	2,084	1,601	2,088

Similar to Dubai and RAK, Abu Dhabi shows a significant increase in production during June and considerably low energy production in February and March because of insufficient solar radiation during these months in the area. Figure 20, Figure 21, and Figure 22 in the appendix show the monthly energy production in the first year in Abu Dhabi.

To this end, the best choice for the project location according to the simulation results is Abu Dhabi with adjustments of the third phase conditions which are constructing the power plant with two different MPPT and implying the same parameters in Table 10. However, the UAE depends on gas and oil for electricity production by 35% and 65% respectively, thus, rapidly increasing the amounts of CO₂ emissions in the atmosphere (Salimi et al., 2022). Therefore, many emirates in the UAE have considered using solar energy for electricity production taking into account that the UAE receives the highest amount of solar radiation in the MENA region with approximately 1826 kWh/kWp as shown in Figure 11 below (Salimi et al., 2022).

The UAE has adopted new strategies in order to maintain a sustainable lifestyle and to avoid shortage in energy in the future, in other words, the UAE vision of implementing new strategies and techniques for energy generation approaches has contributed in increasing the dependency on renewable energy for energy production by 3.5% in 2020 alone (Salimi et al., 2022). The installed PV capacity have reached more than 2500 MW in 2021. This in fact makes the 1MW PV project a convenient idea to enhance the country's vision of energy supply as the demand is constantly increasing.

From another perspective, the software provides charts on the performance of the subarrays, system power generation, and the electricity from the system itself in the first year. As shown in Figure 9 below, Abu Dhabi in phase III shows the most promising results of all three locations in phase III. The focus in this section is on phase III because it is adjusted on both aspects, the physical and electrical rather than the other two first phases with only physical adjustments.



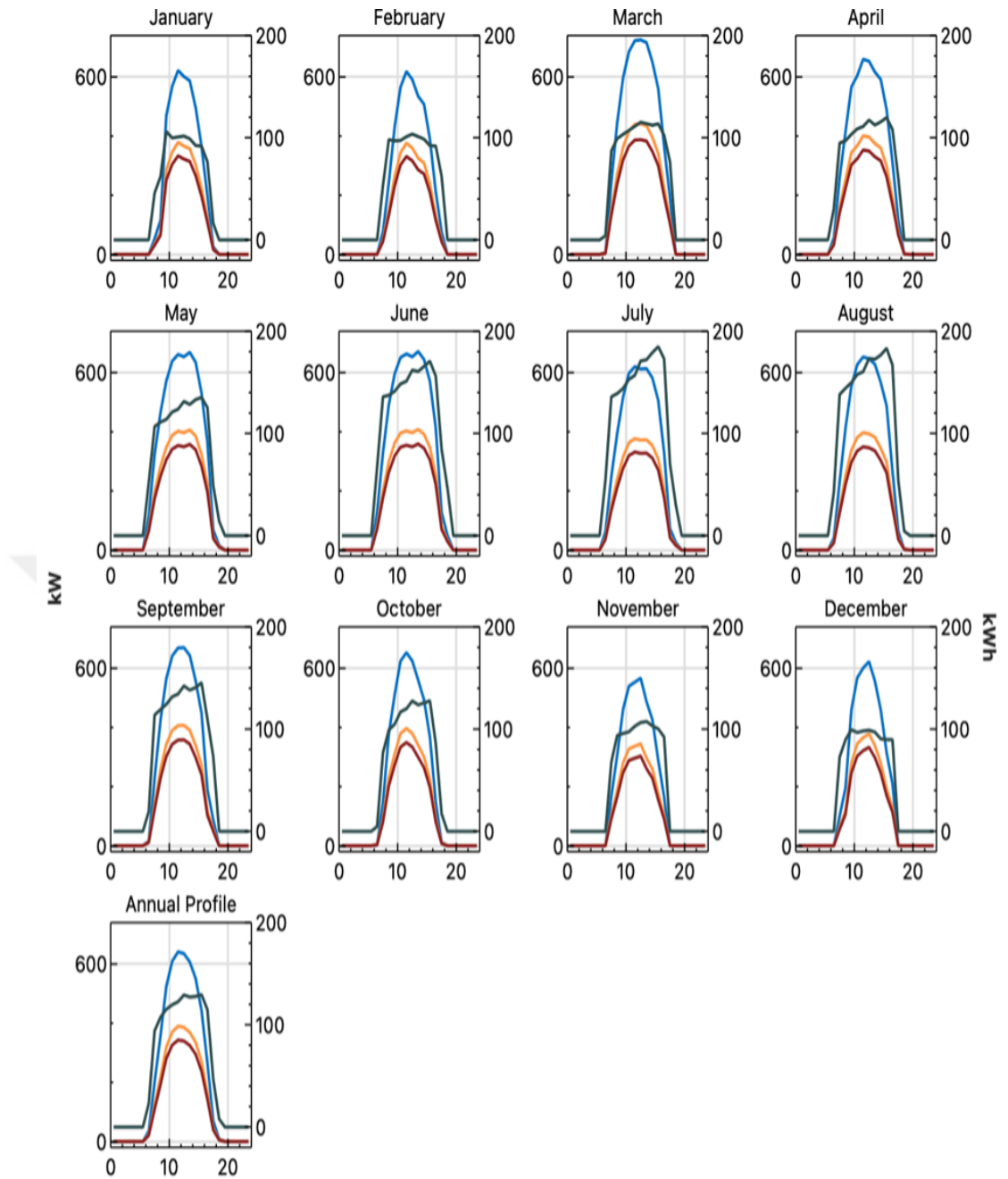


Figure 9 Subarray 1 DC Power Gross (kW) (yellow) + Subarray 2 DC Power Gross (kW) (Red) + System Power Generates (kW) (Blue) + Electricity from System to Load (year 1 hourly) (kWh) – RAK City Phase III.

In the figures shown, the power generated in the system (blue curve) is always the highest and is above 600 kW monthly for Abu Dhabi and Dubai, however, in RAK it is not the same case as many months has more than 600 kW in electricity generation, but it hardly gets any significant amount above that. Due to this curve, it is easier to eliminate RAK city as one of the possible options for the establishment of the power plant, and it is safe to say that Abu Dhabi is the most reasonable choice of them all.

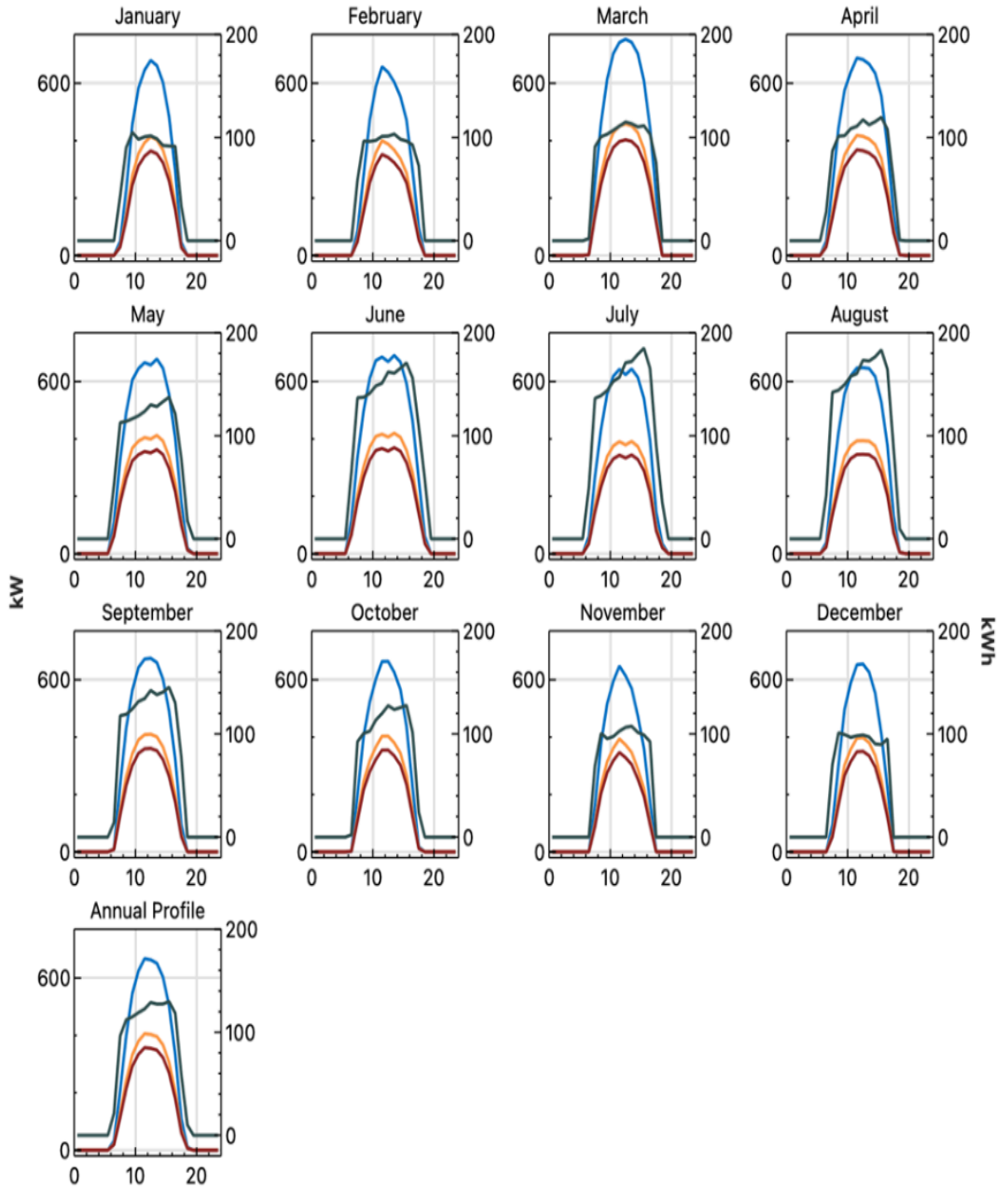


Figure 10 Subarray 1 DC Power Gross (kW) (Yellow)+ Subarray 2 DC Power Gross (kW) (Red) + System Power Generates (kW) (Blue)+ Electricity from System to Load (year 1 hourly) (kWh) – Dubai City Phase III.

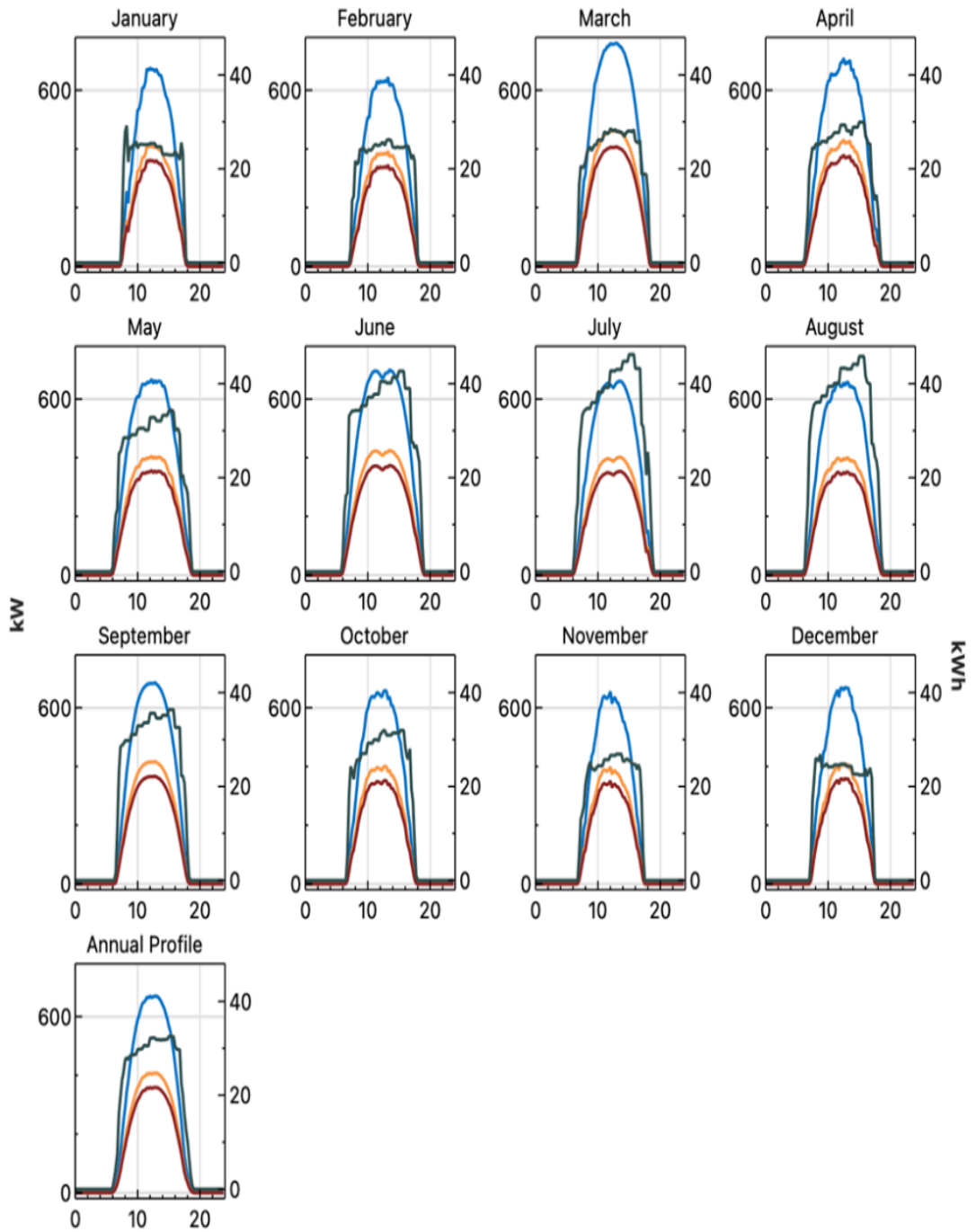


Figure 11 Subarray 1 DC Power Gross (kW) (Yellow)+ Subarray 2 DC Power Gross (kW) (Red) + System Power Generates (kW) (Blue)+ Electricity from System to Load (year 1 hourly) (kWh) – Abu Dhabi Phase III.

V. CONCLUSION

In conclusion, renewable energy is a powerful substitute for conventional energy generation systems that doesn't have negative effects on the environment and provide a constant and available energy supply to the market with reasonable price. Renewable energy, and especially solar energy can have better potentials in some places in the world than other geographical ones, and this is the case for the Middle East, and the Gulf area specifically. United Arab Emirates is one of the leading developing countries in the world, thus, one of the most pollutant places too. This in fact comes from the fact that up until the last decade, the UAE has been depending on conventional power plants for energy production which boosted the carbon emissions levels up to the sky. According to the UAE's officials and government reports, new strategies and policies have been put to enhance the process of conventional energy replacement with renewable ones. Therefore, it is a convenient project to design an efficient solar PV system in the UAE.

The three main cities chosen in this paper were carefully analyzed. Abu Dhabi the capital of the UAE, Dubai the economical capital of the UAE, and Ras Al Khaimah one of the most ancient cities in the area with so much potentials. Each city has its qualities to be set as an option, Abu Dhabi being the capital, its energy demand is the highest, on the other hand, Dubai is one of the most visited and advanced cities in the Middle East that can use another project of renewable energy for electricity generation, and lastly Ras Al Khaimah, its significant potential and lack of similar projects makes it a good choice of a city.

Through the design process, SAM software was used to carry out the necessary operations and drawings. SAM software is an online tool offered by the national renewable energy laboratory (NREL) for solar energy systems simulations. The software offers many options and features that made this project a success without the need to add or use any other helping tool. All results generated using this software

were sufficient to be analyzed and studied throughout this paper. To sum all information given earlier, the city that has the most potential with high level of efficiency of a PV system is Abu Dhabi, the capital of the UAE. Because it gives the most promising numbers in terms of efficiency and overall performance. On the other hand, Dubai is not less of a choice, but giving the results from both cities, Abu Dhabi would have a better performance as a project site. And lastly, Ras Al Khaimah (RAK). The city shows a desirable quality in terms of solar energy, yet it may need a bigger system that can compensate the not so significant energy generation.



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APPENDICES

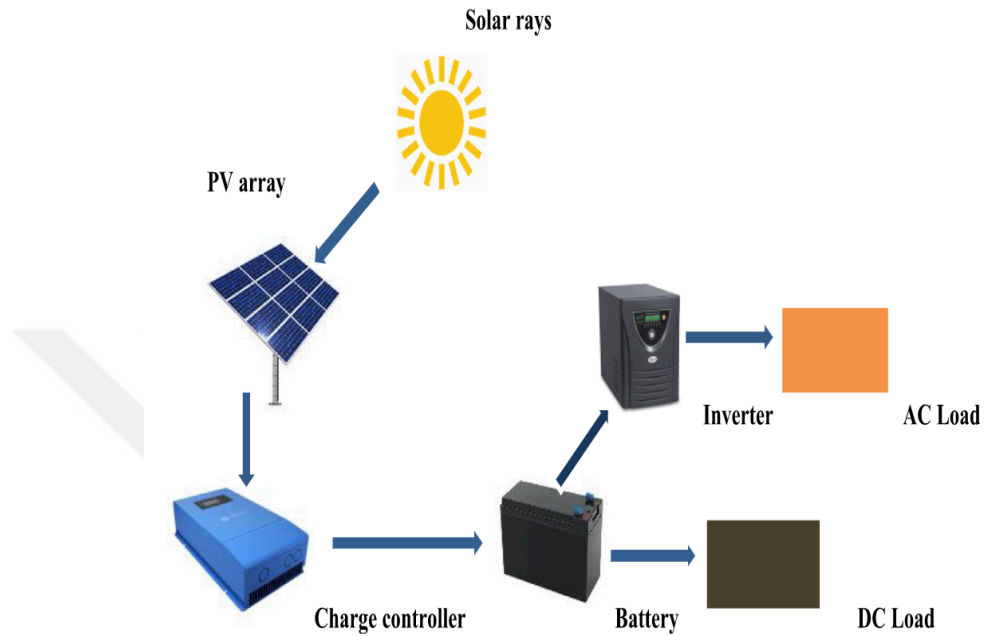


Figure 12 Layout and components of an off-grid PV system (Mohd.Ali & Krishnaswamy, 2018).

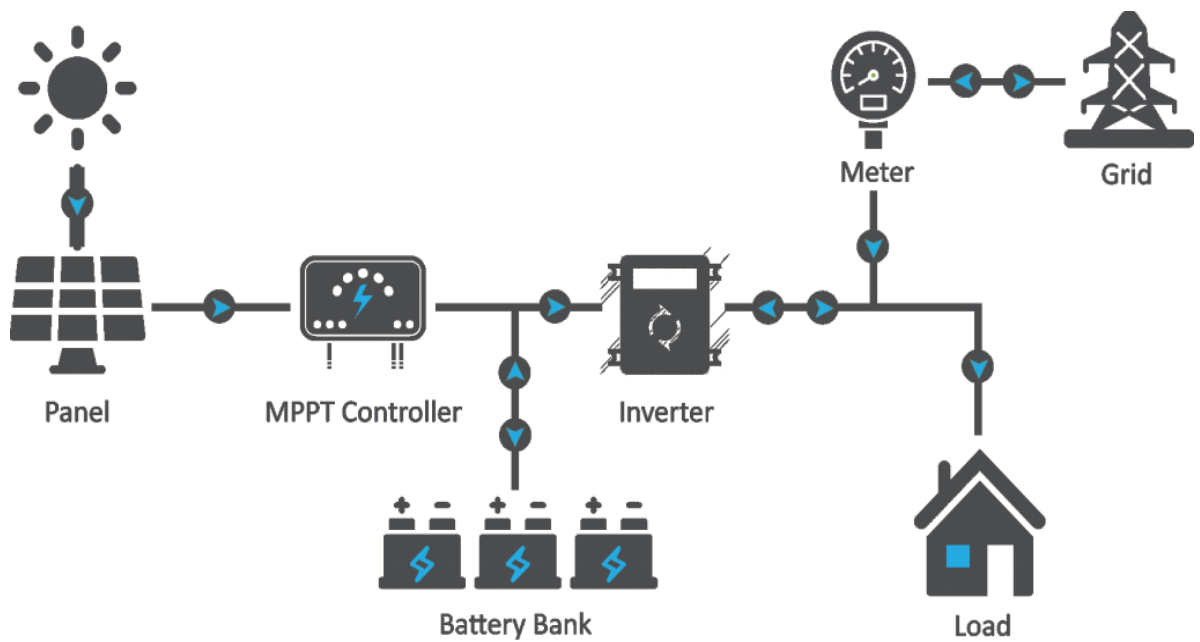


Figure 13 Hybrid PV system (Khare & Rangnekar, 2013)

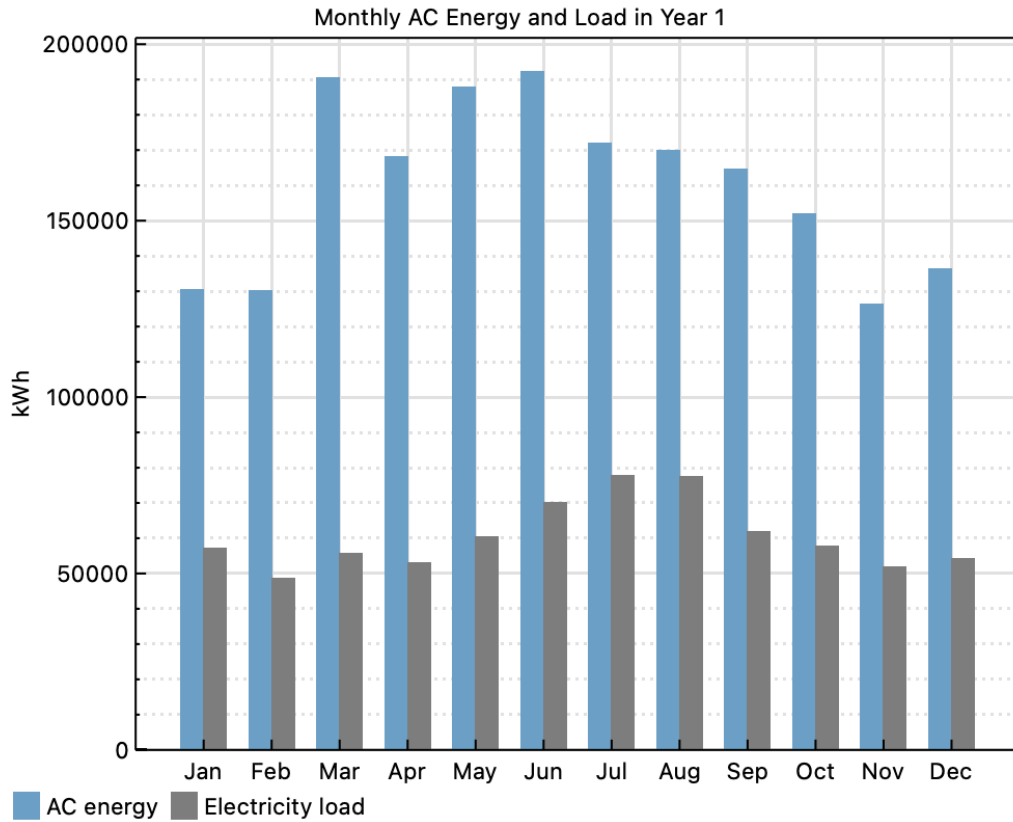


Figure 14 Monthly AC Energy and Load in RAK Year 1- Phase I.

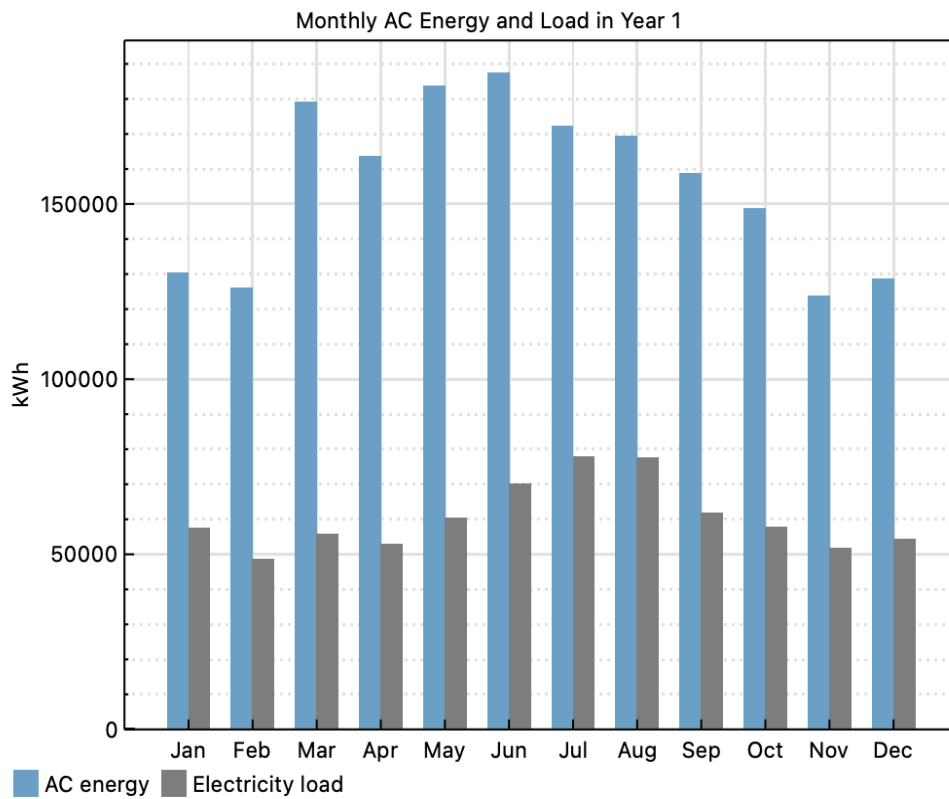


Figure 15 Monthly AC Energy and Load in RAK Year 1 – Phase II.

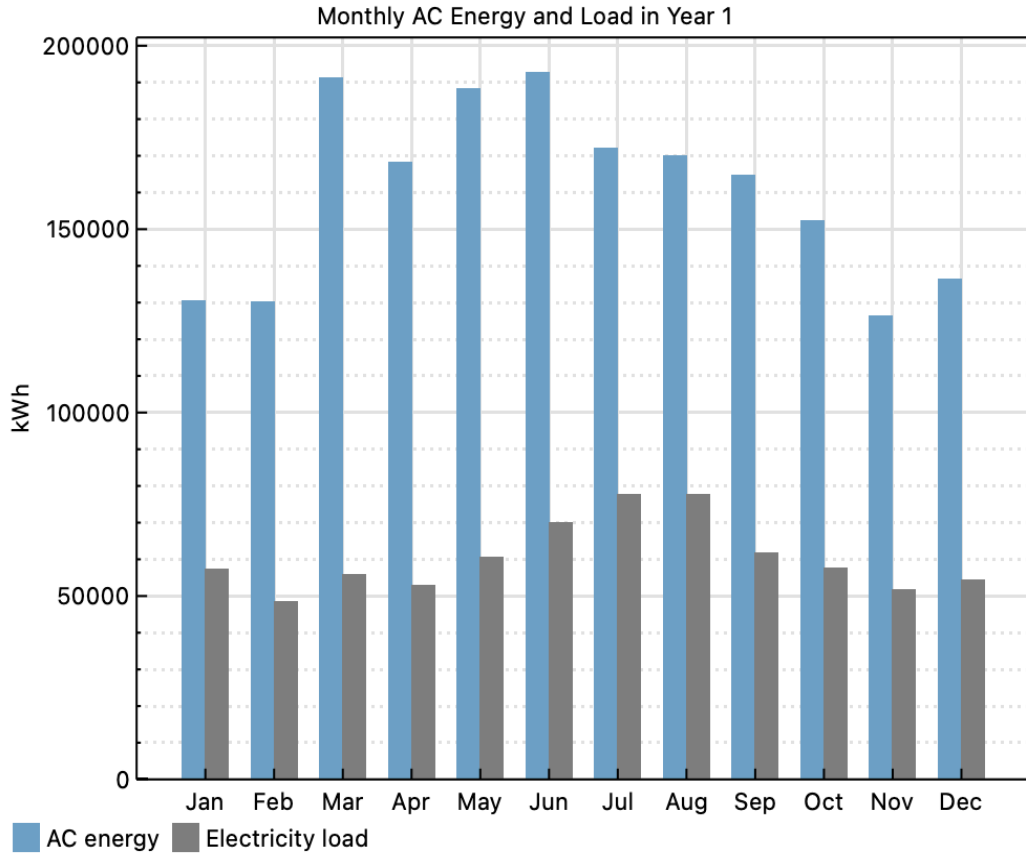


Figure 16 Monthly AC Energy and Load in RAK Year 1- Phase III.

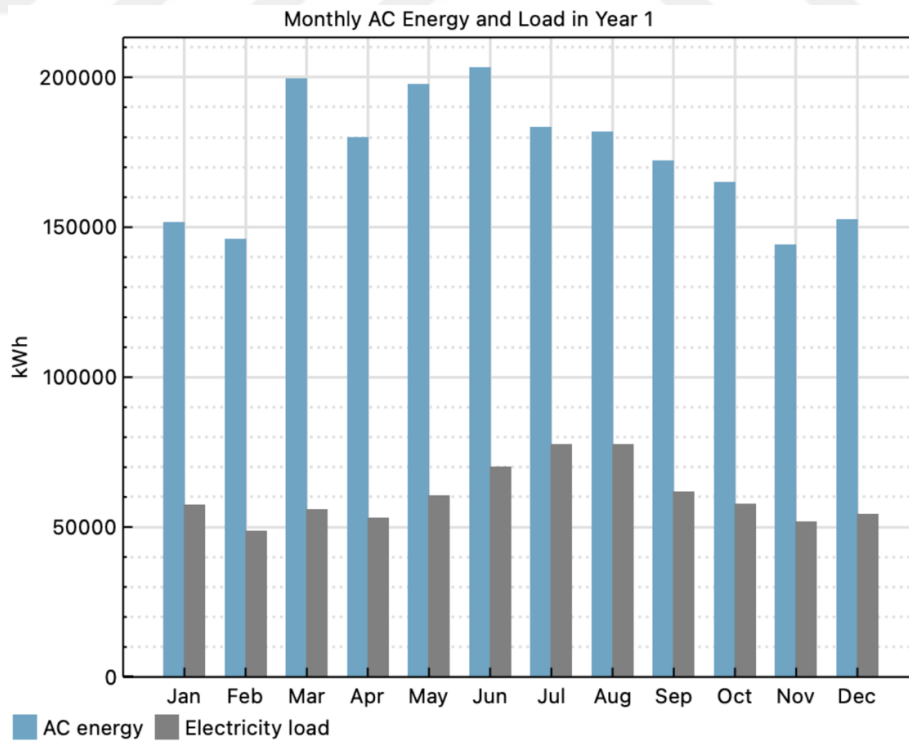


Figure 17 Monthly AC Energy and Load in Dubai Year 1- Phase I.

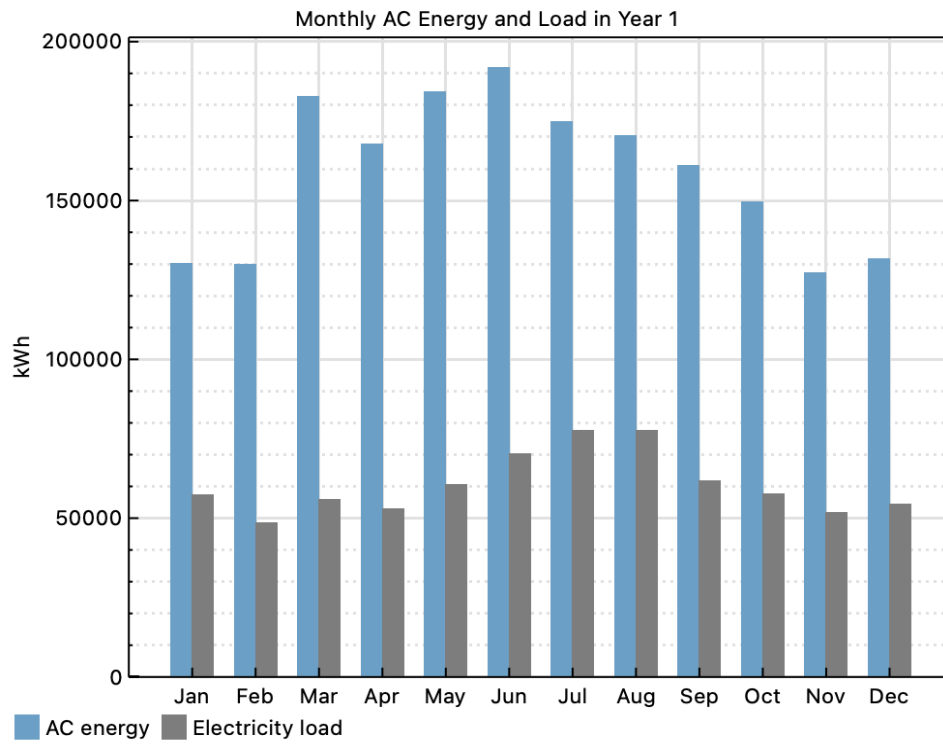


Figure 18 Monthly AC Energy and Load in Dubai Year 1- Phase II.

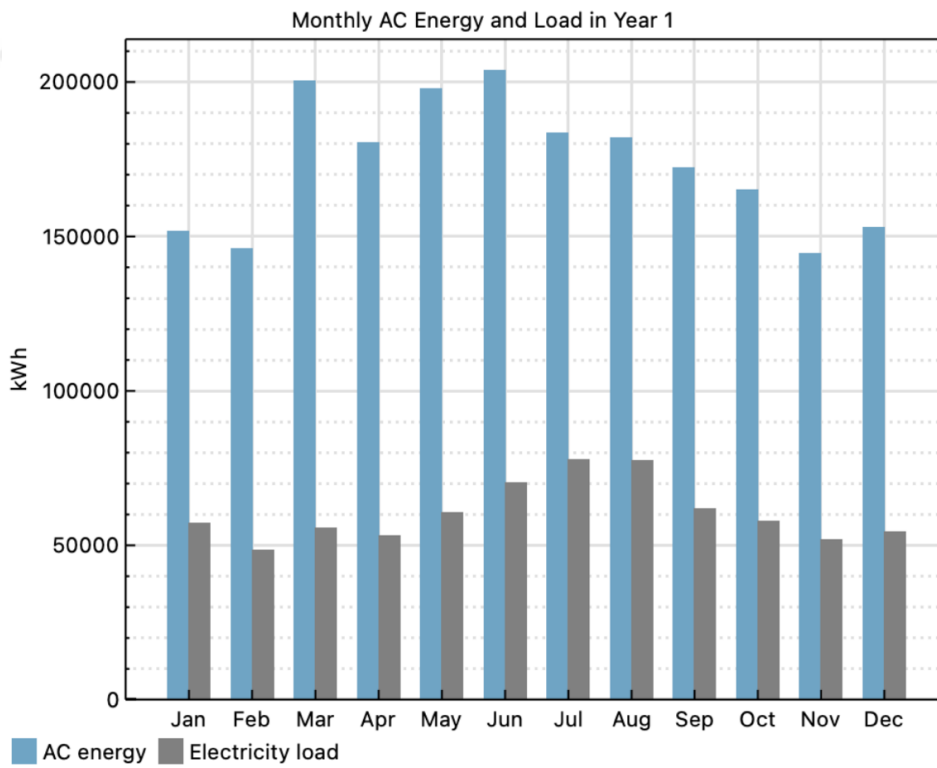


Figure 19 Monthly AC Energy and Load in Dubai Year 1- Phase III.

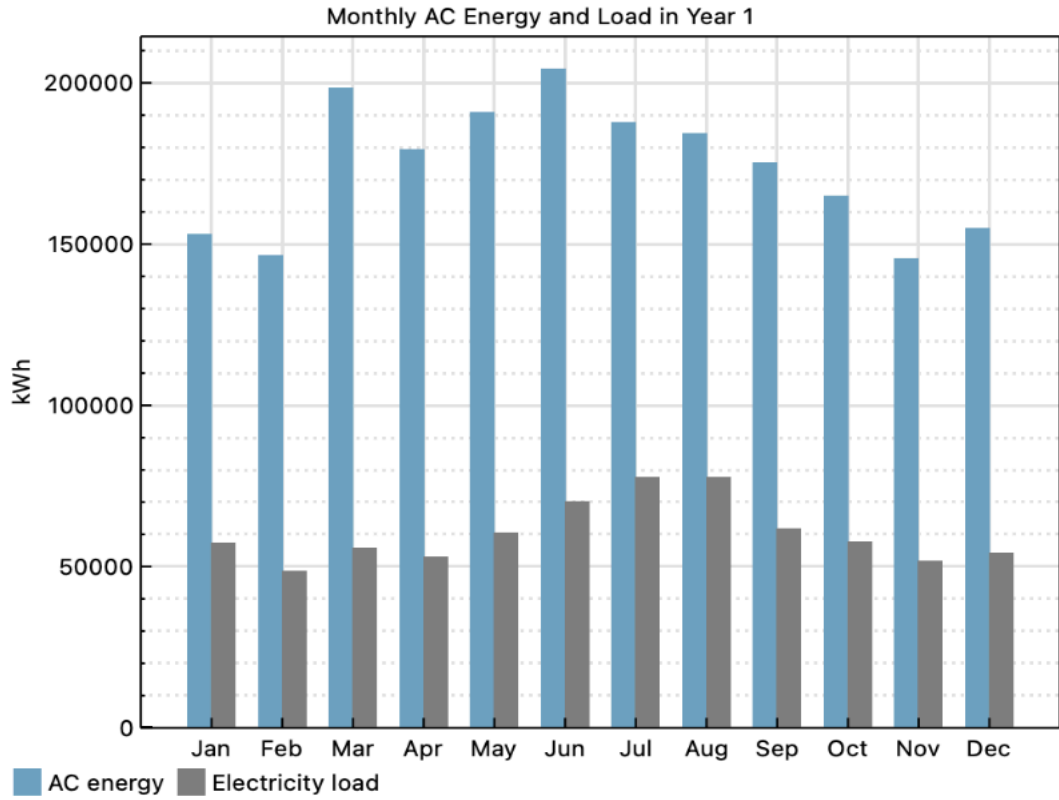


Figure 20 Monthly AC Energy and Load in Abud Dhabi Year 1- Phase I.

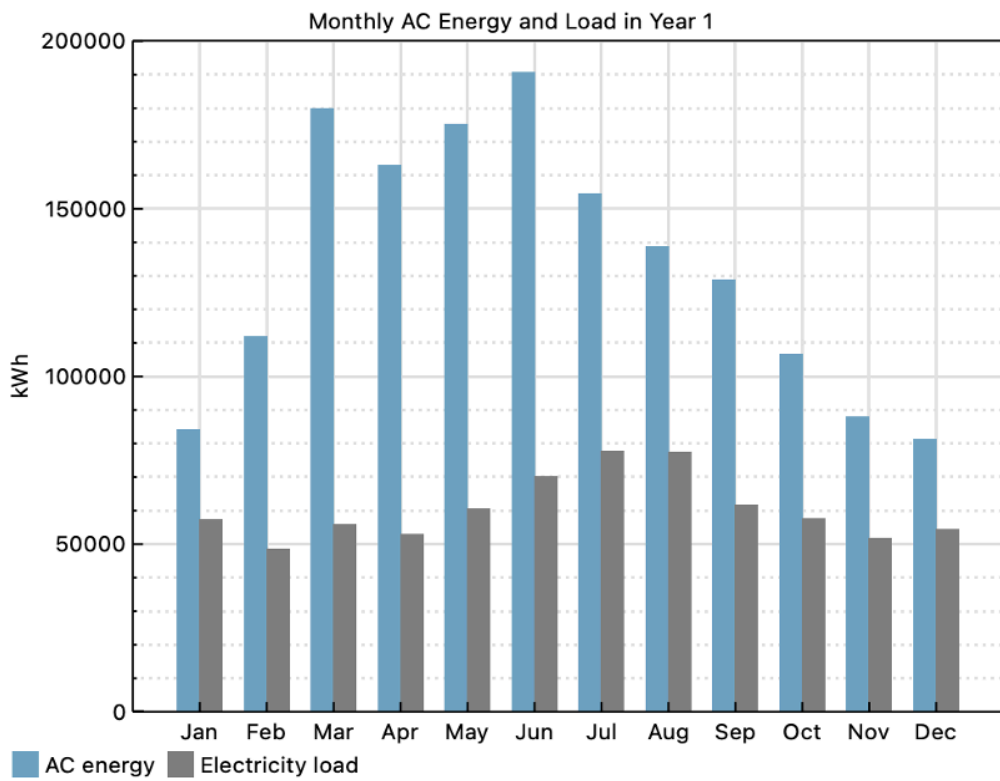


Figure 21 Monthly AC Energy and Load in Abu Dhabi Year 1 - phase II.

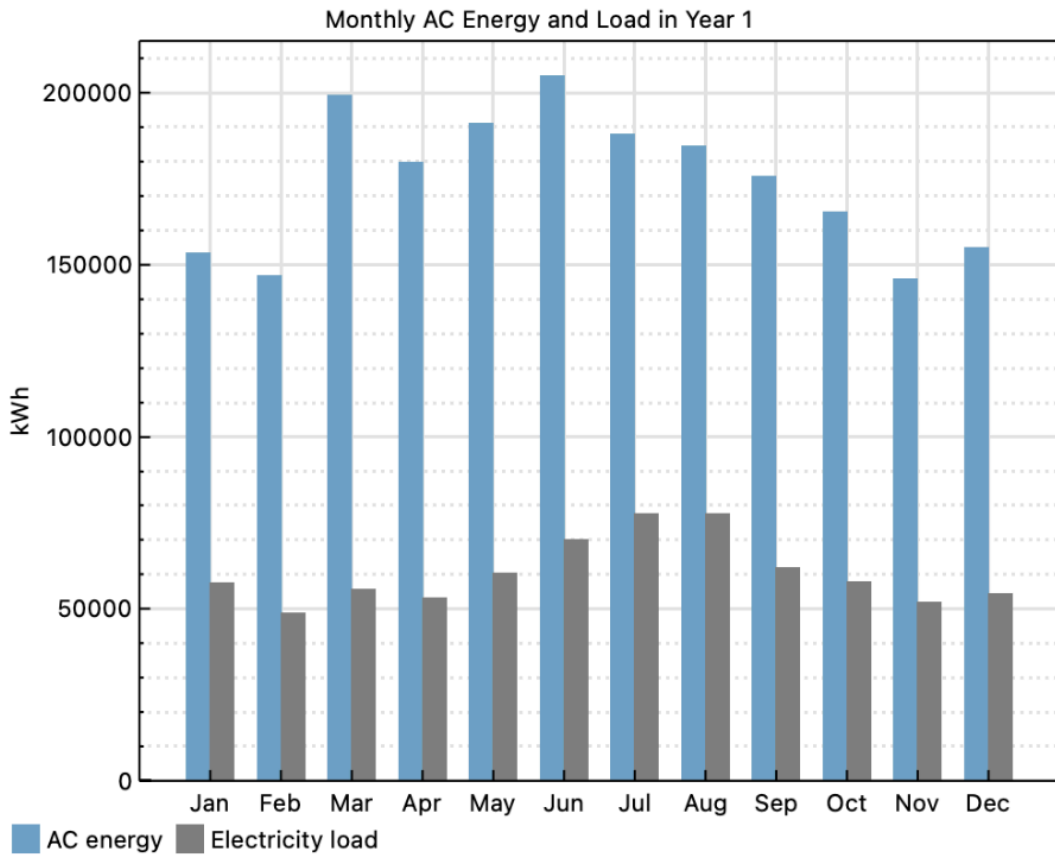


Figure 22 Monthly AC Energy and Load in Abu Dhabi Year 1 - phase III.

Table 11 Phase 1 Characteristics- RAK.

Parameter	Value
Module name	Risen Energy Co. Ltd. RSM72-6-380M
Module specification	Mono-c-Si
Module surface area	1.94 m ²
Number of cells per module	72
Module output power	380 W
Inverter model	INGETEA POWER TECHNOLOGY S A INGECON SUN 915TL U B330 (330V)
Inverter capacity	915000 W
DC-AC ratio	1.09
Angle	Azimuth axis (South)
Tilt angle	20°
Ground coverage ratio	0.3

Table 12 Phase 1 Characteristics- Dubai

Parameter	Value
Module name	Risen Energy Co. Ltd. RSM72-6-380M
Module specification	Mono-c-Si
Module surface area	1.94 m ²
Number of cells per module	72

Module output power	380 W
Inverter model	INGETEAAM POWER TECHNOLOGY S A INGECON SUN 915TL U B330 (330V)
Inverter capacity	915000 W
DC-AC ratio	1.09
Angle	Azimuth axis (South)
Tilt angle	20°
Ground coverage ratio	0.3

Table 13 Phase 1 Characteristics- Abu Dhabi.

Parameter	Value
Module name	Risen Energy Co. Ltd. RSM72-6-380M
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Module output power	380 W
Inverter model	INGETEAAM POWER TECHNOLOGY S A INGECON SUN 915TL U B330 (330V)
Inverter capacity	915000 W
DC-AC ratio	1.09
Angle	Azimuth axis (South)

Tilt angle 20°

Ground coverage ratio 0.3



RESUME

Education:

Master of Science in Energy Technologies *Istanbul Aydin University, Istanbul,*
Expected Graduation Date: September 2023

Relevant Coursework:

- Advanced Energy Conversion Systems
- Renewable Energy Integration
- Power Quality
- Sustainable Energy Policy

Bachelor of Science in Energy Systems Engineering *Istanbul Bilgi University,*
Istanbul, Graduation Date: July 2021

Relevant Coursework:

- Thermodynamics and Heat Transfer
- Fluid Mechanics for Energy Systems
- Electrical Systems and Power Generation
- Energy Efficiency and Sustainability

Key Skills:

- Proficient in energy modeling software (e.g., EnergyPlus, HOMER)
- Solid understanding of renewable energy technologies (solar, wind, geothermal)
- Familiarity with energy policy and regulations
- Strong analytical skills for evaluating energy systems
- Effective communication and collaboration within interdisciplinary teams

Experience:

Research Assistant *Kadir Has Univeristy (Nov 2021-May2022) Istanbul, Turkey*

Operations Intern *Hilton Ras AL Khaimah Beach Resort (Jan 2021-Feb 2021)
RAK, UAE*

Projects: Renewable Energy Integration Project *Master's Program, Spring/2023*

- Suggested a design using a comprehensive plan for integrating Hygrogen energy into the modified diesel engines.
- Investigated electrical engineering and policy researchs to address technical and regulatory challenges.

Design of a Sustainable Industrial Park *Bachelor's Program, Fall/2020*

- Led a multidisciplinary team to develop a comprehensive plan for a sustainable industrial park focused on minimizing environmental impact and optimizing energy efficiency.
- Conducted an energy audit for a local manufacturing facility, identifying opportunities for energy savings.
- Proposed and implemented improvements such as lighting upgrades and equipment optimization, resulting in reduction in energy consumption.
- Presented findings and recommendations to the facility management, enhancing the facility's sustainability efforts.

Research: Solar Glass *Master's Program, Fall/2021*

- Conducted an in-depth literature review on various solar energy technologies, including building integrated and solar panels.
- Developed a comparative analysis framework to assess the technical, economic, and environmental aspects of solar glass solutions.
- Presented findings at a regional energy conference, contributing to the understanding of solar glass advancements.

Honors and Awards:

- Honor Certificate, *Istanbul Bilgi University*

Certificates:

Foundations: Data, Data, Everywhere *Google, Coursera, 2021*

IELTS *British Council 7.0 CEFR LEVEL C1 2021*

Foundation of Project Management *Google, Coursera, 2021*

Engineering Project Management *Rice University, Coursera, 2020*

Solar Energy and Electrical System Design *Buffalo University, Coursera, 2020*

Languages:

- *Fluent in Arabic and English*
- *Moderate level in Turkish*

