System Design and Analysis of Solar Powered System in Residential, Commercial and Agricultural Sector

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MME-131007

A thesis submitted to the

Mechanical Engineering

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

Faculty of Engineering

Capital University of Science and Technology

Islamabad

April, 2017

Certificate

This is to certify that Ans Farooq has incorporated all observations, suggestions and comments made by the external evaluators as well as the internal examiners and thesis supervisor. The title of his Thesis is: "**System Design and Analysis of Solar Powered System in Residential, Commercial and Agricultural Sector of Pakistan"**

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ACKNOWLEDGMENT

Firstly, I would like to express my sincere gratitude to my supervisor Dr. Mujtaba Hasan Agha for his continuous support during my Master's study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better supervisor and mentor for my Master's study.

Besides my supervisor, I would like to thank Abdul Nasir, CEO of Progressive Ventures for their insightful comments and encouragement,

Last but not the least, I would like to thank my family: my parents, my wife, and son (Rayyan Bin Ans) and to my brothers, Sister for supporting me spiritually throughout writing this thesis and my life in general.

DECLARATION

It is declared that this is an original piece of my own work, except where otherwise acknowledged in text and references. This work has not been submitted in any form for another degree or diploma at any university or other institution for tertiary education and shall not be submitted by me in future for obtaining any degree from this or any other University or Institution.

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ABSTRACT

Despite the fact that fossil fuels are found in relatively small number of places, they are consumed worldwide. In contrast renewable energy is available all over the world but it is utilized only by small a segment of world's population. However, due to an increased awareness of environmental impact of fossil fuels and advancement in renewable energy technology, nowadays there is a rise in the use of renewable energy as an alternate source of energy. In Pakistan especially, during the last decade, use of solar energy has been advocated and widely adopted at domestic level.

This study has been undertaken to determine if it would be cost beneficial over a 25 year period to install solar energy for residential, commercial and agricultural sector. A cost benefit analysis was performed to determine if the investment would be financially worthwhile.

The results reveal that solar energy is viable only in the agricultural sector of Pakistan under the present circumstances. In residential and commercial sectors of Pakistan the payback period of solar powered system might turn to be very long. Due to unstable national grid.

Payback period for residential sector is 11.79 years, for commercial sector 7.5 years and for solar water pumping is only 2.47 years, which is lowest among other sectors.

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CHAPTER 1: INTRODUCTION

1.1 Background

For the last 10 years in Pakistan, there has been an increased emphasis on alternate energy sources, which is mainly due to energy crisis and long planned/unplanned power outages in the country. The government of Pakistan is itself seeking opportunities to invest in renewable energies. One example of such government initiative is the state of the art Quaid-e-Azam solar power plant to help increase existing power supply source of the country. Besides these state supported activities, steps need to be taken at grass root level. All individual consumers need to attempt to overcome their part of the shortfall by installing renewable energy projects at their premises. Installing a renewable energy project is a part of short term planning to quickly overcome the energy shortfall. The most common renewable energy technologies are hydel, wind and solar technology.

1.2 Global Interest

More than a century ago, technology was revolutionized with the discovery and use of the fuel in domestic and industrial machines improving the lifestyle of people by many steps in one go. Fast means of transportation, electrical and electronic accessories and an improved industrial yield to meet the increasing demands are among a few of the advantages people got straight away from this addition to their everyday life. As the time elapsed, rapidly dying fuel reservoirs and exponential rise of fuel demand overgrew the production, causing a significant short fall of the product. Here is when the problem arose first.

Demand of fuel became so high that fossil fuel reservoirs failed to meet it while fuel search is a costly and time taking process as oil companies have to conduct long surveys and then, if any traces of the fuel are found, heavy drilling deep down into the earth or in the seas is required. It is not a matter of months but several long years. This supply and demand gap has hiked the fuel prices as well. This situation has led the world to look for easy, immediate and cost effective alternatives like wind, solar, solar thermal and biogas, etc. [1] [2] [3].

Decreasing fuel supplies with dying existing reserves and increasing demand with rising population is worsening the situation with each passing day. The only plausible solution to both the problems is adoption of renewable supplies at a lower level which not only will meet increasing energy demands but will also help save the environment from carbon pollutants, saving the ozone in the long run [4] [5].

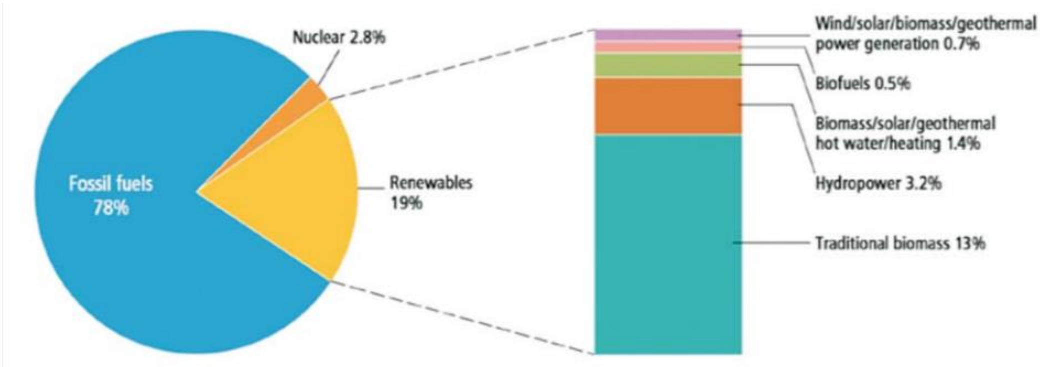


Figure 1: Source: Global Status Report by REN21, 2010

1.3 Local Interest

Pakistan is facing a challenging energy crisis for almost past two decades. Despite large natural oil and gas reserves, Pakistan is unable to overcome the energy crisis due to lack of advanced technology and poor financial planning. Fuel prices on average have risen by as high as 175% from 1996 to 2014 [6]. Similarly the electricity prices has also increased roughly 200% from 2010 to 2014 [7]. Although, government of Pakistan is trying its level best to help overcome the crisis yet no significant positive results have been observed so far. Business conditions are getting worse due to short fuel supplies as well as hiked fuel prices [8].A vast majority of households is unable to afford electricity costs which is developing economic dissatisfaction among countrymen. In this critical situation, the need of the hour is the adoption of cost effective renewable energy alternatives to stabilize the household and industry as well as economy of the country [9] [10].

Geographically, Pakistan is situated in a region where it receives maximum solar energy radiations making it highly suitable for solar energy production. The areas in the costal part of the county (e.g. Karachi and Gawadar) being in direct contact with the Arabian Sea possess a great potential for wind energy.

1.4 Problem Statement

The next chapter is dedicated to reviewing wind and solar energy. Based on this research, it may be concluded in that wind energy in Pakistan is limited and only a few territories are able to produce energy from wind. Energy generation through wind is not feasible for individuals, whereas in this report we are working on solution for individual sites. Wind energy is feasible in Pakistan on city or district level. On the other hand, solar energy is abundant in Pakistan and most of the parts of the country receive an abundant amount of solar irradiations. Solar energy solutions are quicker and faster ways to overcome the energy crisis on individual level. This report offers a cost benefit analysis, with a focus on calculation of the payback periods for solar energy system for residential, commercial and agricultural sector.

CHAPTER 2: REVIEW OF LITRATURE

There has always been an imbalance between supply and demand of energy. Energy shortfall in Pakistan reached 5500 MW in 2015, which is almost 45% of the actual demand [11]. On average, planned load shedding to balance the supply and demand is about 8-10 hours in every 24 hours. It has been 10-14 hours during last year.

2.1 Technology Overview

The photovoltaic industry is growing globally as rapid as 30%, where China is taking the lead in PV module production. In 2010, China shipped solar panels totaling 23,000 MW in terms of consumable power. In 2010, 75% of the global solar transections were from china only [12]. Due to the high consumption of photovoltaic modules, numerous national as well as multinational companies are incorporated each year. With increasing market competition, prices of PV modules are decreasing with each passing day [13]. Recent surveys and studies reveal that the average per watt cost of PV module which had been $1.61, has now reduced to $0.8 in a short span of four years, which is almost exactly opposite to the rise in the electricity prices in the country over the same period [14].

Table 1: Top 10 countries by solar installed capacity [15]

Rank	Country	Installed Capacity (MW)
1	China	43,530
2	Germany	39,700
3	Japan	34,410
4	U.S	25,620
5	Italy	18,920
6	U.K	8,780
7	France	6,580
8	Spain	5,400
9	Australia	5,070

10	India	5,050
23	Pakistan	1,000

China is leading the world in PV installation. Currently, Pakistan is ranked 23^{rd} in the list with a small installation capacity of 1000 MW of solar energy.

Pakistan is situated in a highly feasible region for solar power as the average daily sunshine period is about 10-11 hours in summers and 6-7 hours in winters. On average, the earth receives approximately 1.259 KW/m^2 energy from sun while on a clear day the radiation from sun to Earth reaches up to 80%. The reduction in solar energy radiations is usually cause by fog, humidity and clouds covering the sun [16].

2.2 Solar Power Development in Pakistan

Many efforts have been made to set up and increase solar energy penetration in domestic and industrial uses of Pakistan. The daily average of sunlight in this region is approximately nine hours. One of the early efforts in this regard was the solar system installation in Mimnniala in 1981. After the successful completion of the pilot project, four more solar photovoltaic systems were installed in different areas which include Khukhera near Lasbela (Baluchistan), Malmari in district Thatta, Ghakkar in district Attock and Dital Khan Legari in district Mirpur Khas. Quaid-e-Azam solar power park was announced by the Government of Punjab with the allotment of 5000 acres of land near district Bahawalpur. Till date, 400MW of solar power plant has been installed and successfully connected to the national grid. Total projected capacity of this project is 1000MW in 2020 [17] [18].

Efforts have been made to solarize the off grid villages of Pakistan as well, a successful example of which is the village of Narian Korian near Islamabad where one hundred solar panels have been installed by a local company and they have been able to ease 100 households by making bulbs and fans operational on solar power. Similar initiatives have also been taken by AEDB (Alternate Energy Development Board) of Pakistan where almost 200 solar solutions have been provided in Khuzdar and off grid villages of Karak in province KPK [10] [7].

2.3 Wind Power Development in Pakistan

Pakistan is developing wind power plants in Jhimpir, Gharo, Keti Bandar and Bin Qasim in Sindh. The Government of Pakistan decided to develop wind power energy sources due to problems in supplying energy to the southern coastal regions of Sindh and Baluchistan. The project is being run with partial support and assistance from the government of China. Other areas with good potential for wind energy are Swat and Nukundi area near Afghan/Iran border in district Chagi of Baluchistan where wind speeds are often 12.5% higher than average speed required for wind energy generation [19].

Some examples are:

- Jhimpir Wind Power Plant (operational)
- Gharo Wind Power Plant (operational)
- Bin Qasim Wind Power Project (under construction)

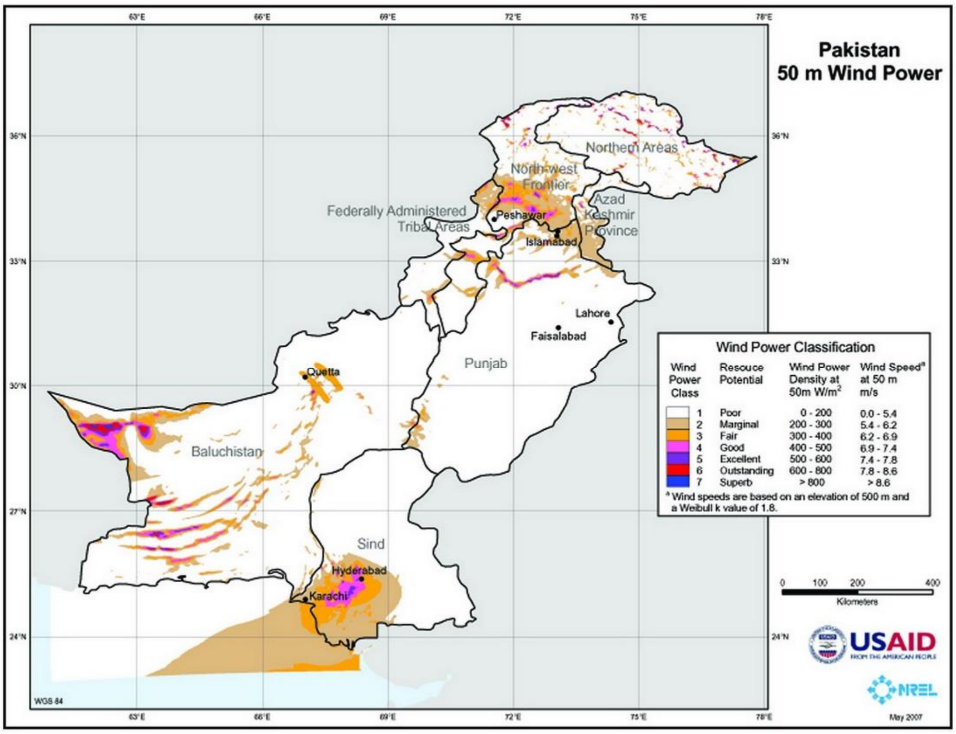


Figure 2: Wind Map of Pakistan Source: AEDB

As per AEDB map, published in May 2007, coastal line of Sindh and a few areas of Baluchistan and KPK are highly suitable and feasible for generating wind energy, while rest of the country regions are unsuitable. These areas for lacking in sufficient wind resources are unable to produce enough power to fulfill the demands. Compared to solar, wind energy potential and scope is quite low. Solar energy resources are not only abundant but affordable and simple too as compared with wind energy equipment [20] [21].

2.4 Solar Energy: Current Position

Till 2011, solar energy had a low profile in Pakistan due to very limited activities regarding solar energy installation and awareness. Pakistan missed its objective of achieving 10% of all its energy demands from renewable energy sources by 2010 [22] [23] [24]. However, appreciably significant initiatives have been taken on state level lately like Quaid-e-Azam and Wah Industries solar power parks.

This review is divided into three categories,

1. Geographical Potential: This section will review the geographical positions of Pakistan that are most suitable for solar installations.
2. Market Potential: This section will discuss the market potential, adoptability and affordability of solar energy.
3. Market Integration: This section will review the Feed in Tariff and Power Purchase Agreements.

2.4.1 Geographical Potential of Solar Energy in Pakistan

Pakistan has a unique geographical location, being situated at a point where it receives maximum solar radiations throughout the year [25]. Some areas of southern Pakistan like Quetta, areas of central and southern Punjab like Lahore, Faisalabad, Multan, Bahawalpur, and Rahimyar Khan receive the maximum of the solar radiations throughout the year. Pakistan usually receives 6.8 to 8.3 KMJ/m^2 per year and an average sunshine is almost 7-9 hours daily.[26].

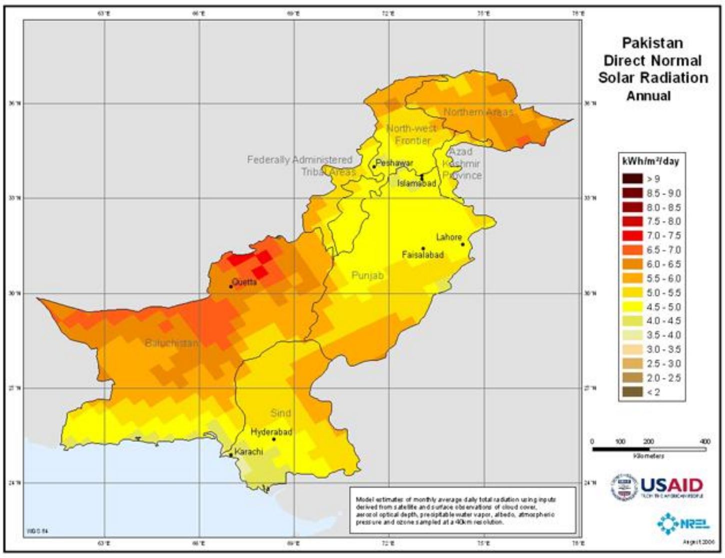


Figure 3: Pakistan direct normal solar radiation

Pakistan has a huge potential for converting the solar energy into useful and beneficial means. This solar energy can be harvested to produce electricity to overcome the energy crisis of Pakistan. According to Energy Book Pakistan 2004-2005, the 0.25 % of solar irradiance falling only on Baluchistan province will be sufficient to meet the current energy crisis of the country [20].

2.4.2 Market Potential

Being a developing country, Pakistan is a market of changing trends. Local market is keen of adopting and adapting to new technologies. Thus, the potential of energy alternatives in general and the potential of solar energy, being cheap and easy to deploy and harvest, in particular, is very bright in Pakistan. Compared to households, solar solutions are feasibly more inclined to commercial, industrial and agricultural sectors due to their high rate of return and shorter payback periods. For households, the payback period is quite long. The average wages of a Pakistani citizen is roughly $255 a month [27]. Per watt cost of solar PV modules is given in table below.

Table 2: International cost of Solar Modules

Solar Panel Technology	**Cost per watt $**
Mono Crystalline	0.79
Poly Crystalline	0.73

Thin Film	0.73

From the above table it is clear that solar modules are still very expensive for local market, especially for the middle class population. Solar energy is much more feasible for entities that aim to use it commercially and for industrial purposes.

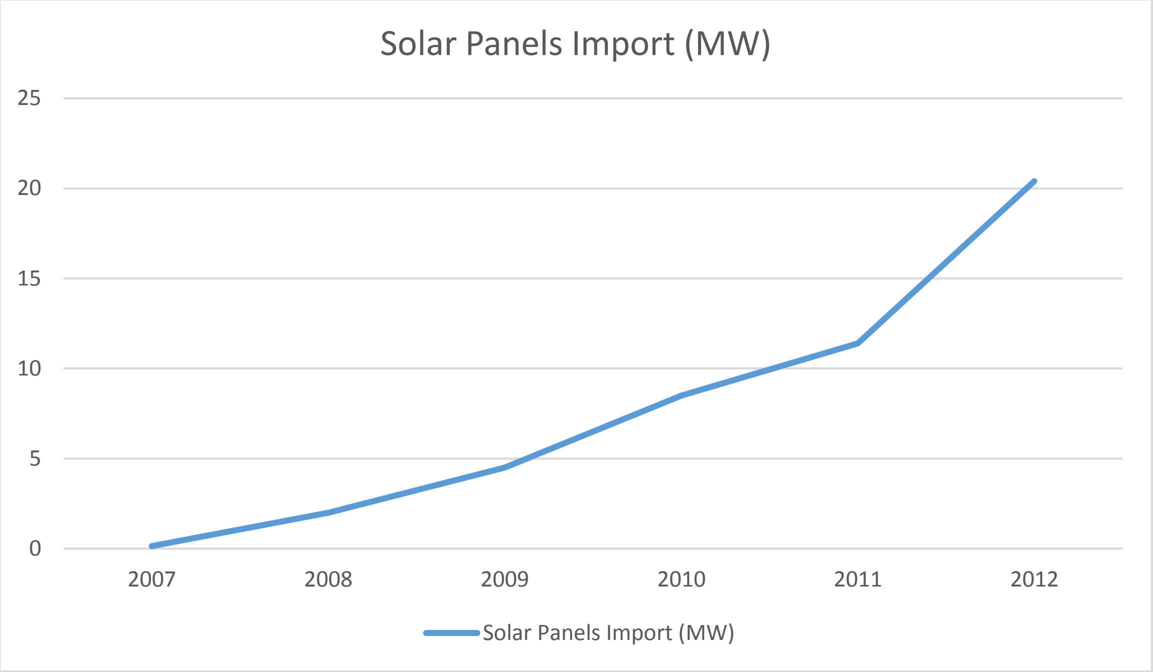


Figure 4: Solar Panels Import in Pakistan MW *[28]*

In 2006 AEDB issued an SRO to exempt the duties on solar energy products which helped boost the technology. In the light of SRO.575 (1) /2006 government waived off the 32.2% duty on import of solar panels to make it more affordable for general public. In 2007, the PV module import was about 0.14MW while at the end of 2012, with a remarkable increase of about 16000%, this import had grown up to 22.4MW [29].

Types of Solar Panels

Solar modules are made from SiO_2 (Silicon), which is abundant on earth and is inexpensively available. The raw sand must be purified up to 99.9999% or in words 1 part per million (1 ppm). The cost of purification of sand up to prescribed levels is significantly high [11]. There are basically three types of solar panels [16].

1. Mono-Crystalline Based Solar Panels

2. Thin Film Based Solar Panels
3. Poly Crystalline Based Solar Panels

Mono Crystalline Solar Panels

All the solar panels have the same basic recipe and all are made from silicon. Mono crystalline solar panels are made from single crystal of silicon. As the word ‘mono’ (meaning “single”) suggests, mono crystalline solar panels are developed from a single crystal on silicon, thus having no such grain boundaries [11] [30]. Mono crystalline solar panels have highest efficiencies in the world. The most recent solar panels claim of having efficiency nearly 22% at laboratory scale. Because of their highest output efficiency monocrystalline solar panels are expensive than the other solar panels [16].

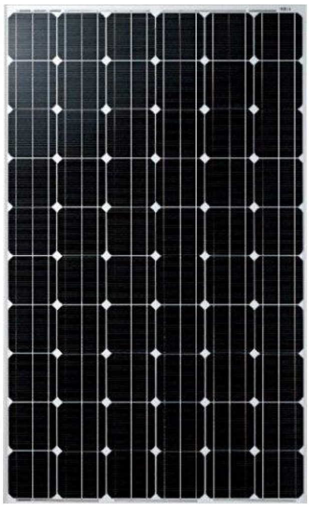


Figure 5: Mono Crystalline Photo Voltaic Module

Poly Crystalline Solar Panels

Poly crystalline solar panels (also referred to multi crystalline solar panels) are developed from multiple crystals of silicon and have different structure than mono crystalline solar panels. Their silicon crystals are less purified, hence cheaper in price. As a consequence of less purity, they have low efficiency. The most recent papers claim that poly crystalline solar panels have efficiency of 17% [11]. This type of modules can sustain high temperature and can perform very well in hotter regions. That is why, poly crystalline modules are used in Africa, Australia and Gulf regions.

Figure 6: Polycrystalline Photo Voltaic Module

Thin Film Solar Panels

Thin film solar panels are entirely different in structure from traditional solar panels. Mostly they are made of single or multi-layer of Cadmium Telluride, with glass used as a substrate. Flexible solar panels are also a subclass of thin film based solar panels. In flexible solar panels the plastic sheet is used as substrate and CIGS (Copper Indium Gallium Selenide) is deposited on it to make it workable [22] [23].

Previously, thin film solar panels had very low efficiencies of only 8-10%, but now the 3rd generation of this film solar panels, currently available in market claim to have an efficiency of 21%. [11].

Figure 7: Thin Film Solar Module

Thin film solar panels have the following distinct advantages over conventional solar panels [11].

1. Have excellent working under low sun light conditions
2. Can be installed on any angle facing to sun.
3. Temperature coefficient is comparatively lower than conventional solar panels
4. Due to low temperature coefficients, they perform well in high temperature conditions.

2.5 Solar Power Applications

Now a days, solar powered appliances are in fashion; from mobile phone charger to mega power plants solar energy is being utilized. Solar energy is appropriate for mid-sized residential facility or small sized commercial facility [16] [23].There are primarily 3 types of solar system configurations.

i. Off Grid Solar Systems
ii. On Grid Solar Systems
iii. Hybrid Solar Systems

2.5.1 Off Grid Solar System

An off grid solar system is the one where primary source of power is solar energy only. In this system, the primary source of power is solar energy, the excess power is stored into battery bank, to be used in night time. The off grid solar system comprises of Solar Inverter, Battery Bank and Solar Panels. [31].

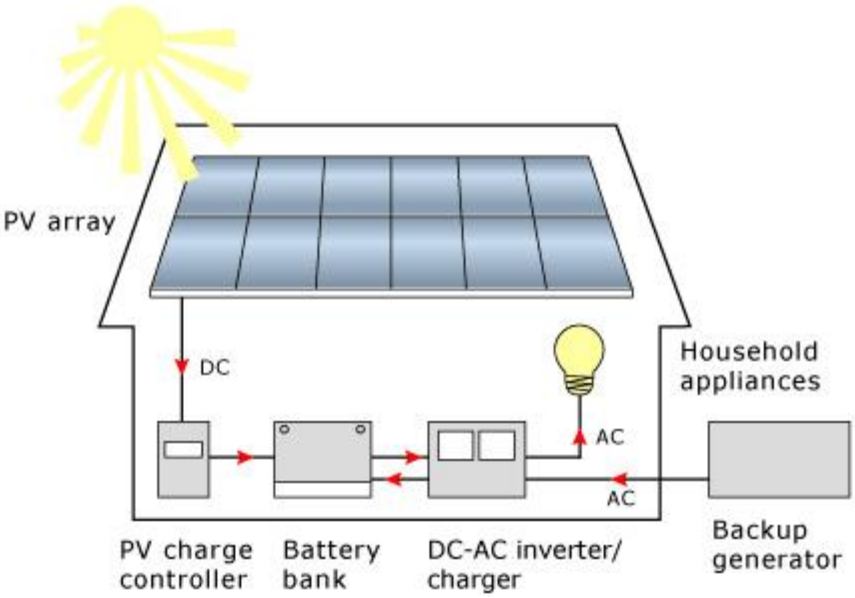


Figure 8: Schematic of Off Grid Residential Site

2.5.2 On Grid Solar System

On grid solar systems are mostly installed in medium as well as large commercial units and are very popular in industrial sector. On Grid solar systems are well suited for any facility that has un-interrupted grid power. As this type of solar systems only use solar energy as primary source and grid as reference, there is no storing mechanism inside the system. The excess energy is fed back into the grid, which is calculated at the end of each month via Net Metering, Feed in Tariff or Power Purchase agreement, whichever is applicable.[32] [33].

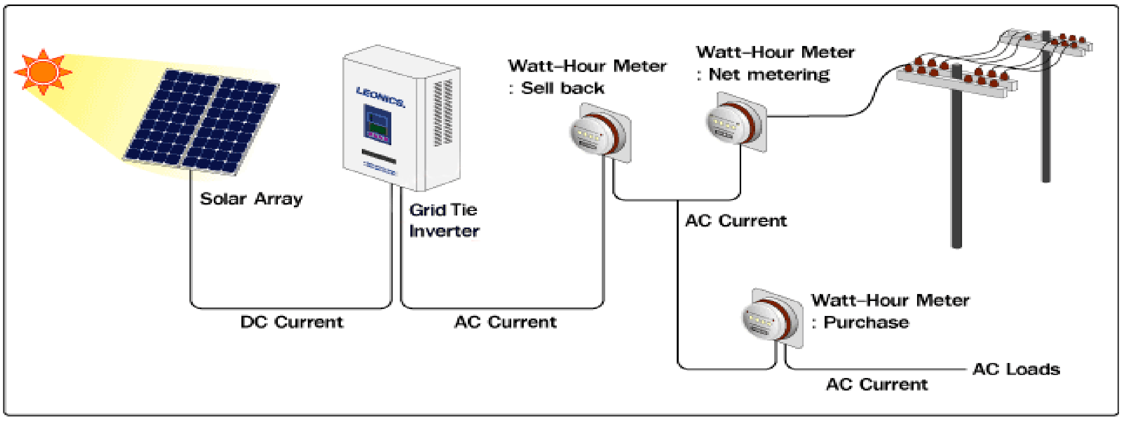


Figure 9: Schematic View of On Grid Solar System

2.5.3 Hybrid Solar Systems

The hybrid solar systems 'as the name suggests' are the mix of off grid and on grid solar systems. They use solar energy as primary source of energy and meanwhile they store excess energy into the battery bank. When battery bank are fully charged, the excess power is then fed into the grid for net metering. [34].

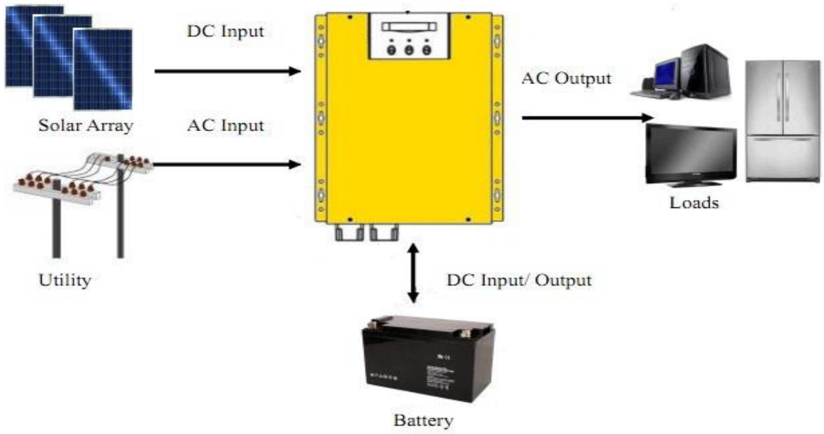


Figure 10: Schematic View of Hybrid Solar System

2.6 Distributed Generation and Electricity Sell Back

Distributed Generation System (DER) or Decentralized Energy is the concept of generating and storing the energy in a verity of micro grids, that are connected to verity of small grid tied devices [35]. Decentralized energy, as the name indicates, is generated or stored by a variety of small, grid-connected devices, referred to as distributed energy resources (DER) [36].

Conventional power stations, such as coal power plants, nuclear or oil and gas driven power plants are centralized and are often connected to the national grid. These centralized systems are very large and require power to be transmitted over large distances, resulting in line losses and electricity theft. On the other hand the small DERs are decentralized and are located close to the production facility and the region where this power is to be consumed. The system can comprise of multiple renewable generation sites, some storage units and distribution units. [37]

Figure 11: Schematic View of a typical DER

DERs mostly use renewable sources for electricity generation like solar, wind, biomass, biogas and geothermal power. The DERs are directly connected to grid connected devices and collect excess energy produced, store it in storage units and distribute it to nearby loads. DERs have lower environmental impacts and improved supply of electricity. DER systems are playing an increasing and important role in the electric power distribution system [38].

Micro grids are the main component of DERs. They are modern, localized and small scaled grid stations to power the adjacent areas. They are decentralized and can operate independently. They have no connection with the national grid stations. Micro grids can handle mixture of different renewable energy sources, such as solar, wind, hydro in conjunction with traditional diesel and gas generators. They help reduce line losses, improve energy transportation and lessen carbon foot prints in atmosphere [39].

On grid solar system is relatively a newer concept in Pakistan. NEPRA has also allowed selling back the excess electricity to partnering DICOS and the sell back amount will be adjusted in the upcoming electricity bills. There are primarily two kinds of procedures through which a producer can sell his renewable (wind, solar, hydro) power. The DERs require grid connected devices that are able to sell back the excess amount of generated power to the DERs. The mechanism used worldwide may be categorized into the following three types:

i. Feed in Tariff (FiT)
ii. Net Metering

iii. Power Purchase Agreements

2.6.1 Feed in Tariff (FiT)

This is a standard purchase contract between the producer (renewable energy producer) and the DER [41]. This contract comprises of sell back tariff, penalties, purchase timeline, purchase quantity and as-sectioned load. FiT aims to offer cost compensation to the renewable energy producers by providing them long term sell back contracts and price certainty to help them finance their renewable energy system capitals initially [38] [39].

FiT offers purchase contracts to residential, commercial, agricultural and private investors. In FiT the sell back rate may differ according to the renewable technology used by the producer (roof top solar systems, wind, hydro etc.). This is to put a limit to a specific renewable energy source in a specific area. Under FiT, renewable energy producers are paid a cost-based return for the energy they supply to the grid. Home owners, commercial consumers, farmers and investors can benefit from FiT. FiT typically offers long-term guaranteed purchase agreement from 15-25 years and the tariff typically declines over the years [40].

2.6.2 Net Metering

Net metering allows producers of the renewable energy to feed the energy into the grid and consume it at any time of the day, regardless of when the energy is generated. Net metering is important for solar energy producers as they can only produce the energy during the day time. This system allows the solar producer to use the excess energy provided to grid at night. If the monthly generated power exceeds the consumption of the consumer, the remaining KWH rolls over to the next month. This mechanism helps the consumer to use the excess power generated from March to August (summers) in September to February (winters).

Net metering only uses one energy meter that is bi-directional which calculates the net energy consumed rather than one meter calculating the energy produced and other calculating the energy consumed. Another advantage of net metering is that it does not require any special metering or even a notification or agreement with grid.

Energy storage

Energy storage integrated net metering systems are also present. The producer stores some excess energy into battery banks and when the battery banks are fully charged, the excess power is fed into the grid. This system is more popular in the countries where the grid power is unstable. This is because the on grid systems only work if there is some reference source present (i.e. grid or generator). If the reference is lost the system will shut down automatically. Energy storage helps the producer to store the energy at the time of grid shutdown during the sun hours. For storage purpose, batteries of various kinds are being used all over the world. Lead acid wet batteries are still used largely but they have small life cycle. Lithium Ion batteries and industrial deep cycle batteries are also being used and have an approximate life of 10 to 20 years [37]. Ni-Fe batteries have the longest life span of approximately 40 years [41].

2.6.3 Power Purchase Agreements

A power purchase agreement (PPA), or electricity power agreement, is a contract between two parties, one which generates electricity (the seller) and the other which is looking to purchase electricity (the buyer). The PPA defines all of the commercials for the sale of electricity between the two parties, including when the project will begin commercial operation, schedule for delivery of electricity, penalties for under delivery, payment terms, and termination. A PPA is the principal agreement that defines the revenue and credit quality of a generating project and is thus a key instrument of project finance. There are many forms of PPA in use today, which vary according to the needs of buyer, seller and the financing counterparties [42].

2.7 Solar Powered Water Pumping System:

Pakistan is an agricultural state and almost 80% of the people live in rural areas and the primary source of their income is farming. Water pumping is still very popular mode of watering the fields despite having a large network of well managed canal system in Pakistan. Water pumps are being run using diesel generators, turbines, tractors or grid. There are many problems related to each of the above mentioned power generation sources. Diesel prices are very high in Pakistan and diesel generators need maintenance off and on, whereas national grid in not stable in Pakistan [43]. There are two basic types of solar water pumps being used in Pakistan.

1. Mono Block

2. Submersible

Mono block or surface pumps are based on old the technology and are very successful in the regions where water level in up to 100 feet down the ground. These water pumps have lower efficiency and are mounted on top of the ground or placed inside a deep well. Since the suction heads of the mono block pumps are small, they perform very well if placed on top of the water reservoir.

Figure 12: A Typical Mono Block Water Pump

Submersible water pumps are the latest in technology and can draw water from deep down the earth. Submersible water pumps are hanged inside the water deep inside the earth by a sling/rope. They are able to lift water from very high dynamic heads. Submersible water pumps are suitable for every condition but most preferably they are used where pump setting is around 120 feet or below.

Figure 13: Typical Submersible Water Pump

Solar water pumping has been improved in many ways with the introduction of new technologies in this field. Drip Irrigation is one of the latest technologies which has proven its advantages over conventional irrigation system significantly [44].

The four major new irrigation technologies include:

2. Rain Gun Irrigation
3. Bubbler Irrigation
4. Drip Irrigation
5. Sprinkler Irrigation

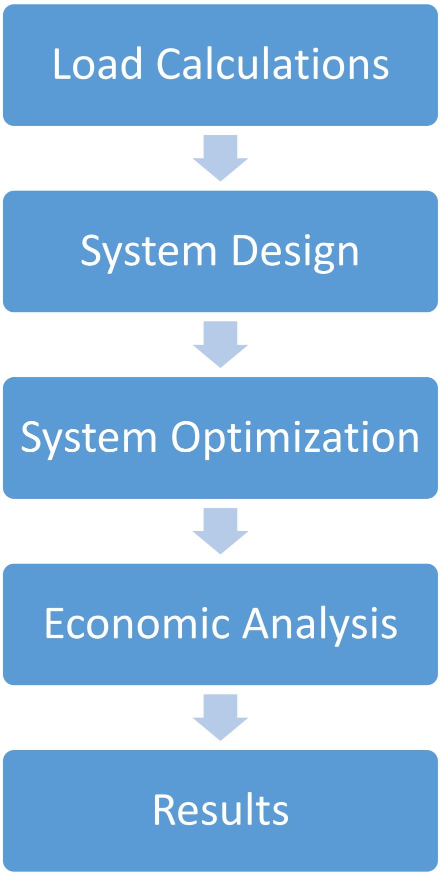
Figure 14: Latest Trends in Irrigation *[45]*

CHAPTER 3: METHODOLGY

There is an increased trend towards installation of solar energy in Pakistan. Solar energy is gaining an acceptance as a viable solution at domestic, commercial and agricultural level. This technology has not been used in industrial sector as their energy requirement is subsequently higher.

The objective of this study is to establish economic viability of solar energy solutions at domestic, commercial and agricultural sectors.

3.1 Procedure of Analysis:



3.2 Introduction to HOMER System Modeling Tool

HOMER is a hybrid system modeling tool developed by NREL (National Renewable Energy Laboratory). Student license was issued free of cost from NREL for this report. HOMER is a micro grid optimization and modeling tool, it takes user data in the form of different component prices, lifetime, grid extension cost, storage system cost, load profile of location and weather data of the selected location. Using this data, HOMER performs calculations and provides results. HOMER can perform mainly three types of calculations known as simulation, optimization and sensitivity analysis. In simulation, HOMER compares the energy supply and demand for every hour of year and decides how to operate dispatch able sources (generators, battery and grid).In optimization, HOMER simulates each system configuration and sorts by net present cost (NPC), whereas in sensitivity analysis, HOMER performs an optimization for each sensitivity variable. There are two different types of strategies that HOMER follows: 1. Load-Following Strategy 2. Cycle Charging. Under the load-following algorithm, generators are not allowed to charge the batteries; the batteries are only charged from renewable energy; under the cycle charging algorithm, the generators are allowed to charge.

HOMER's results show complete comparison of various given systems and their alternate configurations sorted with respect to their NPC and COE (Cost of Energy).From these results we can easily see which system is most feasible for any given location.

3.3 Problem Statement

To minimize the system cost and Payback period by satisfying the power needs keeping in view the power outage and other constraints.

Decision Variables:

i. PV Capacity
ii. Generator Capacity
iii. Generator Fuel Usage
iv. System Converter Capacity
v. Energy Purchased from Grid
vi. Battery Bank Size

Parameters:

i. Battery bank unit size = 1kWh
ii. Solar System Unit Size = 1 KW
iii. Grid Power Unit Size = 1kWh

Constraints:

i. Power Outage is 1 Hr. after every 4 Hrs.
ii. PV degradation is 0.7% Year over year.
iii. Battery State of Charge >= 50%.
iv. Maximum degradation of Solar panels in 25Years = 20%
v. Batter life = 3years or 800kWh output.

Cost Inputs:

i. Solar System 1KW Unit Cost = $730
ii. Battery 1kWh Cost = $ 100
iii. Battery Replacement cost = $ 100
iv. Generator Cost 1KW = $ 180
v. Converter Cost 1 KW = $ 180

3.4 Assumptions

There are few assumptions that have been made during this study, related to electricity tariff, load profiles (Commercial, Agricultural), and initial investment on existing tube wells.

1. Electricity tariff is taken in accordance with FESCO (Faisalabad Electric Supply Company) for all case studies.
2. Average household load is taken at 4KW (Small and medium households)
3. This study does not include large residential and commercial or industrial sectors.
4. Grid line losses are not taken into account during the entire study.

3.5 Scenarios

In total 6 scenarios will be discussed, two from residential, three from commercial and one from agricultural sector. These are the real life scenarios and are most popular in Pakistan.

Residential Case Study:

In the residential sector off gird and hybrid solar system will be in study. Off grid solar systems are the standalone solar systems, having no link with the national grid. They totally rely on solar energy and store excess amount of energy in batteries to use them later during night. On the other hand, the Hybrid Solar Systems use solar energy as primary source of energy and national grid as secondary source. When solar energy is not enough to satisfy the load demand than the system shares some amount of energy from national grid to satisfy the load demand. Furthermore, when there is no solar and grid power available, these type of systems use batteries to power the load at night. Because of using solar, grid and batteries in one system, this system is referred to as hybrid solar system.

Commercial Case Study:

Commercial sector of Pakistan is most affected by the current energy shortage. Schools, banks and daytime businesses need continuous power to perform their operations. In Pakistan, the grid per KWh price for the commercial sector is highest in comparison to all other sectors.

In the commercial case study, three scenarios, off grid solar systems, on grid solar systems and hybrid solar systems will be discussed. As discussed earlier, off grid solar systems are standalone solar system and primary and the only source of energy they rely on is solar energy. The on grid solar systems (often referred to as Grid tie solar systems) only work in conjunction with national grid because they need a reference source to operate. In this type of system grid is the reference source and solar energy is primary source of energy, but when there is grid failure then reference is lost and entire distribution generation system (solar system) will shut down. This case is chosen as NEPRA and AEDB in Pakistan recently allowed net metering. We have not accounted the reverse metering process but still we try to compare the on grid system to other systems.

The third scenario we will be discussing is again a hybrid solution, but this time id different from residential case study. Commercial sector needs a lot more energy than residential unit, so to satisfy the demand during grid failure or at night, a large amount of storage bank (battery bank) will be needed. To make this case study more interesting, we changed the battery bank with a diesel generator. This hybrid system is an on grid system with generator backup, the generator being used only for backup and reference. It is a stepper generator that is computer controlled and running on its minimum value until the energy is demanded.

Agricultural Case Study:

The agricultural sector has always been the backbone of our country and almost 90% of pumping units are installed in remote areas or where the grid is not present. Unstable grid and unstable grid voltages force farmers to use expensive means of energy production to run their water pumps. Solar energy system for water pumping is a standalone system in which only solar energy is used as primary source and the system will only operate during the day time. Calculating the payback period of such a system will be beneficial for our farmers.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Residential Case Study

Residential sector is always passionate on using alternate source of energies to power up their homes. In most of the homes in Pakistan, due to un-reliable gird are forces to install UPS or Generators to fulfil their power needs. Year over Year grid power is becoming costly, now people are shifting their homes on renewable energy sources. By the help of optimization tools, an optimized power solution can be presented. Optimization tool can calculate optimized PV capacity, Battery bank, amount of power shared from gird and can also design auto-sized generators.

4.1.1 Base case for residential case study

To calculate pay back periods and other mathematical calculation we must have some base case. The base case taken for residential sector is the situation in which there is no power outage and all the power requirements are met using the Grid.

The base case is important to compare the other cases, to get an optimized and best suited situation. The base case will give a cost value of grid power, if only grid is used to fulfil the power requirements.

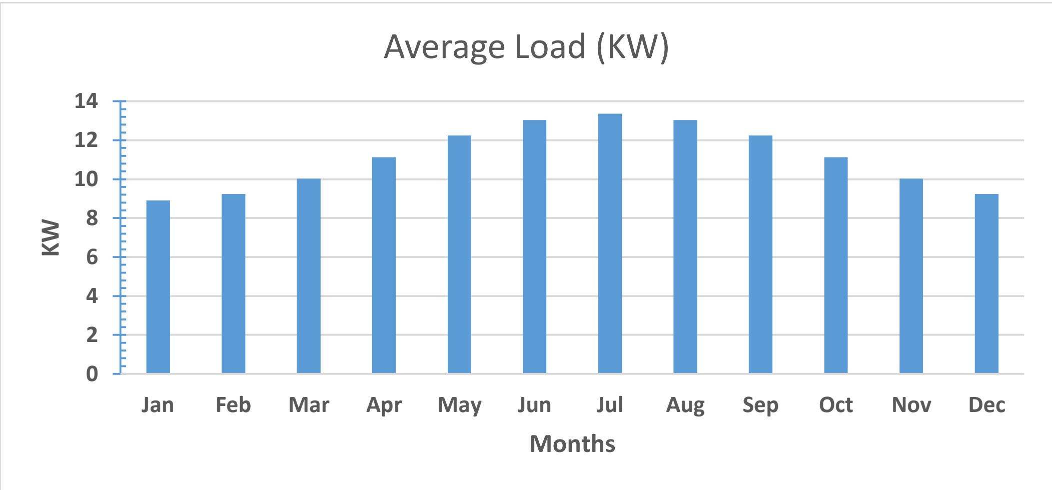


Figure 15: Average load for residential case study

The average load for the residential case study is about 13 kWh per day. From the load profile (figure 15), it can be clearly seen that peak load is during summer season which is very typical of Pakistan.

Total electrical load served to fulfil the required load can be seen in the above graph. This is being the base case, all the load is served from the national grid.

Cost of Electricity:

$$Cost\ of\ ELectricity\ per\ kWH = \$\ 0.13$$

$$Required\ kWH = 4{,}745$$

$$Total\ Electrical\ Load\ Served\ from\ Grid\ kWH = 4{,}745$$

$$\boldsymbol{Total\ Operating\ Cost\ per\ year = \$\ 0.13 * 4745 = \$\ 616.85}$$

The above calculation is for 1 Year time period, and the operating cost is $ 616.85 per year. As solar panel life is take as 25 year and the operating cost of grid for 25 year time period will be:

$$\boldsymbol{Total\ Operating\ Cost\ (25\ Years) = \$\ 616.85 * 25\ Years = \$\ 15421.25}$$

Now all the subsequent cases will be compared to the above base case.

4.1.2 Case Study 1: Off Grid Solar System.

In this case study the residential unit will have no access to grid power and will fulfil its load requirements by using solar power and batteries. Batteries are used for storing backup power to be used in case of power outages. In this specific case batteries are the only source to lighten up the site because there is no grid power present on site.

Load profile will remain the same for all case studies of residential sector. Off grid solar system is the most basic case presented here. Solar energy will work as a primary source of energy and battery bank will support the site in night time, as there is no grid source on site.

Optimization software is used to get the best optimized solar solution. Inputs data is as below:

Table 3: System Parameters with Cost

Parameters	Value	Cost
Battery Bank Unit	1 kWh	$ 100/kWh
Solar Panel Unit	1 KW	$ 730/KW

Constraints remains the same as defined in the methodology section. Here the decision variables are solar array size and battery bank size because there is no grid power, so grid purchases, generator sizing and fuel consumption of generator decision variables are not applicable.

Results:

Canadian Solar Module with 310W rating is used in this project. Batteries are taken from a famous brand TROJEN USA, rated voltage of 6V and 2kWh.

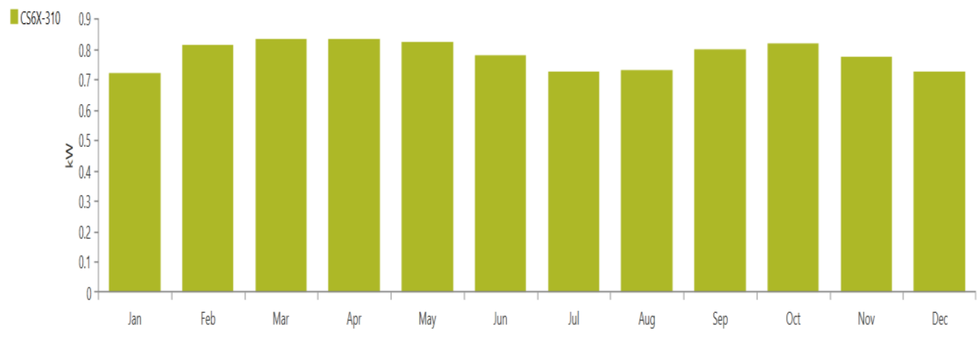


Figure 16: Electricity Generation with Solar Power

Figure 18 showing the total PV production throughout the year and 100% of the load is satisfied from the PV production. Solar panels satisfied the required load as well as charged the battery bank to provide un-interrupted power supply during the night.

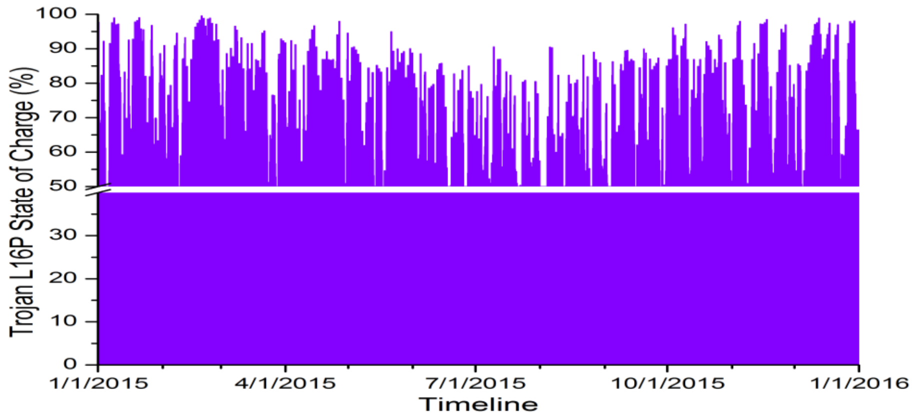


Figure 17: State of Charge (SOC) for Trojan L16P Battery Bank

As per the battery DOD constraint, we can see in figure 19, the battery remained charged 50% throughout the life time of project.

Optimized Solution:

Table 4 : Optimized Solution for Off-Grid Solar System: Residential Case

Sr.	Component	Capacity
1	Solar Panels	4.46KW
2	Trojan Battery 6V,2kWH	16 Pcs
3	System Converter	1.80KW
4	Grid Purchases	Zero

Economic Analysis:

In economic analysis, the system costs, replacement costs and payback period is discussed. As an off grid system, the only source of power is solar panels, for backup the battery bank is being used.

Table 5: Total Cost of the System and Life Period.

Component	**Initial Cost ($)**	**Replacement ($)**	**Operating Cost ($)**	**Total ($)**	**Component Life**
Solar Panels	3,256.89	0	0	3,256.89	25 Years
System Converter	324.23	279.27	0	519.23	15 Years
Battery Bank	4,800	16,587.15	0	18,348.81	10 Years/800kWH
Total ($)	**8,381.12**	**16,866**	**0**	**22,124.93**	

Project lifetime is 25 years, which is taken from the life period of solar panels. There is no replacement cost of solar panels but batteries and system converter need to be replaced as per their life period. According to the calculation, the average life time of battery came out to be 5.29 year, so battery have to be replaced approximately five times. The system converter life span is 15 years so it need to be replaced once in a 25 year life period of project.

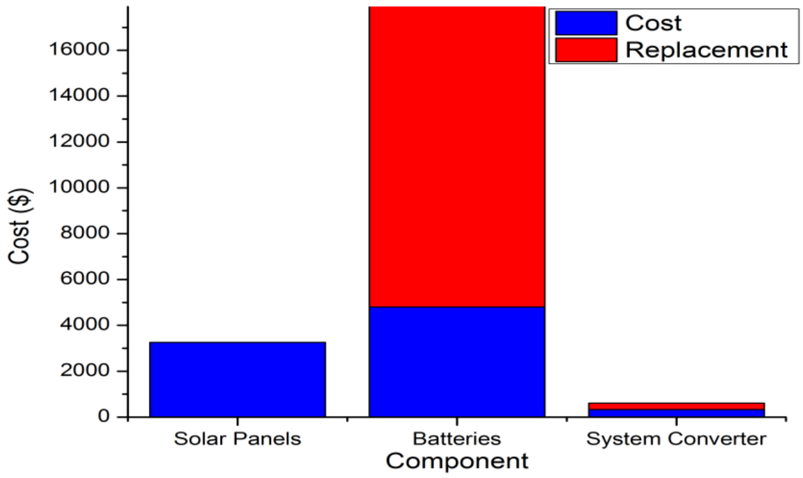


Figure 18: Component wise Capital and Replacement Cost

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV} = \sum \left\{ \frac{\boldsymbol{Net\ Period\ Cash\ Flow}}{(\mathbf{1} + \boldsymbol{R})^{\boldsymbol{T}}} \right\} - \boldsymbol{Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = $ 8,381.12 + $ 16,866 = $ 25,247.2

$$Operating\ Cost\ of\ Base\ Case = \ \$\ 616.85/year$$

$$Operating\ Cost\ of\ \ System = \$\ 0/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = $ 13,162.28

Pay Back Period:

Payback period calculation is the core part of this project. With the help of payback period we can estimate the feasibility of the project. If payback period is too high, then the project may not be feasible in most of the occasions.

$$\boldsymbol{Pay\ Back\ Period} = \frac{\boldsymbol{Initial_{Cost}}}{\boldsymbol{Operating\ Cost\ (base\ case) - Operating\ Cost\ (current\ system)}}$$

$$Initial\ Cost\ of\ project = \$\ 8{,}381.12$$

$$Operating\ Cost\ of\ Base\ Case = \ \$\ 616.85$$

$$Operating\ Cost\ of\ Off\ Grid\ System = Zero$$

$$\boldsymbol{Pay\ Back\ Period} = \frac{\mathbf{8,381.12}}{\mathbf{616.85 - 0}} = \ \mathbf{13.85\ Years}$$

4.1.3 Case 2: Hybrid Solar System (Grid + Solar + Backup)

Grid, Solar and Backup combination is the most popular among residential and small commercial consumers. Solar is taken as the primary source of energy. When sun sets, load is shifted to the secondary source, that is grid power and in case grid is not available during load shedding hours, the load is shifted to battery bank. Battery bank is designed according to the load shedding schedule and battery bank has been prioritized to be charged from solar to save electricity cost.

Decision Variables:

i. PV Capacity
ii. Battery Bank Capacity
iii. Grid Purchases

Constraints:

i. Power Outage is 1 Hr. after every 4 Hrs.
ii. PV degradation is 0.7% Year over year.
iii. Battery State of Charge >= 50%.
iv. Maximum degradation of solar panels in 25Years = 20%

v. Batter life = 10years or 1075 kWh output.

Results:

By using the standard parameters discussed in introduction section and keeping in view the contraints of this problem TABLE 6 shows that, Optimizer picked only 2 batteries as batteries are only used when there is total blackout. There is a tradeoff between PV capacity selection and Grid purchases.

Table 6: Optimized solution for Solar + Grid + Backup System: Residential Case

Sr.	Component	Capacity
1	Solar Panels	2.15 KW
2	Trojan Battery 6V,2kWH	2 Pcs
3	System Converter	1.55 KW
4	Grid Purchases	2,303 kWh

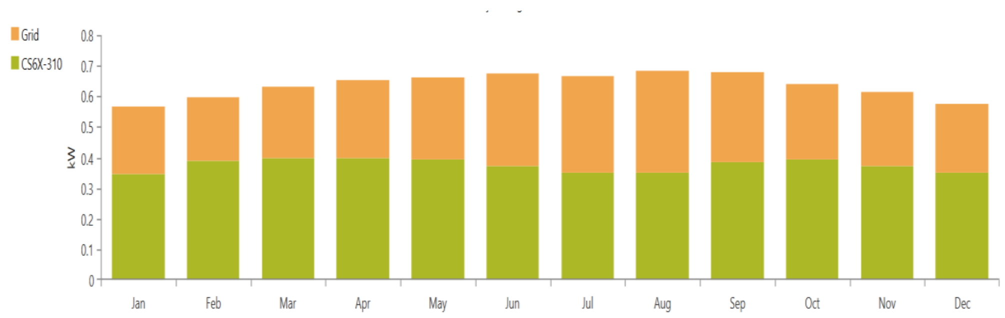


Figure 19: Grid and Solar CS6X-310 Penetration in system

Table 7: Solar and Grid Representation in Hybrid System: Residential case

Source	kWh/year	Percentage %
Solar Panels CSX-301	3,285	58.78
Grid	2,303	41.22
Total	5,588	100.00

From figure 21 and table 7 it is clearly seen that solar energy is dominating with 58.78% because most of the energy requirments are served from the solar panels.

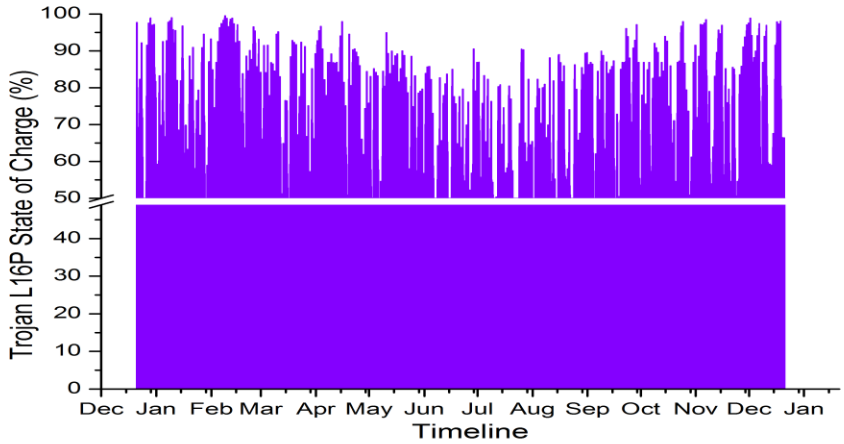


Figure 20: SOC for Trojan L16P

Economic Analysis:

In economic analysis, the system costs, replacement costs and payback period is discussed. As a hybrid System (Grid + Solar + Backup) system, the primary source of power is Solar Panels, secondary source is Grid and for backup battery bank is being used.

Table 8: Components cost, O & M costs and Replacement Cost: Residential Case

Component	**Initial Cost ($)**	**Replacement Cost ($)**	**O & M ($)**	**Total ($)**
Solar Panels	1,566.51	0	0	**1,566.51**
Grid	0	0	6,593.96	**6,593.96**
Battery Bank	600	2,607	0	**3,207**
System Converter	278.88	240.21	0	**519.09**
Total	**2,445.39**	**2,847.21**	**6,593.96**	**11,886.56**

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV = \sum \left\{ \frac{Net\ Period\ Cash\ Flow}{(1+R)^T} \right\} - Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = $ 2,445 + $ 2,847.21 = $ 5292.21

$$Operating\ Cost\ of\ Base\ Case = \$\ 616.85/year$$

$$Operating\ Cost\ of\ \ System = \$\ 409.54/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = $ 7,936.92

Pay Back Period:

Payback period calculation is the core part of this project. With the help of payback period, we can estimate that feasibility of the project. If payback period is too high then project may not be feasible for most of the occasions.

$$\boldsymbol{Pay\ Back\ Period = \frac{Initial_{Cost}}{Operating\ Cost\ (base\ case) - Operating\ Cost\ (current\ system)}}$$

$$Initial\ Cost\ of\ project = \$\ 2{,}445.39$$

$$Operating\ Cost\ of\ Base\ Case = \$\ 616.85/year$$

$$Operating\ Cost\ of\ \ System = \$\ 409.54/year$$

$$\boldsymbol{Pay\ Back\ Period = \frac{2{,}445.39}{616.85 - 409.54} = 11.79\ \text{Years}}$$

4.2 Commercial Sector Case Study

Commercial sector is taken into account because national grid tariff for this sector is highest as compared to all other sectors. Commercial buildings always need un-interrupted power and interruptions in power may cause a loss to company. That is why, commercial sites always use backup generators or battery banks.

4.2.1 Base Case for commercial sector:

Base case is again the simplest one, with power requirements are being satisfied from the national grid only. No load shedding is considered in this base case as we want to calculate the exact consumption of site if there is no blackout. This base case will serve as the comparing mechanism to calculate the payback period for other solar solutions.

The base case is important to be compared to the other cases, to get an optimized and best suited situation. The base case will give a cost value of grid power if only grid is used to fulfil the power requirements.

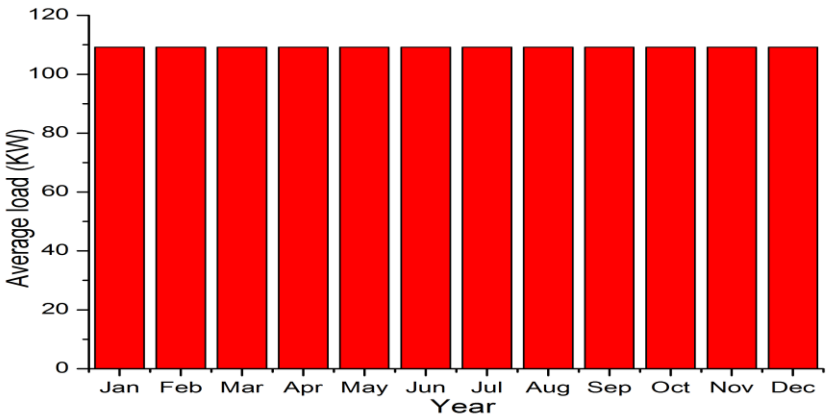


Figure 21: Average Load Profile for Commercial Site

The commercial site has uniform load all the year round, as offices remains open from 9-5 and after that only essential load is operating.

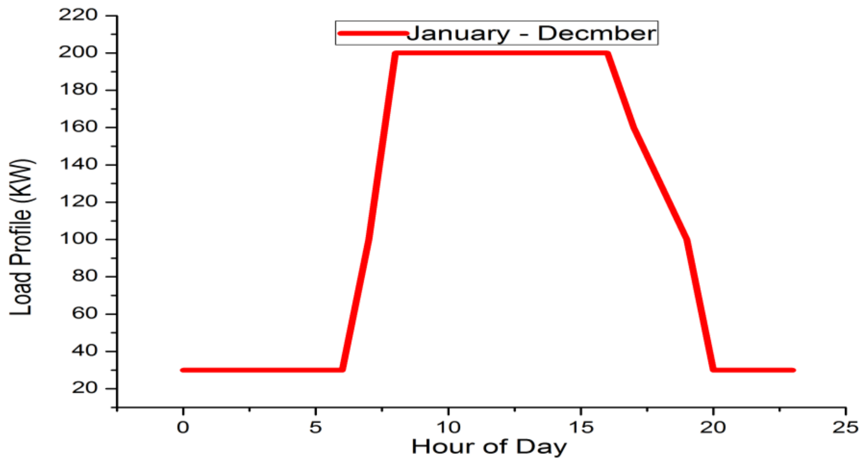


Figure 22: Daily Load Profile for Commercial Site, Jan-Dec

The average load for commercial case study is about 200 kWH per day. Average load vary in between 100-110KW, whereas minimum load is 27-30 KW.

Cost of Electricity:

$$Cost\ of\ ELectricity\ per\ kWH = \$\ 0.17$$

$$Required\ kWH = 73{,}000$$

$$Total\ Electrical\ Load\ Served\ from\ Grid\ kWH = 73{,}000$$

$$\boldsymbol{Total\ Operating\ Cost\ per\ year = \$\ 0.17 * 73{,}000 = \$\ 12{,}410}$$

The above calculation is for 1 Year time period, operating cost is $ 12,410 per year. As solar panel life is take as 25 year, the operating cost of grid for 25 year time period will be:

$$\boldsymbol{Total\ Operating\ Cost\ (25\ Years) = \$\ 12{,}410 * 25\ Years = \$\ 310{,}250}$$

Now all the subsequent cases will be compared to the above base case.

4.2.2 On Grid Solar System with No Backup.

On Grid solution are the most popular among developed countries. Payback periods for these type of solution are the lowest. We have choose grid tie system for analysis because in Pakistan grid tie solutions are gaining huge momentum and recently NEPRA and AEDB have approved NETMETERING regulations in Pakistan. With net metering now consumers, who have grid tie solutions installed on their site now can sell the excess power generated by solar system to grid. On Grid system always need a primary source of power to properly sync the system to grid power. If primary source or reference is lost the system will shut down automatically, regardless you have solar energy or not.

RESULTS:

Parameters for this case will remain same as discussed above but constraints and decision variables will change.

Decision Variables:

i. PV Capacity
ii. Grid Purchases

Constraints:

i. Power Outage is 1 Hr. after every 4 Hrs.
ii. PV degradation is 0.7% Year over year.
iii. Maximum degradation of Solar panels in 25Years = 20%

System Design:

Table 9: Optimized System Design for On Grid Solar System: Commercial Case

Component	Capacity
Solar Panels CSX-310	97.7 KW
Grid Power Purchased	16,949kWh
System Converter MPPT	100KW

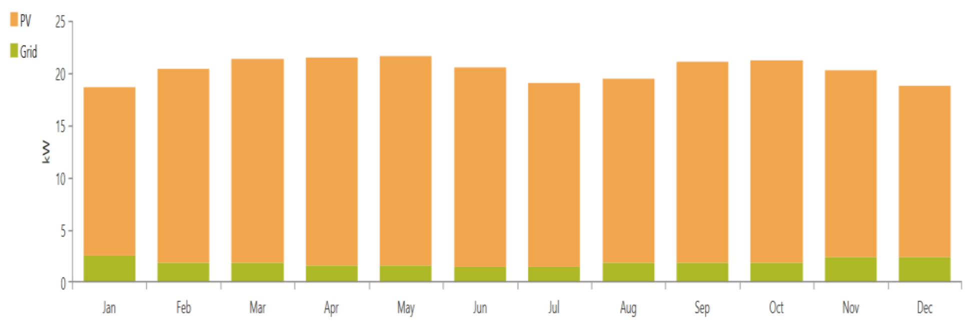


Figure 23: Solar and Grid Representation in Solar System

As an on grid system, the maximum load, as may be noticed in the figure, is satisfied from solar modules. 90.49% load is served from solar power and only 9.51% is taken from grid. This is also because the commercial sites run from 9am-5pm after which only essential load remains. The working time for solar panels are also from 9am-5pm. Thant is why most of the load is served from solar power.

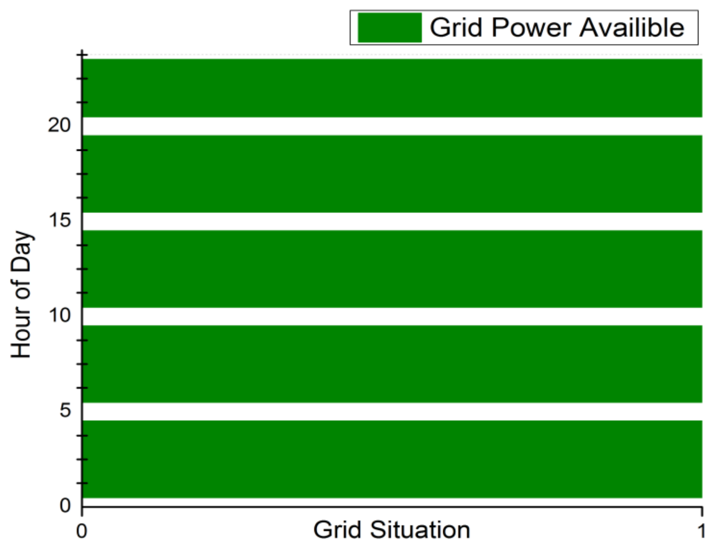


Figure 24: Load Shedding Profile

The drawback of this system is that during load shedding hours the system will shut down. Because of this drawback in this specific case, the unmet power is about 2,993 kWh, which is around 4.29% of energy need.

Economic Analysis:

There will only be two main components involved in on grid system, the solar panels and grid power. From the above we can see that dominating source of power is solar power.

Table 10: Component Level Capital, O&M and Replacement Costs: Commercial Case

Component	Capital Cost ($)	O & M Cost ($)	Replacement Cost ($)	Total ($)
Solar Panels CSX-310	71,476	0	0	71,476
Grid Power	0	63,454.32	0	63,454.32
Total	71,476	63,454.32	0	1,34,930

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV = \sum \left\{ \frac{Net\ Period\ Cash\ Flow}{(1+R)^T} \right\} - Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = $ 71,476 + Zero = $ 71,476

$$Operating\ Cost\ of\ Base\ Case = \$\ 12{,}410/year$$
$$Operating\ Cost\ of\ \ System = \$\ 2{,}881.33/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = $ 193,054.91

Payback Period:

Payback period determines how long it will take the system to pay your initial investment. All the systems are designed on the basis of payback periods.

$$\boldsymbol{Pay\ Back\ Period} = \frac{\boldsymbol{Initial_{Cost}}}{\boldsymbol{Operating\ Cost\ (base\ case) - Operating\ Cost\ (current\ system)}}$$

$$Initial\ Cost\ of\ project = \$\ 71{,}467$$

$$Operating\ Cost\ of\ System = \ \$\ 2{,}881.33/year$$

$$Operating\ Cost\ of\ \ Base\ Case = \$\ 12{,}410/year$$

$$\boldsymbol{Pay\ Back\ Period} = \frac{\mathbf{71,467}}{\mathbf{12,410 - 2,881.33}} = \ \mathbf{7.5\ Years}$$

4.2.3 On grid System with Generator Backup: Solar + Grid + Generator

Solar, grid and generator system is an option for commercial sites. In most of the commercial sites generator is already installed for backup or emergency services. Using the backup generator will more beneficial than using batteries as backup. Battery bank is always an expensive option of storing energy and there are lot of conversion losses while storing and retrieving power from batteries. Using generator is also a good option because it connects directly to AC bus bar which means that there is no need of battery charging converter or rectifier in the system and losses for power conversion are minimal.

Decision Variables:

iv. PV Capacity
v. Generator Sizing
vi. Generator Fuel
vii. Grid Purchases

Constraints:

vi. Power Outage is 1 Hr. after every 4 Hrs.
vii. PV degradation is 0.7% year over year.

viii. Generator lifetime is 15000 hrs.

ix. Maximum degradation of solar panels in 25Years = 20%

Results:

We optimized the given problem, by using the standard parameters discussed in introduction section and keeping in view the contraints of this problem.

Table 11: Optimized System Design for Solar + Grid + Generator: Commercial Case

Sr.	Component	Capacity
1	Solar Panels	68.83 KW
2	Generator Size	32 KW
3	Grid Purchases	18,920 kWh

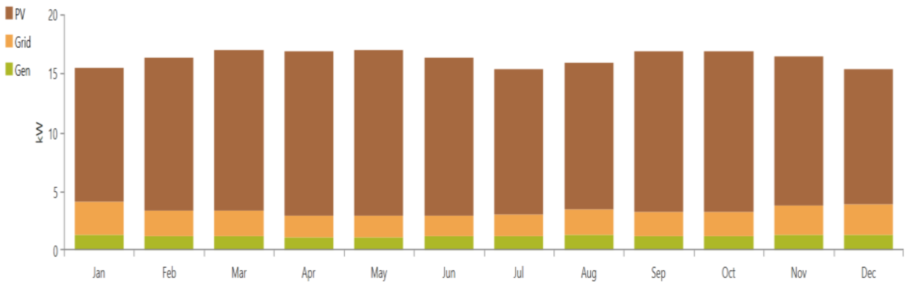


Figure 25: PV Grid and Generator Usage throughout the Year

Table 12: Solar, Grid and Generation representation in total system: Commercial Case

Source	**kWh/year**	**Percentage %**
Solar Panels CSX-301	113,197	79.38
Grid	10,486	13.27
Generator	18,920	7.35
Total	142,602	100.00

Solar Energy is dominating with 79.38%, most of the energy requirments being served from the solar panels. Grid share is minimal because of higher electricty cost. Generator is in between as generator only works in blackout hours when there is no grid and solar power availible.

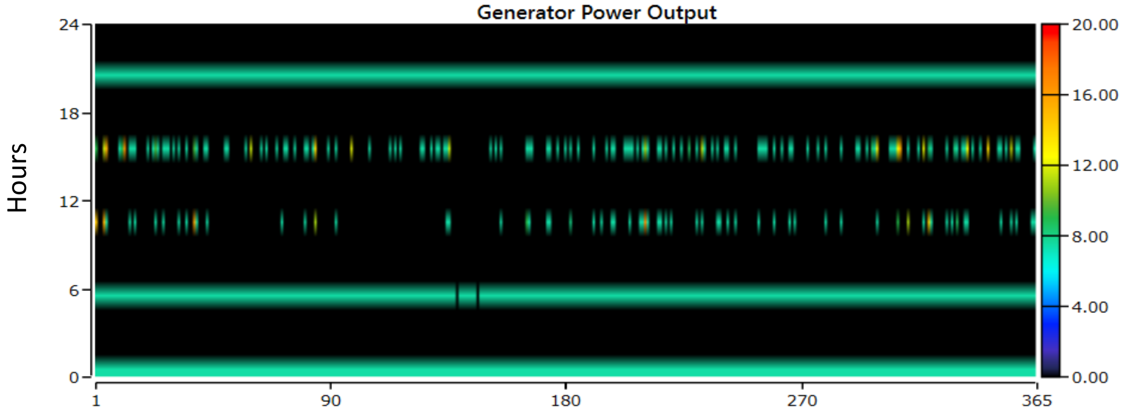


Figure 26: Generator Output throughout the Year

From the figure 28 it may be clearly seen that generator is just a support in load shedding hours. Green line is the load sheeding hours and generator is turned on during these times. From 9am to 7pm, there are two hours of load sheeding and generator is supporting solar system to fulfil the demand.

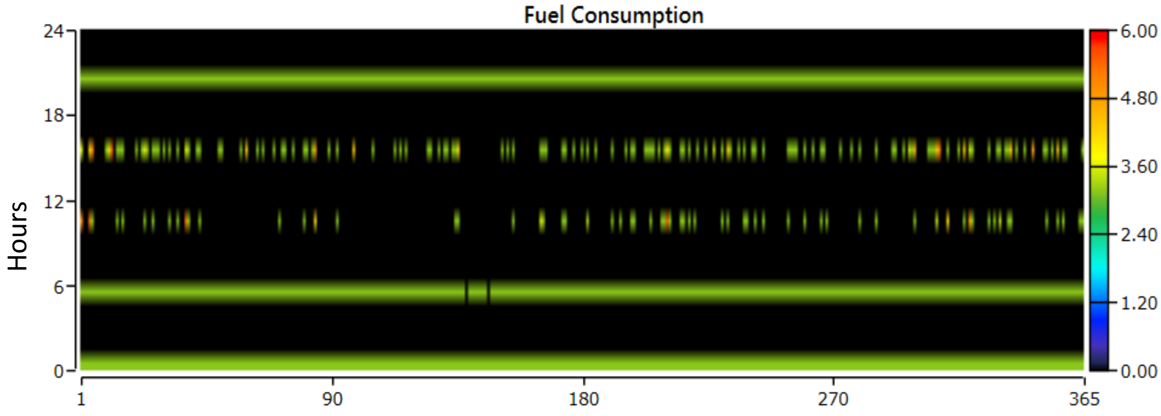


Figure 27: Fuel Consumption of generator throughout the year

Total fuel consumed by the generator is 4,317 lit/year and average daily fuel consumed by generator is about 11.4 lit/day.

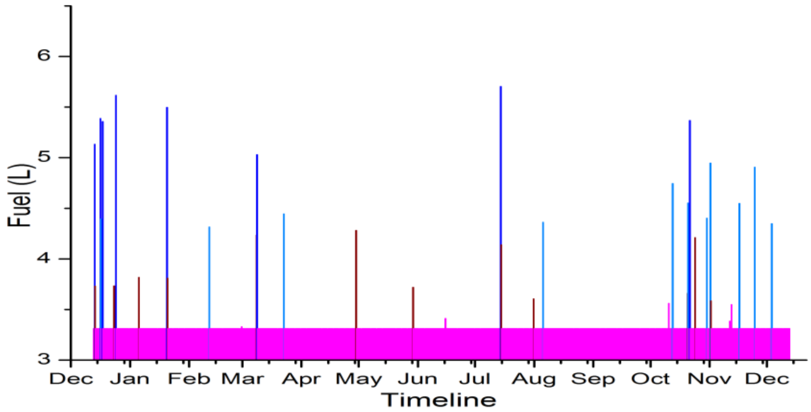


Figure 28: Fuel Consumption of Diesel Generator during Load Shedding

The spikes in the above table are representing the fuel consupmtion during the load sheeding hours. The generator used in this example is an adnvaced generator that consumes the fuel according to load. The generator operates on a minimum of 25% where the fuel cunsuption is approximatly 3.34 lit/hr. As the load is incresed on the generator, the generator consumes more fuel.

Economic Analysis:

In economic analysis, the system costs, generator fueling, replacement costs and payback period is discussed. As a Hybrid (Grid + Solar + Generator) system, the primary source of power is Solar Panels, secondary source is Grid and for backup Generator is being used.

Table 13: Component Level Capital, O&M and Replacement Cost for Hybrid (Grid+ Solar + Genset) Commercial Case

Component	Initial Cost ($)	Replacement Cost ($)	O & M ($)	Fuel ($)	Total ($)
Generator	5,760	9,703.32	9,105.25	70,384.21	**94,052.78**
Solar Panels	50,187.50	0	0	0	**50,187.50**
Grid	0	0	70,934	0	**70,934**
Total	**55,947.50**	**9,703.32**	**80,039.25**	**70,384.21**	**216,074.28**

There is no initial replacement or fueling cost for grid, whereas Generator option has the highest cumulative cost.

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV = \sum \left\{ \frac{Net\ Period\ Cash\ Flow}{(1+R)^T} \right\} - Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = $ 55,947.50 + $ 9,703.32 = $ 65,650.82

$$Operating\ Cost\ of\ Base\ Case = \$\ 12{,}410/year$$
$$Operating\ Cost\ of\ \ System = \$\ 6{,}661.64/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = $138,994.71

Pay Back Period:

Payback period calculation is the core part of this project. With the help of payback period we can estimate the feasibility of the project. If payback period is too high, the project may not be feasible in most of the situations.

$$\boldsymbol{Pay\ Back\ Period = \frac{Initial_{Cost}}{Operating\ Cost\ (base\ case) - Operating\ Cost\ (current\ system)}}$$

$$Initial\ Cost\ of\ project = \$\ 55{,}947.50$$
$$Operating\ Cost\ of\ Base\ Case = \$\ 12410.10/year$$
$$Operating\ Cost\ of\ \ System = \$\ 6661.64/year$$

$$Pay\ Back\ Period = \frac{55,947.50}{12410.10 - 6661.64} = 9.74\ \text{Years}$$

4.2.4 Off Grid/ Standalone Solar System.

Off grid or standalone solar system uses solar modules as the primary and only source of power, and for backup battery bank is used. This case is studied here for commercial site in remote areas where no other energy source other than the solar power is available.

Decision Variables:

i. PV Capacity
ii. Battery Bank Sizing
iii. Grid Purchases

Constraints:

i. PV degradation is 0.7% year over year.
ii. Battery State of Charge >= 50%.
iii. Maximum degradation of Solar panels in 25Years = 20%
iv. Batter life = 3 years or 800 kWh output.

Results**:**

We optimized the given problem by using the standard parameters discussed in introduction section and keeping in view the contraints of this problem. In table 14 optimized solution can be seen.

Table 14: Optimized Solar Solution for Off Grid Case

Sr.	Component	Capacity
1	Solar Panels	130 KW
2	Battery Bank (12V, 1kWH)	128 Units
3	Battery charger converter	32.90 KW

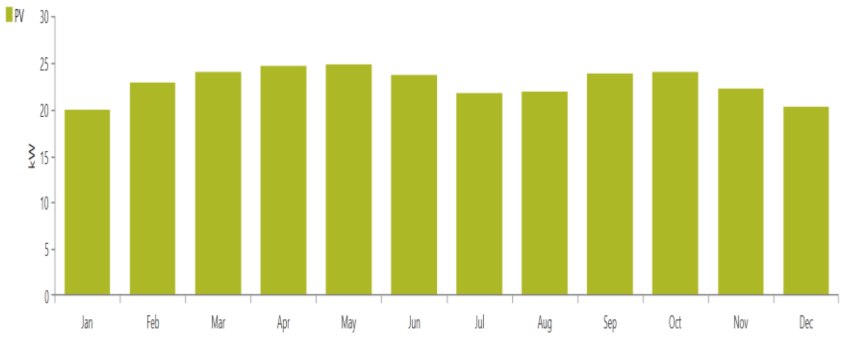


Figure 29: Solar Energy Generation throughout the Year

Table 15: Solar Power Generation and Representation in Off Grid System

Source	**kWH/year**	**Percentage %**
Solar Panels CSX-301	213,436	100
Total	213,436	100.00

Solar Energy is the only source of power generation so 100% of load is satisfied from solar energy. Here 121 KW of solar panels are used which seems larger than the actual laod, but keep in mind there are 128 units of 12V, 1 kWh batteries. These batteries also need solar energy ot fully charge and in night time battery bank will provide un intrepted power to satisfy the load requirments.

Economic Analysis:

In economic analysis, the system costs, generator fueling, replacement costs and Payback period is discussed. As a Hybrid (Grid + Solar + Generator) system, the primary source of power is Solar Panels, secondary source is Grid and for backup Generator is being used.

Table 16: Cost of System for Standalone Solar Unit: Commercial Case

Component	**Initial Cost ($)**	**Replacement Cost ($)**	**O & M ($)**	**Total ($)**
Battery Bank	18,560	65,658.73	8,456.91	**92,675.64**
Solar Panels	94,629.97	0	0	**94,629.97**
Converter	12,544.18	10,804.92	0	**23,349.10**

Total	**125,734.15**	**76,463.65**	**8,456.91**	**216,654**

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV = \sum \left\{\frac{Net\ Period\ Cash\ Flow}{(1+R)^T}\right\} - Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = \$ 5125,734.15 + \$76,463.65 = \$ 202,197.80

$$Operating\ Cost\ of\ Base\ Case = \$\ 12{,}410/year$$
$$Operating\ Cost\ of\ \ System = \$\ 704.74/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = \$351,547.64

Pay Back Period:

Payback period calculation is the core part of this project. With the help of payback period, we can estimate the feasibility of the project. If payback period is too high, the project may not be feasible in most of the situations.

$$\boldsymbol{Pay\ Back\ Period = \frac{Initial_{Cost}}{Operating\ Cost\ (base\ case) - Operating\ Cost\ (current\ system)}}$$

$Initial\ Cost\ of\ project = \$\ 125{,}734$

$$Operating\ Cost\ of\ Base\ Case = \$\ 12410.10/year$$
$$Operating\ Cost\ of\ \ System = \$\ 704.74/year$$

$$\boldsymbol{Pay\ Back\ Period = \frac{125{,}734}{12410.10 - 704.74} = 10.71\ \text{Years}}$$

4.3 Agricultural / Solar Water Pumping Case Study

Solar powered water pumping unit is to be install in a site near Jhang, Punjab. There is no electricity on site and solar will be the only source of power. The technical specifications of solar water pump is given below.

Table 17: Tubewell Technical Specifications

Water Column	40 Ft
Outlet Dia	5 Inches
Total depth	200 ft.
Flow Rate	110,000 lit/hr.

First of all pump selection was done, Alarko USA submersible pump was selected because of its worldwide popularity and outclass performance.

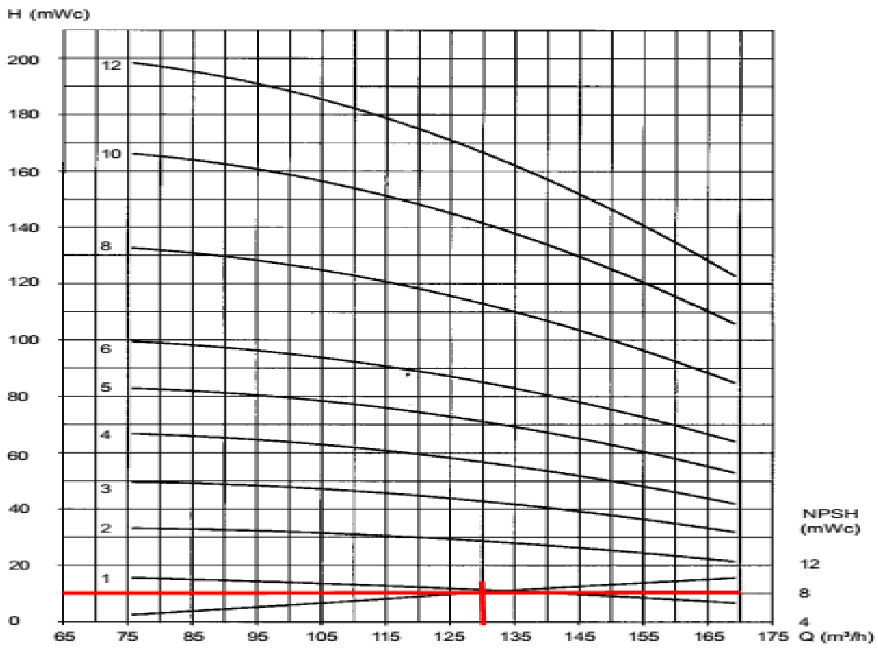


Figure 30: Characteristics Curve for 8125 Series Alarko Carrier Submersible Pumps *[46]*.

Vertical axis of figure 32 represents water level whereas the horizontal axis of the above pump selection curve graph represents flowrate. The pump selected from the graph is 8125/1 as it is meets our requirements.

TYPE Pump + Motor	Rated Power (HP)	Rated Current (Amp)	Pump End	Length Pump + Motor (mm)	Outer Diameter (mm)	Weight (Kg)
8125/1+AL6-10	10	17,8	Pipe Thread ISO 228-G5	1282	201	95
8125/2+AL6-20	20	34,6		1613		129
8125/3+AL6-30	30	54,7		1879	205	158
8125/4+AL8-40	40	61		2044	207	221
8125/5+AL8-50	50	74		2250		249
8125/6+AL8-60	60	90		2466		272
8125/8+AL8-75	75	110		2828		312
8125/10+AL8-95	95	140		3230		359
8125/12+AL10-110	110	173		3549	236	477

Figure 31 ALARKO Carrier Submersible Pump *[46]*

Pump specifications are listed in figure 33, initially pump was selected now from the technical specification. The rated power of the submersible motor pump is 10HP and it will theoretically give 130m^3/hr. of water.

As solar powered pumps are running on standalone solar system, they need only two components, the first is solar panels and the second is Solar Pump Inverter.

Solar Panel Selection:

Jhang is situated in Punjab province where weather usually remains hot. As discussed earlier the mono crystalline solar panels are not good for hotter areas, whereas the poly crystalline solar panels perform very well in high temperature areas.

Table 18: Comparison of Poly Crystalline and Thin Film Solar Panels

Module Type	**Poly Crystalline**	**Mono Crystalline**
Brand	Renesola	Renesola
Model	JC 255M	JC 255P
Module Efficiency	15.05 %	16.1 %
Size (L x H x W) mm	1655 x 999 x 35	1655 x 999 x 35
Cost ($/watt)	0.73	0.83

Poly crystalline solar panels are lower in price and satisfy our need. So for agricultural case study, poly crystalline solar panel will be used.

Solar Pumping Inverter Selection:

Solar pumping inverter is the device which converts DC current to useable AC current to be utilized to run water pumps. They are normally 3Phase AC drives. The pump inverter used in this study is from Hefei Jntech New Energy Co, Limited.

The pump inverter that meet out requirement is JNP11KH having Max DC input current of 40Ampare and rated 3phase AC current is approximately 25Ampares.

Solar System Design:

We are using Renesola Poly crystalline solar panels and 11KW Jntech solar pumping inverter to drive the water pump. Now solar system should be designed to meet the minimum Dc voltage of the pumping inverter.

Technical Parameters

Model	JNP11KH	JNP15KH	JNP18K5H	JNP22KH	JNP30KH	JNP37KH	JNP45KH	JNP55KH	JNP75KH	JNP90KH	JNP110KH
d.c. Input											
d.c. Max. Input Voltage	880Vdc										
Recommended MPPT Voltage	460~850Vdc										
d.c. Max. Intput Current	24.4A	33.3A	41.1A	49A	67A	82A	100A	122A	166A	205A	251A
Max. MPPT Efficiency	99%										
Number of String	3	3	3	1	1	1	1	1	1	1	1
a.c. Output											
Max. Motor Output Power	11kW	15kW	18.5kW	22kW	30kW	37kW	45kW	55kW	75kW	90kW	110kW
Rated Output Voltage	380~460Vac,three phase										
Output Frequency Range	0~50/60Hz										
Rated Output Current	21A	29A	36A	42A	57A	71A	86A	104A	142A	171A	209A
Other Parameters											
Weight	15.1kg	15.1kg	15.1kg	34kg	34kg	34kg	34kg	34kg	48kg	48kg	48kg
Dimension(L*W*H)	305*430*190mm			390*532*210mm						585*690*225mm	
Max. Efficiency	98%										
Protection Class	I										
Protection Level	IP65										
Operating Temperature	-25℃~+60℃; above 60℃ need derate operating										
Cooling Way	Force Cooling										
Display	LCD										
Communication	RS485/GPRS										
Altitude	3000m;above 3000m need derate operating										
Noise Emission	＜50dB										
Compliance	EN50178;IEC/EN62109-1;IEC 61800										

Figure 32: Jntech Pump Drive Technical Specifications *[47]*

Maximum input DC voltages are 880V, but the recommended MPPT DC Voc are 460~850V, therefore panel string must be designed to meet this criteria.

Electrical Characteristics STC	JC255M-24/Bbs
Maximum Power (Pmax)	255 W
Power Tolerance	0 ~ +5W
Module Efficiency	15.7%
Maximum Power Current (Imp)	8.39 A
Maximum Power Voltage (Vmp)	30.4 V
Short Circuit Current (Isc)	8.86 A
Open Circuit Voltage (Voc)	37.5 V

Values at Standard Test Conditions STC (AM1.5, Irradiance of 1000W/m², Cell Temperature 25°C)

Figure 33: Electrical Datasheet of Renesola Poly Crystalline Solar Panel [48]

From renesola data sheet, the following data is extracted: Voc = 37.5 V, Vmp = 30.4 V, Isc = 8.86 Amp and Imp = 8.39 Amp. We must complete the wattage of the system in accordance with the motor power rating. It is recommended to install solar system of at least 1.2 time the power rating of motor. This is due to DC conversion losses of 20% and line losses of approximately of 10%.

$$Motor\ Power\ Rating = 7500\ Watt$$

$$Max\ Vmp\ allowed = 460{\sim}850\ VDC$$

$$Solar\ Panel\ Vmp = 8.39\ V$$

$$String\ Size = 20\ X\ 30.4\ V = 608\ V$$

$$Solar\ Panels\ Voc = 37.5\ V$$

$$18\ Panels\ String = 20\ X\ 37.5 = 750\ V$$

$$Solar\ Panels\ required\ to\ run\ a\ 10\ HP\ Motor = 7460W\ x\ 1.3 = 9{,}698\ Watts$$

$$Solar\ Panels\ calculation = 20\ x\ 2\ x\ \frac{255Watt}{panel} = 10{,}200\ Watt$$

Capital cost:

The cost incurred to install a system is known as the capital cost, which is irrespective of operation and maintenance cost. The product wise cost is listed in table 19 below.

Table 19: Estimated cost for a standalone, solar powered water pumping unit

Product	Cost ($)
Submersible Pump	2,403
Drilled Bore	960
Solar Panels	7,446
Mounting Structure	2,405
Pump Inverter	1,440
Installation	480
Cabling, Grounding, Etc.	1,440
Total	**$ 16,574/-**

A 10HP solar pumping unit will cost about $ 16,574. The solar panels average life is 25 years where as the solar pumping inverter has a designed life of 10 years.

Pay Back Period:

Payback period of system will be calculated in comparison to national grid. Solar system for tube wells can only have off grid function that's why

Solar vs Electricity:

There is no grid on site, application and installation cost of grid will be applicable in this condition. The solar system working hours are only sun hours (8hours daily) will be accounted for the entire system design.

Grid running cost calculation:

$$Tubewell\ working\ = 08\frac{hr}{day}$$

$$Total\ working\frac{hr}{year} = 2920\ hr$$

$$Tubewell\ motor\ wattage = 10\ Hp * 0.746\frac{kW}{Hp} = 7460Watt$$

$$7460\ Watt\ motor\ will\ consume\frac{units}{min} = \frac{1}{7460\ W}\text{x}1000 = 0.13\frac{\text{KWH}}{\text{min}}$$

$$7.46\ kW\ motor\ consumes\ 1\ \ KWH\ in\ minutes = 0.13\frac{KHW}{min} * 60 == \frac{7.8min}{KWH}$$

$$Motor\ will\ consume\ \frac{\frac{60\ min}{hr}}{7.8\ min/KWH} = 7.692\frac{KWH}{hr}$$

$$7460W\ motor\ consumpter\ per\ year = 7.629\frac{KWH}{hr} * 2920\frac{KWH}{year}$$

$$= 22276.68\frac{KWH}{Year}$$

$$22{,}276.68\ units\ will\ cost = 22276.68\frac{units}{year} * 0.13\frac{\$}{unit} = 2896\frac{\$}{Year}$$

Net Present Value (NPV):

Net present value states the value of the entire system at the end of the life cycle. It calculates the actual benefit that the system provides during its tenure. Discount rate value is taken as 6.02%, which is current KIBOR value in Pakistan.

$$\boldsymbol{NPV = \sum\left\{\frac{Net\ Period\ Cash\ Flow}{(1+R)^T}\right\} - Initial\ Investment}$$

Total initial investment = Initial Cost + Replacement Cost = $ 19,937 + $ 0 = $ 19,937

$$Operating\ Cost\ of\ Base\ Case = \ 2{,}896/year$$
$$Operating\ Cost\ of\ \ System = \$\ 0/year$$

Time Periods = 25 Years

Discount rate = 6.02%

NPV = $ 56,887.53

Pay Back Period Calculations:

Table 20: Cost comparison of Grid and Solar powered pumping unit.

Sr.	**Grid**	EXPENSE ($)	**SOLAR PUMP**	EXPENSE ($)
1.	**Grid Connection 10 KW**	1,923	**Solar Power**	16,545
2.	**Drilled Bore**	960	**Drilled Bore**	960
3.	**Pump Complete 10 HP**	2,403	**Pump Complete 10 HP**	2,403
4.	**Running Hours**	2920 hr./year	**Running Hours**	2920 hr./year
5.	**Operating Cost**	2,896	**Operating Cost**	Zero
6.	**Total Cost $**	8,182/-	**Total $**	19,908

$$\boldsymbol{Pay\ back\ period} = \frac{\boldsymbol{Solar\ Cost}}{\boldsymbol{Grid\ Expenses}} = \frac{\$\ \mathbf{19,908}}{\$\ \mathbf{8,182}} = \ \mathbf{2.43}\ \boldsymbol{Years}$$

CONCLUSIONS

This report has discussed in total of six scenarios, two from residential sector, three from commercial and one from agricultural sector. Every possible attempt has been made to obtain an optimized solar solution by minimizing the initial cost and payback period

Table 21: Payback Periods for different case studies

	Case Study	**Pack Back Period (Years)**
Residential Sector	Off Grid	13.85
	Hybrid (Sol+Grid+Backup)	11.79
Commercial Sector	Off Grid	10.71
	On Grid	7.5
	On Grid with Generator Backup	9.74
Agricultural Sector	Standalone	2.43

Residential Sector:

In residential sector, two case studies have been discussed, off grid and hybrid (Sol+Grid+Backup) system. The off grid solar solution has a payback period of 13.85 years, and while the hybrid system has a payback period of almost 11.79 years. In both cases the payback period is quite high. But if we compare the off grid with hybrid system the hybrid system takes the lead. The off grid system is a standalone system in which no other power generation source is present. It has several drawbacks. The system is optimized for providing continuous power from solar energy for 6 hours and backup is designed for the rest of the 18 hours. If there is no sunshine for a complete 24 hours, the system will shut down and only get back to work when sun shines. Also the battery bank replacement costs are too high as compared to grid power.

On the other hand the Sol+Grid+Backup or hybrid solar system is more flexible and more trouble free. It has solar power as the primary source of power generation and grid as secondary. The battery works only when there is no grid and solar power available. This system has priority of using solar energy first, then grid followed by the backup battery bank. From the payback period and ease of use and flexibility, the Sol+Grid+Backup/Hybrid Solar System is best the choice for small residential site.

Commercial Sector:

Solar energy is most suitable for commercial sector. Operation time of commercial offices, schools, colleges and banks is day time (9AM – 5PM). Also the unit cost of electricity for commercial sector is much higher than other sectors. At present, 1 KWH of grid electricity is almost 25 cents. We discussed three case studies in commercial sector: on grid System (with no backup), on grid system with generator backup and off grid standalone solar system.

Table 22: Commercial Site case study results comparison

Sr.	**Mode**	**Initial Cost ($)**	**Operating Cost/Year ($)**	**Replacement Cost ($)**	**Payback Period (Y)**
1	On Grid	71,467	12,410	Zero	7.5
2	On Grid with Gen Backup	55,947	6661.64	9,703	9.74
3	Off Grid Standalone Solar	125,734	704.74	76,463	10.71

There are several drawbacks in each of the solar system. By overlooking the table 22, on grid solar system is the clear winner in terms of payback time, but on grid solar system has several other drawbacks. On the other hand on grid with generator support system has very high operating cost, whereas standalone solar system has much higher initial investment.

Table 23: Drawbacks and Advantages of Commercial Case Studies

Mode	Drawback	Advantage
On Grid	During Grid failure hours the system will shut down as it has no backup support.	No Replacement Cost
On Grid with Gen Backup	High operating cost	Low Initial Investment
Off Grid Standalone Solar	High Initial Investment and replacement cost	Low operating cost

Table 23 is discussing the advantages and short comings of different case studies. On grid system is not feasible in current scenario as there is almost 5 hours load shedding during the day time. Commercial setups do not afford energy outages hence on grid solutions are not feasible until there is ZERO energy outage. On the other hand, on grid with generator support has very high operating cost as compared to other two system, but there is no energy outage during the working hours. Initial investment for this solar system is the lowest, i.e., only $ 55947. The third setup is off grid standalone solar system, it has the highest initial investment amount the three cases discussed, but this system has the lowest operating cost. In contrast to others, this system has the highest replacement cost. This system uses batteries as backup source that is why all the batteries need to be changed after a specific time period, whereas there replacement cost of generator is much lower than batteries.

On grid system is rejected because of energy outage. Off grid standalone system has higher payback period of 10.47 years and it also requires a high initial investment as well as higher replacement cost. That is why the system is also not feasible. The on grid system with generator back up seems to be well suited for the commercial sector as it requires the lowest initial investment, small replacement cost and on the top it fulfils the needs of the site.

Agricultural/ Solar Water Pumping:

Pakistan is an agriculture based country. Most of the people in Pakistan do farming to earn their livelihood. Many forms of energy are used to run the deep well tube wells and submersible pumps to draw water from the earth. The famous mode of drawing water is by using diesel engines, tractors or national grid. Diesel generators are much more expensive, tractors also consume diesel fuel. National grid in Pakistan is not stable; in rural areas of Pakistan, the load shedding hours almost touch 18-20 hrs. , a day thus making it infeasible for farmers to run their water pumps.

Table 24: Comparison of Solar, Electricity and Diesel Based Water Pumping Units

Mode	Advantage	Disadvantage
Solar Power Water Pump	Standalone, No Maintenance, Payback period is very quick.	Huge Initial Investment, Weather Dependent, Not operational in night
Electricity Powered Water Pump	Small initial Investment	Energy Outage of -18-22hrs
Diesel Based Water Pumps	Standalone	High Maintenance cost, High fuel prices.

Solar powered water pumps have distinct advantages over the other technologies. The only drawback is the inability to run the water pump during night. Owing the heavy investment, the payback period for solar water pump is still the lowest among all sectors (residential, commercial and industrial), being only 2.47 years.

The report concludes that solar energy is not feasible for residential and commercial sectors of Pakistan. Solar energy will only be viable in these sectors if load shedding is completely vanished. Because of load shedding, the commercial and residential sector need backup generators or backup batteries to store extra energy to utilize it during load shedding hours. Backup storage systems have high replacement, maintenance and operation costs that make the whole system very expensive thus effecting the payback period.

Solar water pumping is the only area in which solar energy is found to be viable. These standalone systems, when compared to the national grid give a very shot payback period of 2.47 Years. It may be concluded that solar energy is feasible only in agricultural sector of Pakistan in present conditions until the grid is stabilized.

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Appendix

Residential System	System Size	Payback period (Years)
Off Grid	10KW	10.85
	15KW	9.12
Hybrid (Sol+Grid+Backup)	10KW	8.75
	15KW	7.2

Appendix1: Payback period of residential system by varying system sizes