# TECHO-ECONOMIC ANALYSIS OF HYBRID RENWABLE POWER SYSTEM FOR REMOTE AREA

**In partial fulfillment for the award of the degree of Bachelor of Electrical Engineering Submitted by:**

**RAHUL NAYAK**

**(Reg no. E1710005)**

**PRANAV SORTE**

**(Reg No. E1710056)**

**KOUSTUBH SHETE**

**(Reg No. E1710061)**

**Under the guidance of**

**Prof. SUMBUL ABIDI**

**Department of Electrical Engineering**

**Sardar Patel College of Engineering**

**(An Autonomous Institute Affiliated to University of Mumbai)**

**Munshi Nagar, Andheri (West)**

**Mumbai – 400058**

**2020-2021**

# Approval Sheet

**This is to certify that the project on "Techno-Economic Analysis of Hybrid Renewable Power System for Remote Area"**

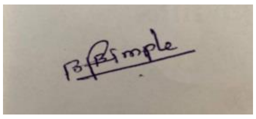
**is a bonafide work presented by:**

**Rahul Nayak**

**Pranav Sorte**

**Koustubh Shete**

**Prof. Sumbul. H. Abidi** — **Dr. B.B Pimple**



- - - - - - - - - - - - - - - - -   - - - - - - - - - - - - - - - - -

**Dr. Nandkishor Kinhekar** — **Prof. Matilda Justin**

- - - - - - - - - - - - - - - - -   ______________________

**Head of the Department**

----------------------------------------

**Principal**

----------------------------------------

**Date:**

**Place: SPCE, Mumbai.**

# Acknowledgement

We would like to express our sincere thanks to our guide Prof. Sumbul Abidi for taking time from her busy schedule to provide us with a great deal of help, support and encourage us to work diligently at every aspect of our project. Her views have always been equitable, striking a perfect balance between encouragement and constructive criticism. Her constructive tips and suggestions helped us to successfully do the project. We have benefited a lot from her immense knowledge and experience.

We express our sincere gratitude and thankfulness to our Dr. B.B Pimple, Prof. Matilda Justin, Dr. Nandkishor Kinhekar for their valuable suggestions, motivation and support for our project.

Our project at various stages has entailed us to seek help from a variety of individuals, we would like to thank each one of them for their forbiddance and guidance.

Finally, we would like to thank our parents and our friends for constantly supporting and encouraging our efforts. A very special thanks goes to all B.Tech Electrical batch (2017-2021).

# Abstract

The demand for electricity is increasing day by day, which can't be fulfilled by non-renewable energy sources alone. It has become imperative for the power and energy engineers to look out for the renewable energy sources such as sun, wind, geothermal, ocean and biomass as sustainable, cost-effective and environment friendly alternatives for conventional energy sources. However, the non-availability of these renewable energy resources all the time throughout the year has led to research in the area of hybrid renewable energy systems.

The renewable energy sources are emerging options to fulfill the energy demand, but unreliable due to the stochastic nature of their occurrence. Hybrid renewable energy system (HRES) combines two or more renewable energy sources like wind turbines and solar systems. In the past few years, a lot of research has taken place in the design, optimization, operation and control of the renewable hybrid energy systems. It is indeed evident that this area is still emerging and vast in scope.

The objective of this project is to present a comprehensive review of various aspects of HRES. This project discusses pre-feasibility analysis, optimum sizing, modeling and other factors. Along with this, techno-economic analysis of Hybrid Energy Renewable System is done to serve a remote community. The optimization of the key performance indicators of the proposed hybrid power system is done. We also focused on a feasibility study to integrate a battery energy storage system and converter with a hybrid wind-solar standalone system. The results obtained from this work are analyzed to select the best options among the available configurations based on the lowest TPV and LCOE produced by each configuration. The results from several case studies show that incorporation of PV and WTG have reduced the operating cost of the system.

# Table of Content

# Acronyms

| | |
|---|---|
| NREL | National Renewable Energy Laboratory |
| TLCC | Total Life Cycle Cost |
| RES | Renewable Energy System |
| LCOE | Levelized Cost of Energy |
| NOCT | Nominal Operating Cell Temperature |
| GHG | Green House Gases |
| WTG | Wind Turbine Generator |
| PV | Photo Voltaic |
| BESS | Battery Energy Storage System |
| AGM | Absorbent Glass Mat |
| TPV | Total Present Value |
| CRF | Capital Recovery Factor |
| IC | Initial Capital Cost |
| TC | Transportation Cost |
| PSV | Present Scrap Value |
| RC | Replacement Cost |
| AE | Annualized Energy |
| CSP | Concentrated solar power |
| HRES | Hybrid Renewable Energy Systems |
| CE | Conventional Energy |
| CSP | Concentrated Solar Power Plants |
| NEP | National Electricity Policy |

# List of figures

# CHAPTER 1

# Introduction

## 1.1 Overview

Energy of all forms is the source of livelihood on earth. Prehistoric humans have used energy from sun, called solar energy today, for various purposes, such as planting and drying crops, and also used wind energy for mechanical purposes. Water and energy generated from flowing water, which is hydro energy, support human beings in all areas of life. As man progressively developed technologically throughout all ages, the need for energy became more important. Hydrocarbons were discovered as a primary energy source for technological purposes during the advent of industrialization. Though other forms of energy such as solar, wind, hydro, geothermal, tidal, and nuclear are still used, hydrocarbons account for about 84 percent of today's energy mix due to their widespread availability, ability to store and transport them to places where they are needed, and cost-effectiveness of production. Crude oil, natural gas, and coal, as well as their derivatives, make up the hydrocarbons known as fossil fuels. As the world's population expands, so does the demand for energy, which necessitates the use of more fossil fuels. The world now has huge supplies of fossil fuels, but because these sources are non-renewable, the risk of running out of these resources in the long run is a major issue, especially in light of the world's rapidly rising population. The key issue is that even if the world does not know when these fuels will run out, there is still cause for concern because their consumption is expected to rise by nearly 40% by 2030. The disadvantage of fossil fuels is that they release carbon dioxide ($CO_2$) into the atmosphere, which can raise global temperatures and make living difficult. The second source of concern is the supply of fossil fuels, which has two aspects. The first is the irregular economic tides of the world and the regional stability of regions naturally endowed with substantial resources of fossil fuels.

There are two main energy challenges for the world—growing need for energy and environmental degradation. The growing need for energy is the result of technological advancement and increasing world population calling for more dependence on fossil fuel. The consequence of using fossil fuel is environmental degradation due to the greenhouse gas emission (such as carbon dioxide, $CO_2$). Due to fossil fuel depletion, high cost, and increasing environmental concerns, there is a big trend to use RES to address the power generation especially for the isolated or remote areas. Utilization of different RES with storage and backup units to form a hybrid renewable energy system (HRES) can give more economic and reliable source of energy.

## 1.2 Challenges for electrification in rural area

Access to affordable and reliable energy supplies is a necessary and sufficient prerequisite to economic development and poverty reduction. More than 1.6 billion people living in rural communities worldwide are deprived of electricity. The reason is the challenge that stems from the extremely high cost involved in providing electricity to rural areas through conventional means such as national grid extension or stand-alone diesel generation.

## 1.3 Renewable energy technology applications in electricity production

RES is highly variable and site-specific. Employing a single stand-alone WECS or PV electric system will invariably suffer from power supply variability making it impossible to meet load requirement at all times. To forestall this side effect, we will be using hybrid systems. Wind and solar complement each other; periods of low or no wind speeds usually have a lot of sunshine and vice versa. A second reason to pursue hybrid systems is cost as a single PV system will require a large storage system that will increase the cost. In addition to supplying reliable power, a hybrid system will also reduce the TLCC significantly.

## 1.4 Existing systems

An existing standalone HRES is available in Deokjeokdo island. Deokjeokdo island (latitude: 37.22°, longitude: 126.15°) is the biggest island in the Ongjinkun area in South Korea, located 50 km far from Incheon Ocean port. At the end of 2013, the total population of Deokjeokdo island was approximately 5000 and its area is 21 km2. The island has a relatively large population engaged in agriculture and tourism, rather than fishing, and is actively developing tourism resources as Green Island. This island is excessively far from the primary land of South Korea, so it is not monetarily suitable to associate it with the main framework for power transmission. Subsequently, this island has its very own power generation system fueled by diesel. In any case, the local government has demonstrated its enthusiasm to make Deokjeokdo island, a green island as far as power generation is concerned.

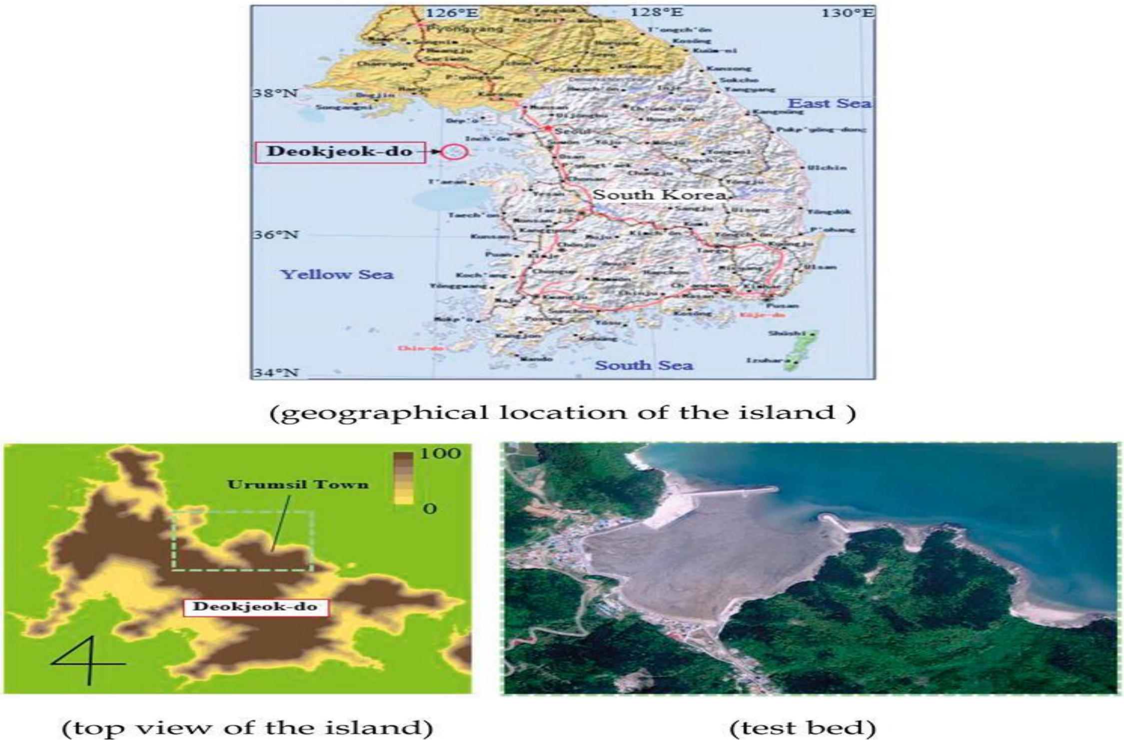



Fig 1.1 Island location

Analysis of experimental HRES installed at Deokjeokdo island:


Fig 1.2 Installed HRES at Deokjeokdo Island [24]

The experimental HRES consists of two Darrieus type vertical axis wind turbines (VAWT) and photovoltaic (PV) panels. The total capacity of this system is 24 kW, with each wind turbine rated at 1.5 kW and solar panels of 3 kW capacity, respectively. In order to record the wind conditions such as wind speed and wind direction, a vertical tower called the "wind master" has been installed at the local site. Anemometer and anemoscope are attached on the wind master to record wind speed and wind angle, respectively. Solar panels are inclined at 30° to capture the maximum radiation from the sun. Systems can independently provide electricity to Deokjeokdo island throughout the year without any external assistance such as grid, etc. Analysis showed that the prevailing wind direction at Deokjeokdo island is either north-east or south-west, with mean wind speed of 3.6 m/s at 10 m height. Similarly, average value of daily solar radiations was estimated to be 4.13 kWh/m2 with mean clearness index of 0.5.

A case study finds an optimum HRES to fulfill the yearly electricity demand of Deokjeokdo island corresponds to approximately 7.296 MWh/year. Over 8760 simulations were performed to find out two optimum HRESs based on lowest NPC (system A) and lowest LCOE (system B), respectively. The overall NPC of system A was calculated to be 11.29 million USD, whereas for system B, it was 17.61 million USD. On the other hand, LCOE for system A was slightly higher than system B as it was 0.158 $/kWh for system A and 0.123 $/kWh for system B. Both systems can independently provide electricity to Deokjeokdo island throughout the year without any external assistance such as grid, etc.

### 1.5 Pilot projects

One company, F-sight, is providing insight to the energy grid of the future with the development of a pilot project in Israel using its Energy AI solution. Located in an advanced energy community in Northern Israel, the pilot project will work with massive inflows of solar, wind, and storage systems, electric vehicles, multiple smart appliances, and anything with significant grid flexibility – all overlapped with the Energy AI platform. The sustainable community project is currently under simulation and the first phase of the pilot is planned for two years, with possibility for extension.

Companies are looking forward to the transition towards 100% renewable energy. The objectives set out in the United Nations 2030 Agenda and the Paris Agreement can only be met through an urgent and complete decarbonization of our entire energy system. This requires that all of our energy requirements – power, heating and cooling, and transportation – are reliably met by 100% renewable energy and accessible to all people.

## 1.6 Dissertation objective

First objective is the modelling of Hybrid Standalone Renewable Energy System consisting of PV panel, wind turbine and battery energy storage system. Next is to optimizing the size of system by minimizing levelized cost of energy (LCOE). Last objective is the designing of a cost efficient and reliable energy system for a remote area.

## 1.7 Organization of dissertation

The organization of this dissertation is as follows:

Chapter 1 is an introduction of the dissertation which includes the overview, challenges for electrification in rural area, existing HRES systems, pilot projects and the objective of the project which gives the clear idea about this B.Tech dissertation.

Chapter 2 gives details of location of data we have procured in order to perform cost analysis and sizing of microgrid, along with information of solar irradiance and wind speed of the location.

Chapter 3 explains the load profiling carried out for 50 villages under consideration. The chapter also discusses the time-varying seasonal load profiling with graphs for each.

Chapter 4 gives information of selection of Photovoltaic Panel by considering cost, area, cell type, etc and selection of Wind Turbine by considering factors like cost, power rating, cut in speed, etc. Battery selection is done by comparing leading battery technologies and explanation of converter selection is also discussed.

Chapter 5 explains the calculation of output power of PV panel and wind turbine along with variation of this power-time series in different season.

Chapter 6 discusses the calculations in order to correctly size the PV panel, wind turbine, BESS and converter to cover energy without over-sizing the microgrid.

Chapter 7 explains some important benchmark like LCOE, CRF, etc for various cases considered for determining if the HRESs are financially worthwhile.

Chapter 8 discusses how the costs of PV panel, wind turbine, BESS will decrease in the next decade and the factors leading to the reduction of these costs. This will also lead to a decrease in the levelized cost of energy of system. Comparison with conventional energy is also visualized.

Chapter 9 discusses the conclusion and also the direction for future work.

# CHAPTER 2

# Data Procurement

The Data for our project has been taken from the website of National Renewable Energy Laboratory. For India, the 15 mins real time data of solar irradiance and wind speed was not readily available for a span of one year so we decided to take the location in USA for which the real time data of Solar irradiance and Wind speed was readily available for a span of one year over 15 mins interval.

## 2.1 Location

The location which we have chosen is an on-shore location having sufficient wind speed and solar irradiance throughout the year. It is a flat land with an arid climate. Coordinates of our location - 37°40’48.0 N, 100°29’28.4” W i.e Montezuma, KS, USA.

## 2.2 Solar Data

Availability of reliable solar radiation data is vital for the success of solar energy installations in different sites of the country. For solar collectors which are flat in nature, solar radiation data in the form of Global Horizontal Irradiance (GHI) is useful whereas for solar collectors which are concentrating in nature Direct Normal Irradiance (DNI) data is required. The Solar Data consists of Solar Irradiance in $W/m^2$ for every 15 mins interval for a span of year.

Annual Profile of Solar Irradiance:

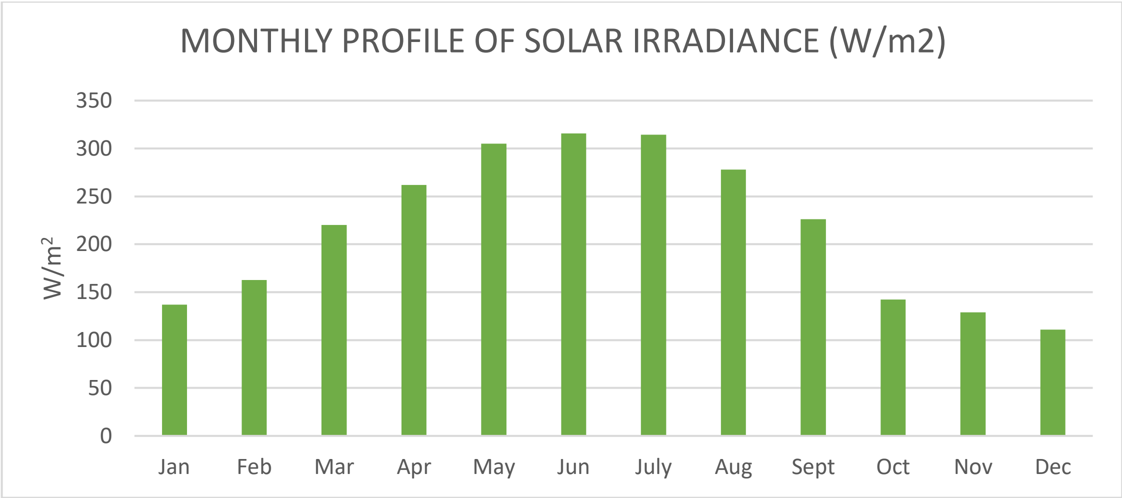



Fig 2.1 Annual profile of solar irradiance

In the above Fig 2.1 it can be seen that the solar irradiance increases till month of June and then it decreases. Solar irradiance is maximum in June and is about 316 W/m$^2$ and the average solar irradiance throughout the year is 217 W/m$^2$.

GHI map:

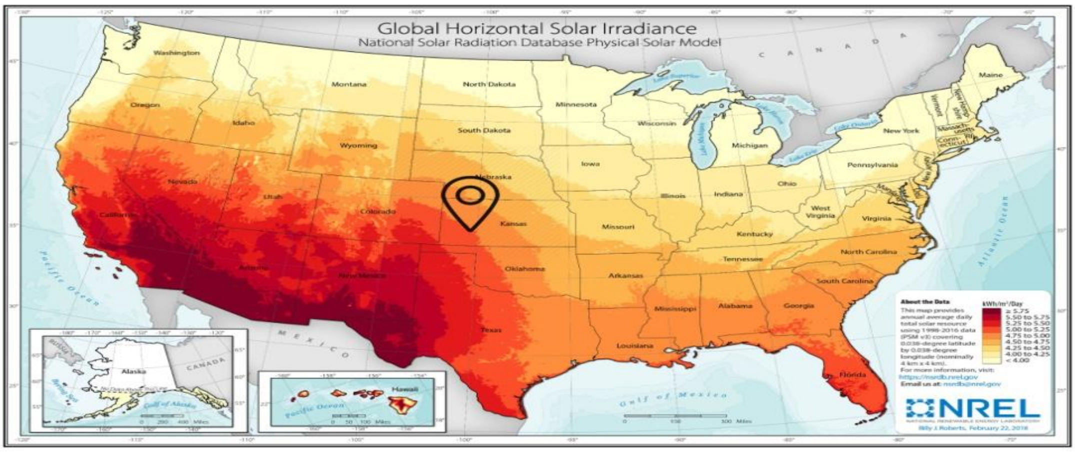



Fig 2.2 GHI Map

The above Fig 2.2 gives GHI for the given location which is necessary in calculation of solar irradiance. This map provides with an idea of the amount of sunlight over the desired location.

## 2.3 Wind Data

Wind Turbines are designed to operate within a specific range of wind speeds. The limits of that range are known as the cut-in speed and cut-out speed. The cut-in speed is the point at which the wind turbine is able to generate power. Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed. The wind data comprises Wind speed in m/s for every 15 mins interval for a span of year.

Annual profile of Wind speed:

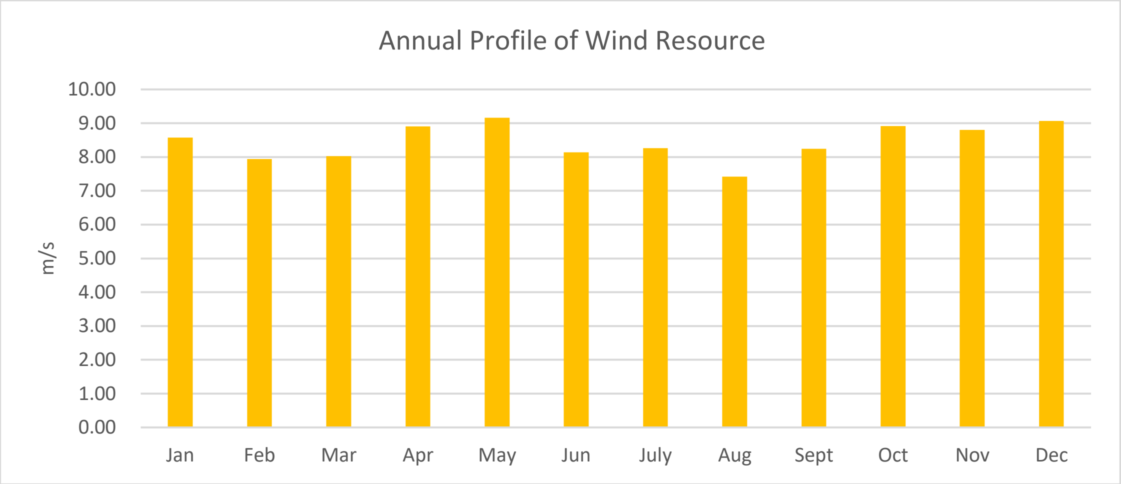



Fig 2.3 Annual Wind profile

In the above Fig 2.3 it can be observed that the wind speed in our data is varying for each month. It is maximum in month of May in which the wind speed 9.16 $m/s^2$ and is minimum in the month of August in which the wind speed is 7.42 $m/s^2$. The average wind speed throughout the year is 8.45 $m/s^2$. All the Data has been collected from NREL website. The coordinates of the Location are - 37°40’48.0 N, 100°29’28.4” W. The following are the links used for Data collection:

- https://maps.nrel.gov/wind-prospector
- https://www.nrel.gov/gis/solar.html

# CHAPTER 3
# Load Profiling

## 3.1 Daily Load analysis of remote village

To perform cost analysis and sizing of microgrid, the remote village under consideration has 50 houses and appliances used in the village which act as a load for our system. Appliances considered in the village are television, tv set-up box, fans, water heater, well pump for domestic as well as agricultural use, mixer, tube-lights, washing machine, fridge. Also, 2 flour mill and 30 streetlights are considered to be present in the village under consideration, hence this also adds up to form the load.

While constructing the load profile, we have assumed number of fans to be three, well-pumps as two, street lights as thirty, tube-lights as five, flour mills to be two and TV set-up box, TV, water heater, mixer, washing machine, fridge as one quantity.

| Appliance | Rating (W) | Daily Usage |
|---|---|---|
| TV set-up box | 30 | 6 hrs |
| TV | 155 | 2 hrs |
| Fans (3) | 90 | 22 hrs |
| Water Heater | 2200 | 45 min |
| Well Pump (2) | 750 | 2 hrs |
| Street Light (30) | 100 | 12 hrs |
| Mixer | 425 | 30 min |
| Tube Lights (5) | 60 | 7 hrs |
| Washing Machine | 500 | 1 hr |
| Fridge | 250 | 24 hrs |
| Flour Mill (2) | 2230 | 2 hrs |

Table 3.1 Power consumption

Depending upon time of the day, the appliance which is ON and OFF was surveyed. For example, water heater will be used in the morning and tube-lights will be ON during the night time. Similarly for different appliances depending upon the time they are used. By doing this we observed that peak load demand for our system occurs in the morning and appliances which contribute during peak hour are TV, TV set up box, three fans, water heater, two well-pump, mixer, washing machine and fridge.

For peak load calculation, first we calculate peak load demand for a single house which is 5330 W. Now, in worst case scenario, all the 50 houses will demand 5330 W. Therefore, peak load for 50 houses is 266.5 KW. Considering the 5% margin, we get the peak load of the village as 280 KW which is during the summer season.

## 3.2 Seasonal load analysis

Usually during the summer, load demand is more because of excessive heat. Crops require more water, as a result agricultural load increases. Also, residential load increases during summer due to excess heat. Whereas, in autumn agricultural load is very less hence when compared to winter load demand in autumn is more and maximum load demand is during summer season.

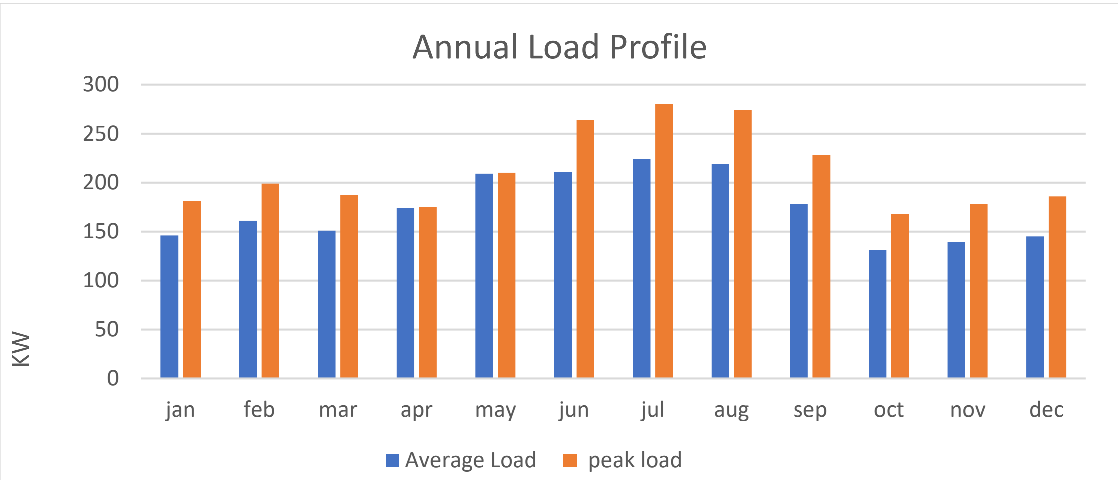



Fig 3.1 Annual Load profile

From the above Fig 3.1 it can be observed that the average load and the peak load demand is maximum in summer season in the month of July which is 224 KW and 280 KW respectively and minimum in autumn in the month of October which is 131 KW and 168 KW.

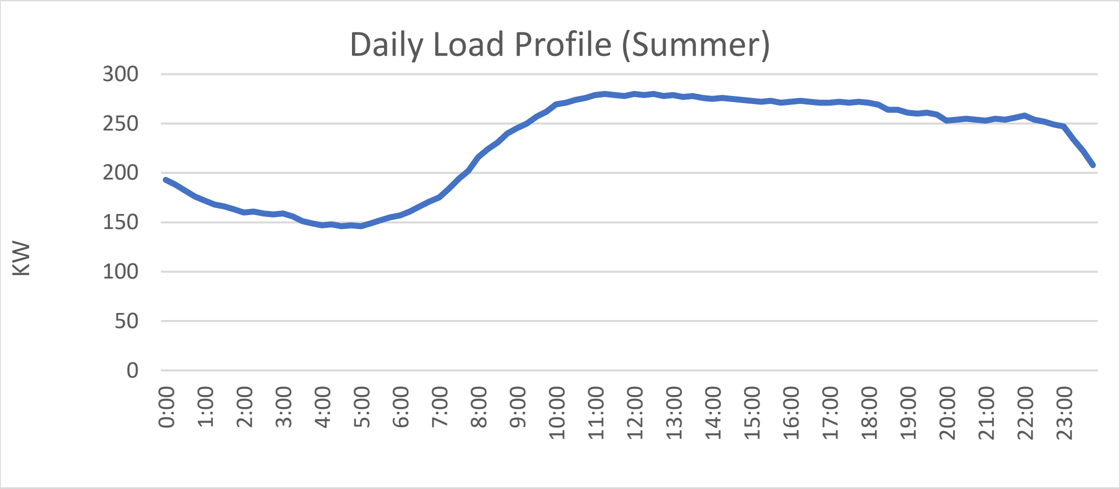



Fig 3.2 Daily Load Profile (summer)

In Fig 3.2 Daily load profile for summer season is shown for a 24 hours period where it can be seen that the load demand starts to increase from 160 KW at 7:00 am and reaches its peak of 280 KW at about 11:15 am. I can be seen that the load demand is minimum throughout the night.

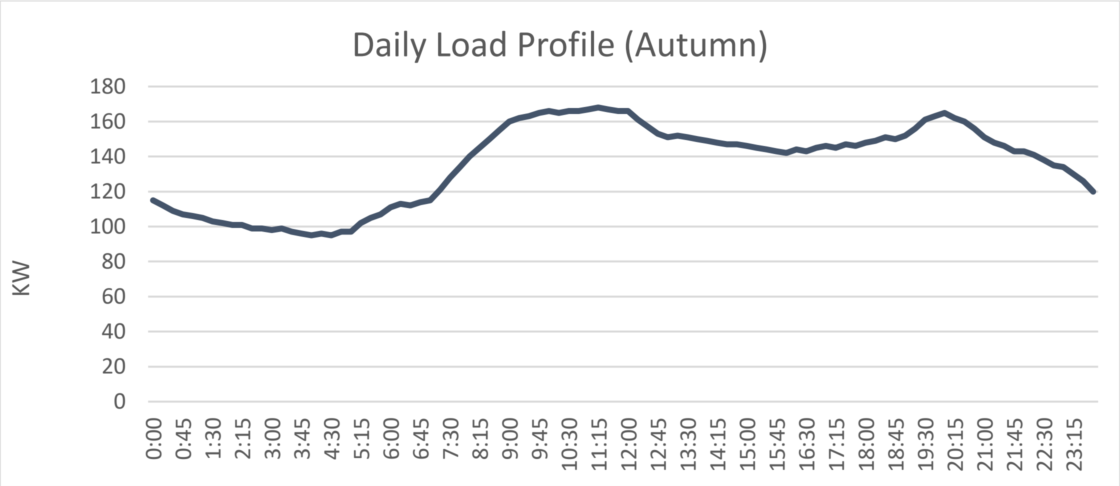



Fig 3.3 Daily Load Profile (Autumn)

In Fig 3.3 Daily load profile for autumn season is shown for a 24 hours period where it can be seen that the load demand starts to increase from 100 KW at 7:00 am and reaches its peak of 168 KW at about 11:30 am. It can be seen that the load demand is minimum throughout the night except it increases in the evening due to flour mills and lighting load in between 6:00 pm to 9:00 pm and then it decreases.

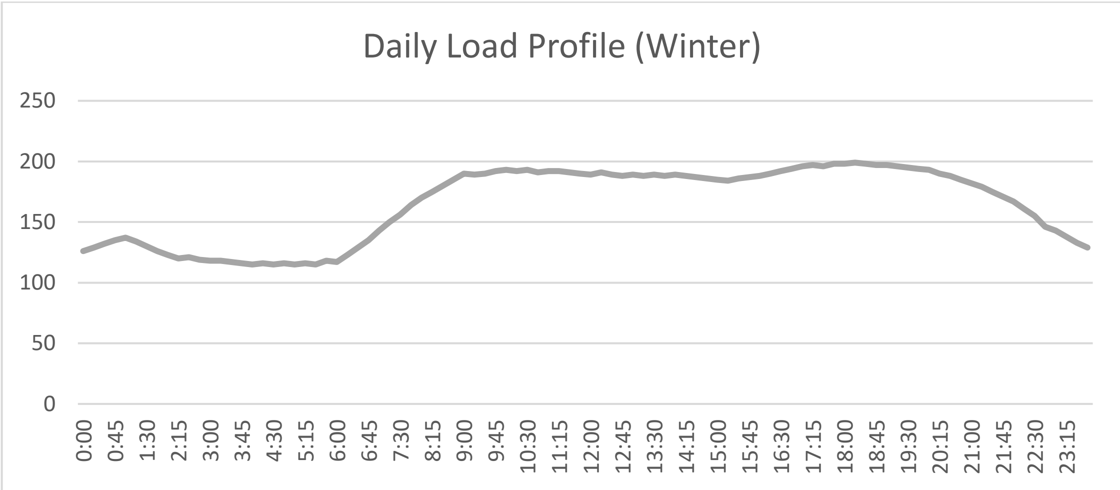



Fig 3.4 Daily Load Profile (Winter)

In Fig 3.4 Daily load profile for winter season is shown for a 24 hours period where it can be seen that the load demand starts to increase from 120 KW at 7:00 am and reaches its peak of 200 KW at about 6:00 pm. It can be seen that the load demand is minimum throughout the night.

# CHAPTER 4
# Selection of components

## 4.1 Selection of Photovoltaic panel

The solar panel selection was done based on the market cost, efficiency of panel, operating temperature, availability, power rating, area of panel, reviews and cell type. The comparison which we had performed for selection of solar panels is shown below

| Sr No. | Brand | Efficieny (%) | Cost (Rs) | Area ($m^2$) | Cell Type | Power Rating (Wp) | Temperature range (degrees) |
|---|---|---|---|---|---|---|---|
| 1 | Vikram | 15.63 | 10962 | 1.919 | Polycrystalline | 325 | -40 to 85 |
| 2. | Adani | 16.84 | 7590 | 1.96 | Polycrystalline | 330 | -40 to 85 |
| 3. | Tata | 17.05 | 9240 | 1.939 | Polycrystalline | 330 | -40 to 85 |
| 4. | Blue Bird | 16.92 | 9700 | 1.935 | Polycrystalline | 330 | -40 to 85 |

Based on all the above parameters we selected **Adani Solar Panel of 330 Wp**

Some highlights of our panel are:

1. More power/m2 compared to industry average.
2. Higher specific energy yield (KWh/KWp) due to superior cell module.
3. Superior performance at NOCT condition.
4. Superior low light irradiation performance 200W/m2.
5. Resistant to PID, salt mist and Ammonia.
6. Triple EL checking to ensure defect free modules.

## 4.2 Selection of wind turbine

The cut-in speed is the point at which the wind turbine is able to generate power. Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed**.** The wind turbine was selected based on the availability of rated speed from our data, market cost, cut in speed, cut out speed, hub height, and power output. The is the comparison which we had performed for selection of solar panels is shown below

| Sr No. | Brand | Cost (Rs) | Power Rating(KW) | Rated Speed (m/s) | Cut in speed (m/s) | Cut out speed (m/s) |
|---|---|---|---|---|---|---|
| 1. | Right Renewable Tech | 16.75 lacs | 20 | 9.5 | 3 | 20 |
| 2. | EOCycle EO20 | 14 lacs | 20 | 7.5 | 2.8 | 20 |
| 3. | SM windsol private Ltd | 15.5 lacs | 20 | 11 | 3 | 25 |
| 4. | Atlantis | 17 lacs | 20 | 11.5 | 3 | 25 |

Based on all the above parameters and comparison we selected **EOCycle EO20 - 20KW**

## 4.3 Battery selection

In our study we compared two leading battery technologies in BESS i.e lead acid and lithium ion batteries. We have compared parameters like usable capacity depending upon DOD, life span, installation cost, transportation cost and maintenance cost for both the battery technology in economic analysis.

### 4.3.1 Lead Acid battery technology

1. Limited Usable Capacity:

It is typically considered wise to use just 30% – 50% of the rated capacity of typical lead acid “Deep Cycle” batteries. In our economic analysis we have considered the usable capacity is 50% of rated capacity.

2. Limited Cycle Life:

Even the best deep cycle lead acid batteries are typically only good for 500-1000 cycles. If frequent tapping is done into battery bank, this could mean that batteries may need replacement after less than 2 years use. In our economic analysis we have considered the average life span of 5 years.

3. Maintenance Requirements:

Flooded lead acid batteries must be periodically topped off with distilled water, which can be a cumbersome maintenance chore if battery bays are difficult to get to. AGM and gel cells are truly maintenance free. Being maintenance free comes with a downside though – a flooded cell battery that is accidentally overcharged can often be salvaged by replacing the water that boiled off. A gel or AGM battery that is overcharged is often irreversibly destroyed. In Lead-acid BESS, IC is around 20%, TC is around 10% and maintenance cost is 5% of total BESS cost.

4. Placement issues:

Flooded lead acid batteries release noxious acidic gas while they are charging, and must be contained in a sealed battery box that is vented to the outside. They also must be stored upright, to avoid battery acid spills. AGM batteries do not have these constraints, and can be placed in unventilated areas. This is one of the reasons that AGM batteries have become so popular with sailors.

5. Slow & Inefficient Charging:

The final 20% of lead acid battery capacity cannot be “fast” charged. The first 80% can be “Bulk Charged” by a smart three-stage charger quickly (particularly AGM batteries can handle a high bulk charging current), but then the “Absorption” phase begins and the charging current drops off dramatically. Just like a software development project, the final 20% of the work can end up taking 80% of the time. Not fully charging the final few percent would not be much of a problem in practice, if it wasn’t for the fact that a failure to regularly fully charge lead acid batteries prematurely ages them.

### 4.3.2 Lithium-Ion battery technology

1. Superior “Usable” Capacity:

Unlike with lead acid batteries, it is considered practical to regularly use 85% or more of the rated capacity of a lithium battery bank, and occasionally more. In our economic analysis we have considered Usable Capacity is 90% of rated capacity.

2. Extended Cycle Life:

Laboratory results expects to see 2000 to 5000 cycles out of a well-cared for LiFePO4 battery bank. These are theoretical results but recent measurement shows that a battery will still deliver more than 75% of its capacity after 2000 cycles. In contrast, even the best deep cycle lead acid batteries are typically only good for 500-1000 cycles. In our economic analysis we have considered the average lifespan of 15 years for Li-Ion technology.

3. Fast & Efficient Charging:

Lithium-ion batteries can be “fast” charged to 100% of capacity. Unlike with lead acid, there is no need for an absorption phase to get the final 20% stored. And, if charger is powerful enough, lithium batteries can also be charged insanely fast. If enough charging amps are provided, a Lithium-ion battery can be fully charged in just 30 minutes. But even if not charged to 100%, unlike with lead acid, a failure to regularly fully charge Lithium-ion batteries does not damage the batteries. This gives lots of flexibility to tap into energy sources without worrying about needing to do a full charge regularly.

4. Little Maintenance Requirements:

Lithium-Ion batteries are fairly maintenance free. A “balancing” process to make sure all the cells in a battery bank are equally charged is automatically achieved by the BMS (Battery Management System). In Lithium ion BESS, IC is around 8%, TC is around 4% and maintenance cost is 1% of total BESS cost.

5. Fewer Placement Issues:

Lithium-ion batteries do not need to be stored upright, or in a vented battery compartment. They can also be easily assembled into odd shapes – an advantage when trying to squeeze as much power as possible into a small compartment. This is especially useful in an existing battery bay that is limited in size, but there is a need of more capacity than lead acid is currently able to provide.

6. Projection of Battery cost:

Globally, the sharp decline in prices of lithium-ion (Li-ion) batteries is expected to transform how electricity from renewable sources, such as solar and wind, is integrated into the grid. Estimates of declines in Li-ion battery pack prices vary from 50% during 2012–2017 as per McKinsey & Co. (Frankel et al. 2018) to 73% during 2013–2018 as per Bloomberg New Energy Finance (BNEF). Based on BNEF 2010–2018 data, the learning rate (reduction in price for each doubling of cumulative volume) is 18%.

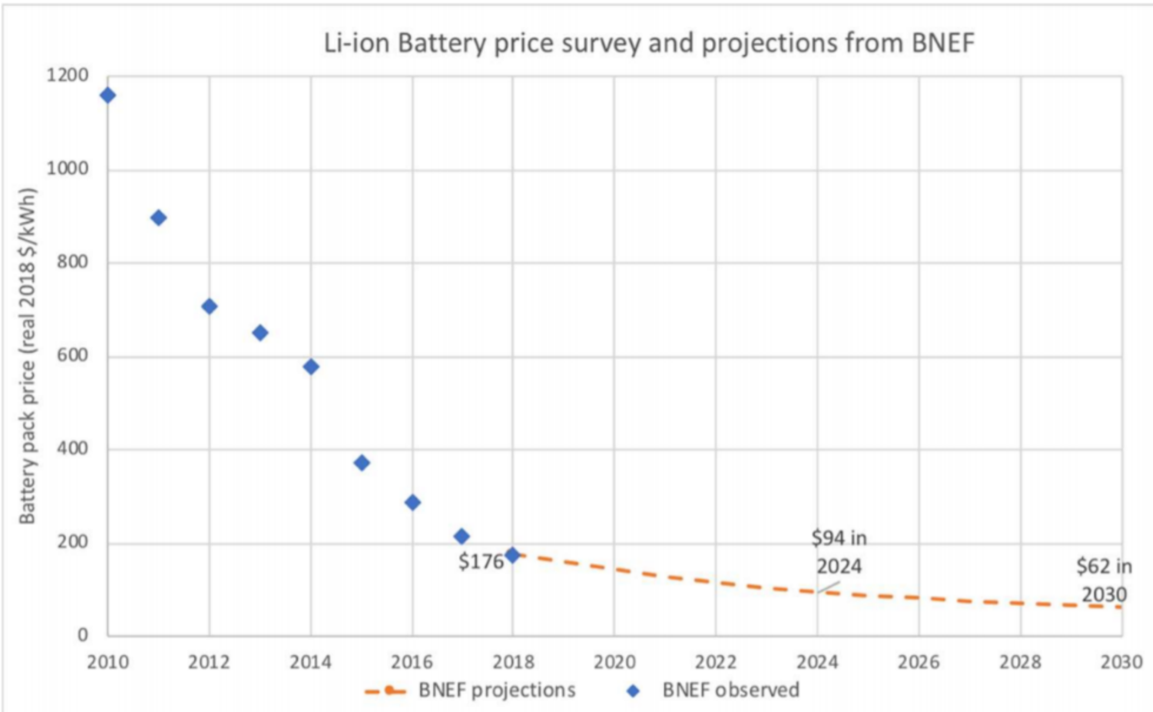



Fig 4.1 Li-ion battery cost projection from 2010-2030 referred from Prayas Reference paper.

As observed from Fig 4.1, Li-ion battery cost will reduce by 64% over the next decade. Hence Li-ion battery will become more affordable in coming years eventually reducing the cost of energy.

### 4.3.3 Cost analysis of PB-Acid and Li-Ion:

There are several types of batteries to choose from. One question that often comes up is ‘what is the difference between lead acid and lithium ion, and when should each battery type be used?’. Here, we’ll compare two of the most common battery options paired with Hybrid Renewable Energy Systems: lithium-ion and lead acid.

| | **LEAD-ACID AGM** | **LITHIUM-ION** |
|---|---|---|
| Installed capacity | 600 KWh | 600 KWh |
| Usable capacity | 360 KWh | 575 KWh |
| Lifespan | 5 | 15 |
| Number of installations | 3 (1 + 2 replacements) | 1 |
| Battery cost | Rs 9072000 | Rs 6177600 |
| Installation cost | Rs 1814400 | Rs 494208 |
| Transportation cost | Rs 907200 | Rs 247104 |
| Maintenance Cost | Rs 453600 | Rs 61776 |
| TOTAL COST | **Rs 12247200** | **Rs 6980688** |

Table 4.1 Comparison of PB-Acid and Li-Ion

It can be observed from Table 4.1 that even though Li-ion per unit cost of energy is 50% more than Pb-acid, Li-ion technology proves to be cheaper in the longer run. The is because Li-ion has a life span of 15 years and Pb-acid has a lifespan of 5 years. So, if we consider the project life time of 15 years, we will require 3 Pb-acid batteries as compared to 1 Li-ion battery. Hence Pb-acid Technology increases project cost in the longer run as compared to Li-ion battery technology. Also, IC (Installation Cost) and TC (Transportation Cost) of Li-ion is slightly less as compared to lead acid batteries since Li-ion batteries weigh ⅓ of lead acid batteries. But due to the fact that Pb-acid needs to be transported and installed 2 more times as compared to Li-ion in 15 years, Li-ion battery IC and TC is 72% less as compared to Pb-acid battery technology. Another reason Li-ion technology is inexpensive is that the maintenance cost of Li-ion is 80% less as compared to Pb-acid battery.

## 4.4 Converter

The role of a bi-directional converter in a power system is to convert the DC voltage from PV units and battery to AC voltage that can be used at the load points. Bi-directional converter can be used to convert AC voltage from a WTG to DC voltage to charge the battery. The rating of converter should be equal to rating of BESS (for ideal case).

For our analysis, we have selected **ABB MGS100 60KW** converter. The cost of this converter is 4Lacs and efficiency is 95%.

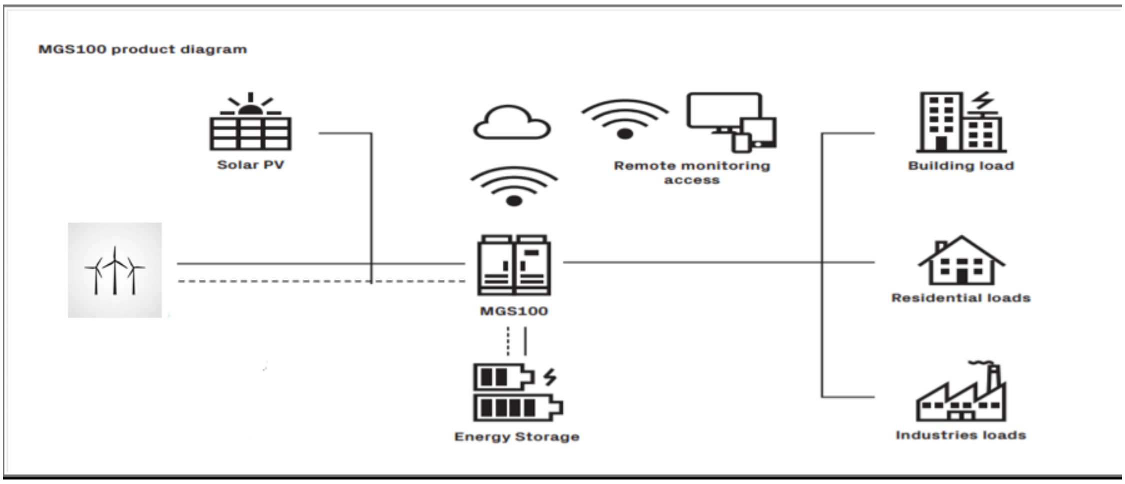



Fig 4.2 ABB MGS100

Product highlights :-

1. The system is formed from an integrated solar PV and battery energy storage converter with an additional AC input.
2. With the added benefit of remote monitoring, vital diagnostics are always available and maintenance is simple.
3. It has multi-source energy mix including AC generation (diesel/biofuel) or grid connection and solar PV input including embedded maximum power point tracking (MPPT).
4. It also consists of battery energy storage input for lead-acid or lithium-ion batteries and has embedded input and output protection devices.
5. Control system with programmable logic functionality to customize operational modes is also included.

# CHAPTER 5

# Power-Time Series

## 5.1 Solar power calculation

A PV system consists of solar panels that convert sunlight directly into electricity for standalone and grid connected power applications. The universal acceptance of PV system in recent years for power generation is due to the government policies to encourage utilization of PV system, high demand of electricity, environmental concerns, low operating cost and no fuel cost. The best places to use the PV system for reduction of fuel cost of the diesel generator is the rural areas that are not connected to the grid and where the transportation of diesel from the urban centers to the rural areas is too expensive due to long distances. For this reason, the PV system can be used in conjunction with other RESs to reduce the fuel consumption and GHG emissions of the conventional generating units. The output power of PV system depends on solar irradiance, area under irradiance and the conversion efficiency of PV panel. The output power of PV system can be estimated by using the following expressions of output power for PV panel is given using formula

$$\mathrm{P_{pv}} = \mathrm{A_{pv}} \times \mathrm{H_{t(AV)}} \times \eta_{\mathrm{pv}} \tag{5.1}$$

$A_{pv}$ represents area of PV Module which is1.960 $m^2$, $\eta_{pv}$ is the efficiency of PV i.e16.45%, $H_{t(AV)}$ is the average global solar irradiation ($W/m^2$). The average solar irradiation $H_{t(AV)}$ for every 15 mins interval throughout the day is collected for a period of 1 year is used to evaluate the output power of a PV module.

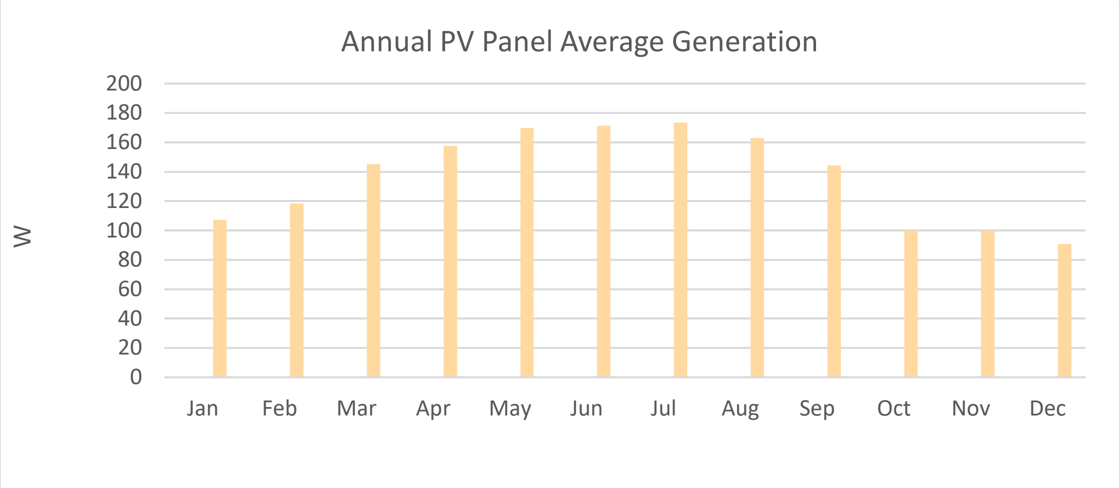



Fig 5.1 Annual PV generation

The above Fig 5.1 shows us the annual PV generation for 1 panel of 330 Wp according to the solar irradiance for that month over the site location. It can be seen that the PV generation peaks in the month of July (summer season) at 172 W/panel.

**Seasonal Power Output of PV Panel:**

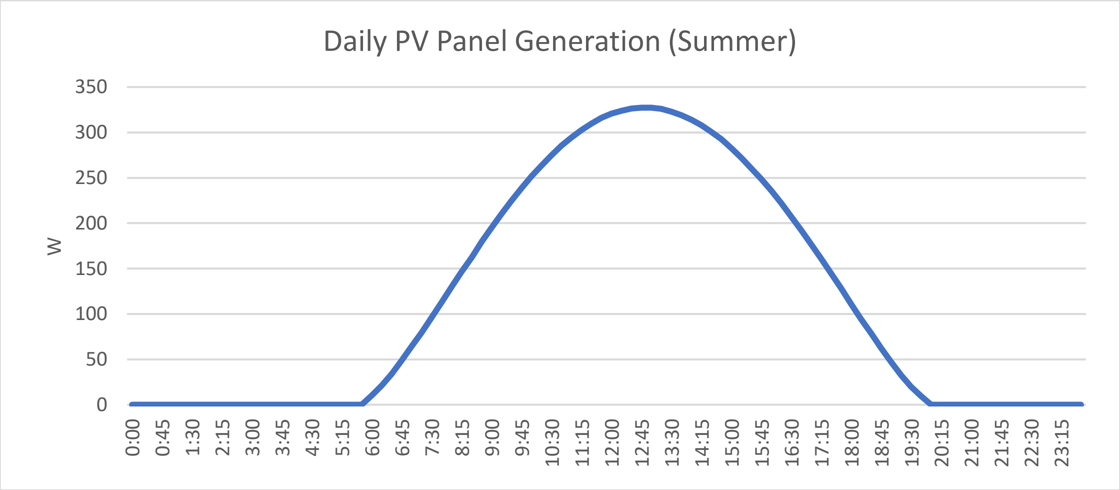



Fig 5.2 Daily PV generation (Summer)

The above Fig 5.2 shows us the daily PV generation for 1 panel of 330 Wp according to the solar irradiance for that day over the site location in the month of summer season. It can be seen that the PV generation peaks in the afternoon at about 1:00 pm.

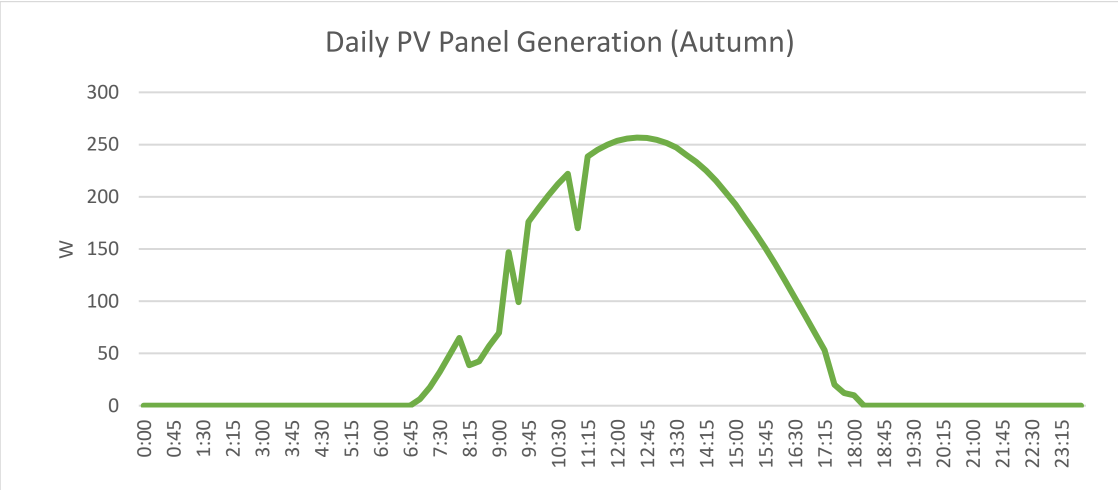



Fig 5.3 Daily PV generation (Autumn)

The above Fig 5.3 shows us the daily PV generation for a single panel of 330 Wp according to the solar irradiance for that day over the site location in the month of autumn season. The generation curve is not smooth during days of autumn season may be due to the presence of the dark clouds.

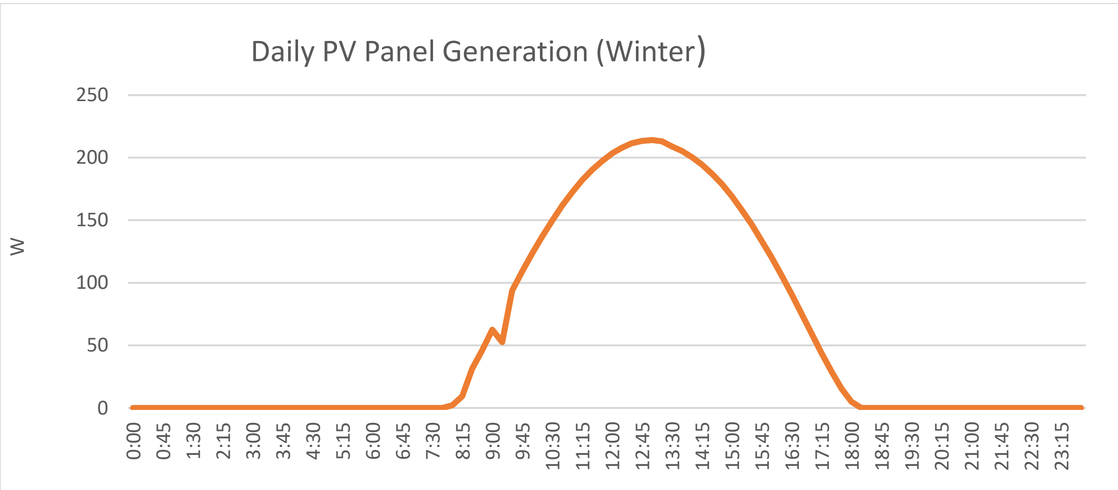



Fig 5.4 Daily PV generation(winter)

From Fig 5.4 it is observed that the daily PV generation for a typical day in winter season peaks to 215 W at 1:00 pm. Thus, from the Fig 5.2, Fig 5.3, Fig 5.4 it can be observed that the PV generation is more in summer season as compared to other seasons and this is supported by solar irradiance graph, which clearly shows that solar irradiance is more in the months of summer season.

## 5.2 Wind power calculation

The wind system has been playing a proactive role in power generation of many countries as well as a prime mover for many mechanical devices. It can be utilized by the power utilities and independent power producers to generate electrical power from the wind resources at the commercial level. The wind system can be used for a standalone or grid connected power system because of the characteristics like low maintenance and operating cost, low capital cost, no fuel cost, no direct GHG emission and so on. The output power of a WTG depends on the wind characteristic, tower height, wind shear and so on. The power output of a wind system can be expressed as

$$P_W(v) = P_r \begin{cases} 0 & v \le v_c \\ P_n(v) & v_c \le v \le v_r \\ 1 & v_r \le v \le v_{co} \\ 0 & v \ge v_{co} \end{cases} \tag{5.2}$$

$$P_n(v) = \frac{v^3}{{v_r}^3} \tag{5.3}$$

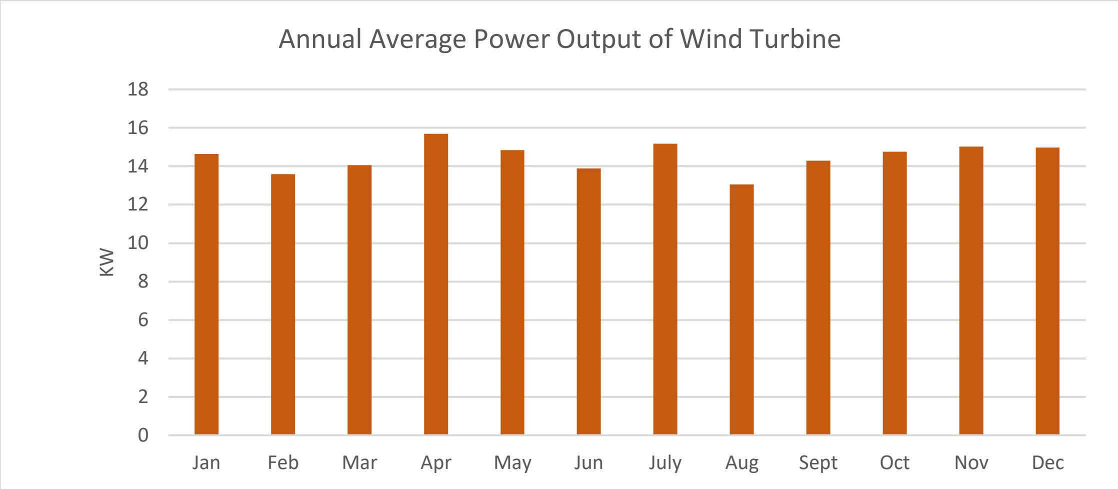



Fig 5.5 Annual power output of wind turbine

In the above Fig 5.5 we observe that the wind power generation is varying for each month. Power generation is maximum in month of April and minimum in August. The average generation throughout the year by 1 WTG is 14.5 KW. The power generation is quite uniform ranging between 12 KW to 16 KW this is also evident from wind-speed data which clearly shows that wind speed at the location is above 7.5 m/s (i.e Rated wind speed) for most of time throughout the year. Hence, we are able to get the rated output from the wind turbine.

## Seasonal Power output of Wind Turbine

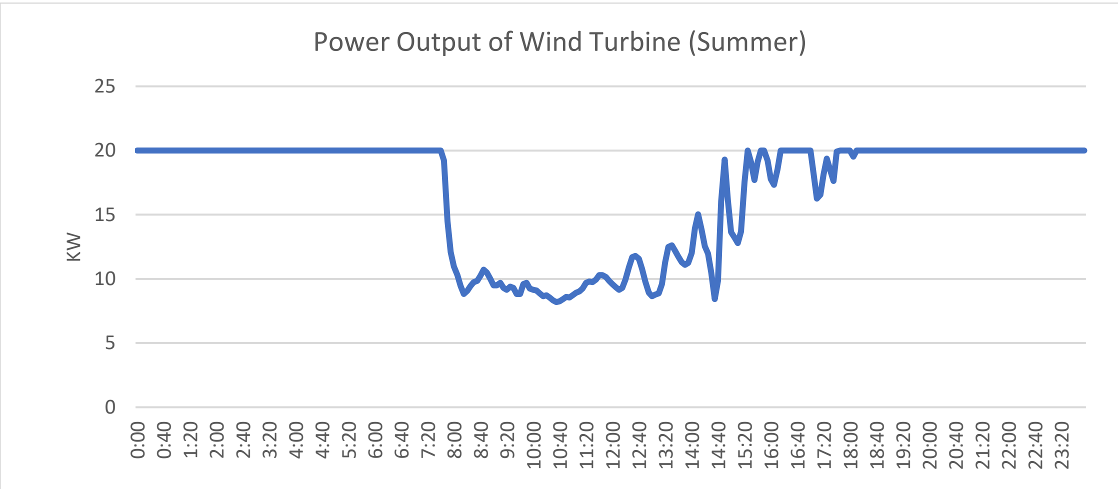



Fig 5.6 Power output of wind turbine (summer)

In Fig 5.6 it can be seen that the power generation of WTG is constant for most of the time except in the day time from 7:30 am to 4:00 pm where the wind speed is less than the rated speed so the rated output is not achieved.

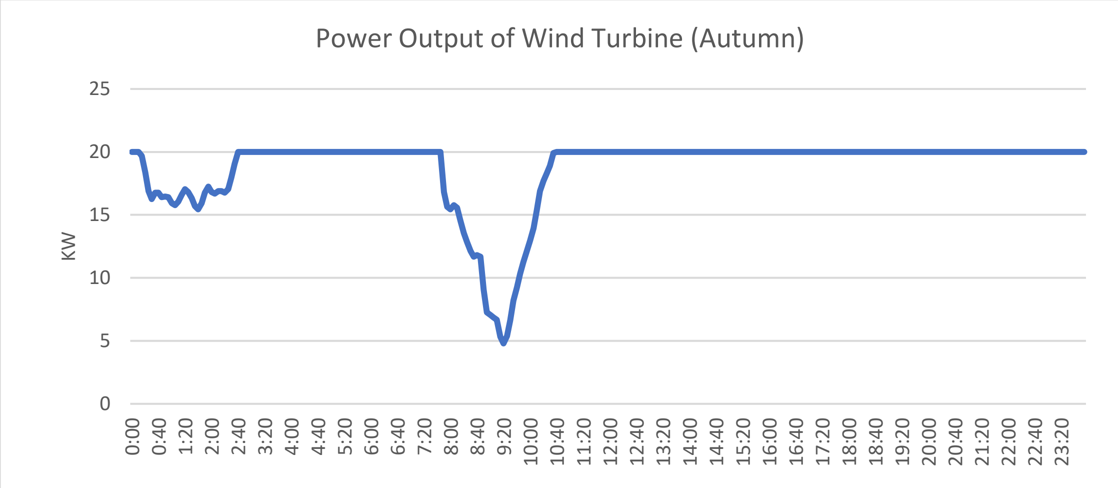



Fig 5.7 Power output of wind turbine (autumn)

In Fig 5.7 it can be seen that the power generation of WTG is constant for most of the time except in the day time from 7:30 am to 11:00 am where the wind speed is less than the rated speed so the rated output is not achieved.

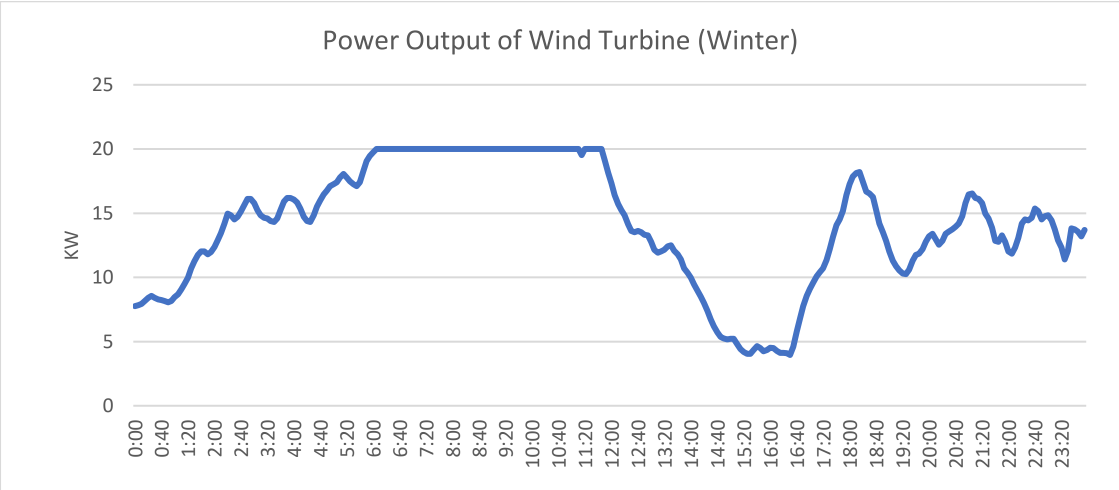



Fig 5.8 Power output of wind turbine (winter)

Fig 5.8 shows that depending on wind speed, generation changes on basis of (5.2) and (5.3) used to calculate wind power.

# CHAPTER 6

# Sizing

Investing in a solar system and wind turbines is a smart solution. The latest wind turbines and photovoltaic (PV) systems are much efficient, easy to maintain, and operate, with long-term performance and energy savings. To obtain maximum output of the system, it is important to correctly size it to cover energy use patterns without over-sizing PV array and wind turbine.

Renewable energy, such as hydro power, photovoltaics and wind turbines, has become the most widely applied solutions for addressing issues associated with oil depletion, increasing energy demand and anthropogenic global warming. Solar and wind energy are strongly dependent on weather resources with intermittent and fluctuating features. To filter these variabilities, battery energy storage systems have been broadly accepted as one of the potential solutions, with advantages such as fast response capability, sustained power delivery, and geographical independence. During the implementation of battery energy storage systems, one of the most crucial issues is to optimally determine the size of the battery for balancing the trade-off between the technical improvements brought by the battery and the additional overall cost. Numerous studies have been performed to optimize battery sizing for different renewable energy systems using a range of criteria and methods. Below are the steps taken in order to size PV Panel and Wind turbine and also determine the battery capacity for various cases.

<u>Step1 :-</u>

Finding worst load day i.e the day when daily average load is maximum. Convert 15 minutes load profiling data of a complete year into daily load data by taking an average of 15 minutes interval for each day.

Worst Day Load = 229.218 KW

<u>Step 2:-</u>

Consider various cases of power sharing of wind turbine and PV panel, to satisfy worst case load demand from Step 1.

| Wind % | Solar % |
|---|---|
| 0 | 100 |
| 10 | 90 |
| 20 | 80 |
| 30 | 70 |
| 40 | 60 |
| 50 | 50 |
| 60 | 40 |
| 70 | 30 |
| 80 | 20 |
| 90 | 10 |
| 100 | 0 |

Table 6.1 Different cases based on Load Sharing

Step 3:-

Determine size of Wind Turbines and PV panels for various cases taken in Step 2 using formulae mentioned below. Here, 'X' represents the number of wind turbines, 'Y' is the number of PV panels, 'a' represents the percentage of power shared by wind turbine and 'b' is the percentage of power shared by PV panel.

To calculate the number of wind turbines,

$$20 \times X = 229.218 \times a \tag{6.1}$$

To calculate the number of PV panels,

$$0.33 \times Y = 229.218 \times b \tag{6.2}$$

Using (6.1) and (6.2) we obtain Table 6.2

| Wind % (a) | Solar % (b) | No of Wind Turbine (X) | Approximate No (X) | No of PV panel (Y) | Approximate No (Y) |
|---|---|---|---|---|---|
| 0 | 100 | 0 | 0 | 694.60 | 695 |
| 10 | 90 | 1.14 | 1 | 625.14 | 625 |
| 20 | 80 | 2.29 | 2 | 555.68 | 556 |
| 30 | 70 | 3.43 | 3 | 486.22 | 486 |
| 40 | 60 | 4.58 | 5 | 416.76 | 417 |
| 50 | 50 | 5.73 | 6 | 347.30 | 347 |
| 60 | 40 | 6.87 | 7 | 277.84 | 278 |
| 70 | 30 | 8.02 | 8 | 208.38 | 208 |
| 80 | 20 | 9.16 | 9 | 138.92 | 139 |
| 90 | 10 | 10.31 | 10 | 69.46 | 69 |
| 100 | 0 | 11.46 | 11 | 0 | 0 |

Table 6.2 Calculation of number of PV and WTG

Step 4:-

Find generation (Wind + Solar) for every case taken. The power time series for wind turbine and PV panel was calculated for a complete year using (5.1), (5.2) and (5.3) respectively. Total generation for every 15 min interval for the complete year can be calculated using (6.3)

$$N_{WT} \times P_{outWT} + N_{PV} \times P_{outPV} = \text{Total Generation} \qquad (6.3)$$

| Time | P output WT (KW) | P output PV (W) |
|---|---|---|
| 9:45 | 20 | 91.57 |
| 10:00 | 20 | 104.79 |
| 10:15 | 18.59 | 117.04 |
| 10:30 | 13.50 | 128.65 |
| 10:45 | 11.13 | 139.29 |
| 11:00 | 11.13 | 148.65 |
| 11:15 | 20 | 157.03 |
| 11:30 | 20 | 164.45 |

Table 6.3 Wind and Solar generation at same instant of time

Suppose in order to find total generation for data set of Table 6.3 and a case when power shared by wind turbine is 10% and that by PV panel is 90% i.e $N_{WT}$ = 1 and $N_{PV}$ = 625 is considered, then the total generation is 77.23 KW at an instant of time (at 9:45 am) using (6.3). Following this method for all values of Table 6.3, Table 6.4 is tabulated.

| Time | P output WT (KW) | P output PV (W) | Wind + Solar Power (KW) |
|---|---|---|---|
| 9:45 | 20 | 91.57 | 77.23 |
| 10:00 | 20 | 104.79 | 85.49 |
| 10:15 | 18.59 | 117.04 | 91.75 |
| 10:30 | 13.50 | 128.65 | 93.91 |
| 10:45 | 11.13 | 139.29 | 98.19 |
| 11:00 | 11.13 | 148.65 | 104.04 |
| 11:15 | 20 | 157.03 | 118.14 |
| 11:30 | 20 | 164.45 | 122.78 |

Table 6.4 Total generation at different time instants

Step 5 :-

Finding difference of generation (Wind + Solar) and the load for all 15minute intervals for complete year, for all eleven cases i.e

$$P(diff) = P_{Gen}(t) - P_L(t) \tag{6.4}$$

Step 6 :-

Taking absolute maximum of $P(diff)$ and then expressing battery capacity in KWh

$$\text{Ebatt(KWh)} = \text{Absolute max}\{\text{P(diff)}\} \times \Delta\text{t} \tag{6.5}$$

Considering $\Delta t$ as 2hrs for calculation, the values for all eleven cases are given in Table 6.5

| Wind % | Solar % | No of Wind Turbine | Approximate No | No of PV panel | Approximate No | Required Battery capacity (KWh) |
|---|---|---|---|---|---|---|
| 0 | 100 | 0 | 0 | 694.60 | 695 | 537.48 |
| 10 | 90 | 1.14 | 1 | 625.14 | 625 | 516.00 |
| 20 | 80 | 2.29 | 2 | 555.68 | 556 | 516.00 |
| 30 | 70 | 3.43 | 3 | 486.22 | 486 | 517.86 |
| 40 | 60 | 4.58 | 5 | 416.76 | 417 | 521.28 |
| 50 | 50 | 5.73 | 6 | 347.30 | 347 | 524.76 |
| 60 | 40 | 6.87 | 7 | 277.84 | 278 | 528.12 |
| 70 | 30 | 8.02 | 8 | 208.38 | 208 | 531.66 |
| 80 | 20 | 9.16 | 9 | 138.92 | 139 | 535.08 |
| 90 | 10 | 10.31 | 10 | 69.46 | 69 | 539.46 |
| 100 | 0 | 11.46 | 11 | 0 | 0 | 560.00 |

Table 6.5 Sizing of components in HRES

In this way, the sizing of PV panel and wind turbine is carried out and battery capacity is determined for various cases taken.

Converter:

For ideal case, the rating of converter should be equal to rating of BESS.

$$\text{Converter Rating} = \frac{\text{Power Rating of BESS}}{\eta\text{Converter}} \tag{6.6}$$

$$\eta\text{Converter} = \frac{\text{Poutput}}{\text{Pinput}} \tag{6.7}$$

Power rating of BESS is calculated as shown in table 6.5. The efficiency of the converter ABB MGS100 60KW is 95%. Substituting the values in (6.6), converter rating and number of converters required for all 11 cases taken can be calculated as shown in Table 6.6. As price of a single ABB MGS100 60KW is 4Lacs, total cost of converters for each case is Rs 20Lacs.

| Battery Power (KW) | Converter Capacity (KW) | No of converters |
|---|---|---|
| 268.74 | 282.8842105 | 5 |
| 258 | 271.5789474 | 5 |
| 258 | 271.5789474 | 5 |
| 258.93 | 272.5578947 | 5 |
| 260.64 | 274.3578947 | 5 |
| 262.38 | 276.1894737 | 5 |
| 264.06 | 277.9578947 | 5 |
| 265.83 | 279.8210526 | 5 |
| 267.54 | 281.6210526 | 5 |
| 269.73 | 283.9263158 | 5 |
| 280 | 294.7368421 | 5 |

Table 6.6 Sizing of converter

# CHAPTER 7
# Economic Modelling

## 7.1 Economic Parameters

The most important benchmark to determine if the HRESs are financially worthwhile can be analysed by using the following parameters: the Total Present Value (TPV) and Levelized cost of energy (LCOE), Capital Recovery Factor (CRF). The aforementioned operating parameters are used in this study as the economic criteria to evaluate the feasibility of renewable hybrid system configurations. These key performance indicators are used to investigate the impacts of PV, WTG and BSS on the hybrid system. The applications of these methods are presented as the following. The following parameters are used to determine whether the HRES is financially profitable.

Levelized cost of energy (LCOE):

The levelized cost of energy (LCOE), or levelized cost of electricity, is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. It is used for investment planning and to compare different methods of electricity generation on a consistent basis. The LCOE "represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle", and is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered. LCOE is given by formula

$$\mathrm{LCOE} = \frac{\mathrm{TPV\ X\ CRF}}{\mathrm{AE}} \tag{7.1}$$

where AE is the annual total energy of the load, TPV is total present value, CRF is capital recovery factor.

Capital Recovery Factor (CRF):

CRF will help to determine how much annual revenue we will need so that the initial investment cost is recovered. It is determined by formula

$$\mathrm{CRF}(r,T) = \frac{r(1+r)^T}{(1+r)^T - 1} \tag{7.2}$$

$$r = \frac{r^{nom} - f}{1 + f} \tag{7.3}$$

Total Present Value (TPV):

The total present value (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. TPV is given by formula

$$\mathrm{TPV} = \mathrm{IC} + \mathrm{RC} + \mathrm{OMC} - \mathrm{PSV} \tag{7.4}$$

where, IC is Initial capital cost that includes the costs of all components of the system including the civil work, installation, and electric connections and testing. RC is Replacement Cost that includes the current amount that must be paid to acquire an asset of the same value as a replacement for an asset that is no longer functional or viable. OMC represents the maintenance cost all over the lifetime of the project for all components at the time of installation. This is the sum of all yearly scheduled operation and maintenance costs. PSV is Present Scrap Value which is the system's net worth in the final year of its life-cycle period array.

## 7.2 Calculation and analysis of economic parameters

A feasibility study of the HRES project is determined by evaluating its economic system metrics. The following are the calculations of economic parameters for the system.

### 7.2.1 Calculation of Capital Recovery Factor (CRF)

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). CRF can be calculated by using (7.1) and (7.2) by putting values of parameters $r^{nom}$ (nominal interest rate) as 4.5 %, f (annual inflation rate) as 4.06 % and T (project lifespan) as 15 years. Thereby, we get CRF as 0.12183.

### 7.2.2 LCOE of system

The LCOE, which represents the average revenue per unit of electricity generated that would be required to recover the costs of infrastructure and operating a generation plant during an assumed financial life and duty cycle, is given by formula in (7.1). To calculate LCOE we require IC, RC, OMC and PSV as given in (7.4). IC, RC, OMC and PSV values for different system is given in Table 7.1 by following study in Mohamed A. Mohamed [7].

| | Initial capital Cost (Rs) | Replacement Cost (Rs) | O&M Cost (Rs) | Life Span | Scrap Value (Rs) |
|---|---|---|---|---|---|
| WTG | 1650000 | 1320000 | 20625 | 20 years | 330000 |
| PV | 7500 | 6750 | 75 | 30years | 750 |
| Battery | 19000 | 15200 | 950 | 15years | 3800 |
| Converter | 400000 | 360000 | 2800 | 20 years | 40000 |

Table 7.1 Variables required to calculate TPV

Calculation of Economic parameters for all cases:

Suppose, to find LCOE for Case 2. Here, power shared by wind turbine is 10% and power shared by PV panel is 90%. Using TPV (7.4), TPV of PV system is Rs 4265625, TPV of wind turbine as Rs 1402500. Similarly, total present value of battery and converter can be calculated. TPV of BESS and Converter = Rs 8003391.68. Adding all system TPV, the total TPV of system as Rs 13671516.7.

Next step is to find LCOE by using (7.1). As calculated previously, the Capital Recovery Factor is equal to 0.12183 and AE, which is the annualized energy produced, can be calculated from power time series. For case 2, AE is 381826 KWh. Hence, by using (7.1), LCOE is obtained as Rs 4.3021986. Similarly, LCOE for all 11 cases is calculated and is shown in Table 7.2.

| Wind % | Solar % | No of Wind Turbine | No of PV panel | Battery capacity (KWh) | No of BESS modules | Converter Capcity (KW) | No of converters | PV + WT TPV (Rs) | Batt+Converter TPV (Rs) | Total TPV (Rs) | LCOE (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 100 | 0 | 695 | 537.48 | 224 | 282.88 | 5 | 4743375 | 8253300.31 | 12996675.3 | 4.09 |
| 10 | 90 | 1 | 625 | 516 | 215 | 271.58 | 5 | 5668125 | 8003391.68 | 13671516.7 | 4.30 |
| 20 | 80 | 2 | 556 | 516 | 215 | 271.58 | 5 | 6599700 | 8003391.68 | 14603091.7 | 4.60 |
| 30 | 70 | 3 | 486 | 517.86 | 216 | 272.56 | 5 | 7524450 | 8025031.81 | 15549481.8 | 4.90 |
| 40 | 60 | 5 | 417 | 521.28 | 217 | 274.36 | 5 | 9858525 | 8064821.73 | 17923346.7 | 5.66 |
| 50 | 50 | 6 | 347 | 524.76 | 219 | 276.19 | 5 | 10783275 | 8105309.72 | 18888584.7 | 5.97 |
| 60 | 40 | 7 | 278 | 528.12 | 220 | 277.96 | 5 | 11714850 | 8144401.58 | 19859251.6 | 6.28 |
| 70 | 30 | 8 | 208 | 531.66 | 222 | 279.82 | 5 | 12639600 | 8185587.64 | 20825187.6 | 6.59 |
| 80 | 20 | 9 | 139 | 535.08 | 223 | 281.62 | 5 | 13571175 | 8225377.56 | 21796552.6 | 6.9 |
| 90 | 10 | 10 | 69 | 539.46 | 225 | 283.93 | 5 | 14495925 | 8276336.58 | 22772261.6 | 7.21 |
| 100 | 0 | 11 | 0 | 560 | 233 | 294.74 | 5 | 15427500 | 8515308.80 | 23942808.8 | 7.58 |

Table 7.2 LCOE Calculation

Observing the LCOE for all cases from Table 7.2, it is seen that LCOE is lowest for case 1 and highest for case 11. There is an upward trend in the cost of LCOE as there is reduction in the contribution of PV Panel and simultaneously an increase in wind turbine contribution. The reason for this trend is a greater variance of wind power generation than variance of solar power generation. For location considered, variance in wind power generation is 56.16228 and variance in PV Power generation is 0.0096. The site location considered is more suitable for solar power generation than wind power generation because of which, the variance of wind power generation is greater than the variance of solar power generation.

# CHAPTER 8
# Cost projection over next decade

According to study published by International renewable energy Agency, PV panel price will fall by 60% and wind turbine cost will reduce by 50% over the coming decade i.e from 2020 to 2030.

## 8.1 Factors contributing to cost reduction :-

1. Technological improvements:

Solar and wind power technologies are constantly evolving from a mature knowledge base that is incorporating incremental innovations that are driving down installed costs, by increasing solar PV module efficiency that reduces not only materials inputs to the module, but also reduces costs in categories strongly linked to the area (e.g., cabling, racking, mounting, installation, etc.). Innovations in manufacturing are also reducing costs, by reducing materials inputs, while increasing the scale of wind turbines can drive down specific costs. Reducing O&M costs: improved technology reliability reduces downtime, maintenance interventions and component replacement costs. At the same time digitization is unlocking performance data that can be used to allow preventative maintenance to reduce forced outages. Improving performance and output: Higher operating temperatures through the use of new heat transfer fluids in CSP plants raise power block efficiency, while larger wind turbines with higher hub-heights and greater swept areas harness more electricity for a given resource onshore or offshore.

2. Economies of scale:

These are acting on the manufacturing side and in some cases at the project level. The growth in the scale of regional markets for wind and solar are allowing the growth in regional manufacturing hubs that create localised economies of scale, while minimizing transport costs. Growth in project size, or more commonly in recent times, the grouping of projects in successful auction bids or rounds, are allowing developers to improve their purchasing power and operating economies of scale.

3. Continued competition:

Competitive procurement of renewables capacity has, and will continue to, sharpen the competition that sees project developers, suppliers and manufacturers of renewable power generation equipment all searching for ways to reduce costs to win the next bid. When combined with increasing economies of scale, the supply chain cost reductions can be an important driver of lower costs.

4. Other factors:

Greater developer experience, mature technologies and increased operational experience, all act in important ways to reduce costs. Greater experience reduces the need for contingency funds, reduces working capital needs and when combined with the increasing technology maturity and operational experience with large asset portfolios can reduce financing costs, so crucial to achieving low electricity costs.

## 8.2 Projections over next decade

### 8.2.1 PV panel projection

On the basis of reasons given in 8.1 section, Fig 8.1 is plotted with 2 years interval. Fig 8.1 shows how PV system price will fall from 2020 to 2030.

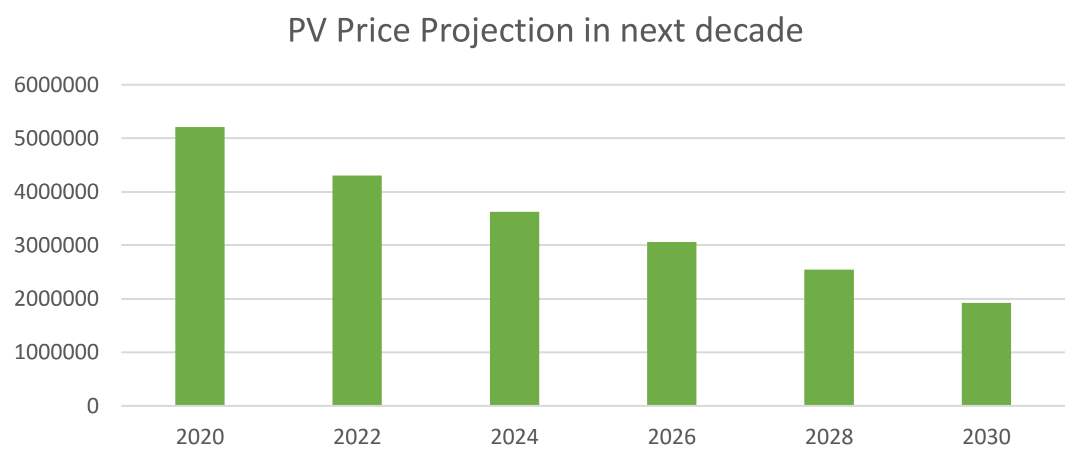



Fig 8.1 PV price projection

From Fig 8.1, there is a 60% decrease in PV system cost i.e price has reduced from Rs 52,12,500 in 2020 to Rs 19,26,359 in 2030. Also, the efficiency of solar panel will increase in the coming years which will reduce the number of panels required eventually reducing the PV system cost. Also, the price of solar modules will decline as more of them are produced as more production will give us the chance to learn how to improve the production process.

### 8.2.2 Wind Turbine projection

On the basis of reasons given in 8.2 section, Fig 8.2 is plotted with 2 years interval. Fig 8.2 shows how WT system price will fall from 2020 to 2030.

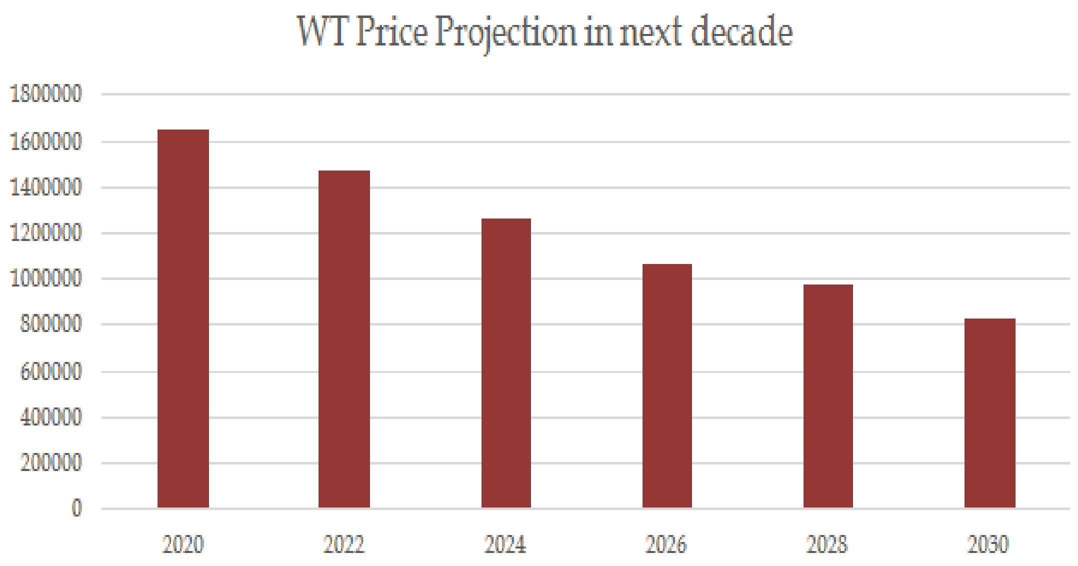



Fig 8.2 WT price projection

From Fig 8.2 in 2020 it can be seen the cost of wind turbine is Rs 16.5Lacs and it reduces by 10.5% in 2022 whereas from year 2022 to 2024, there is reduction of cost by 14.5%. In 2026 the cost is Rs 1070994 and reduces by 8% up-to 2028. Thus, it can be seen a 50% decrease in wind system cost i.e price has reduced from Rs 16,50,000 in 2020 to Rs 8,25,000 in 2030.

### 8.2.3 BESS projection

Globally, the sharp decline in prices of lithium-ion (Li-ion) batteries is expected to transform how electricity from renewable sources, such as solar and wind, is integrated into the grid. Using study published by Prayas [13] plot of BESS price from 2020 to 2030 with an interval of 2 years is shown in Fig 8.3.

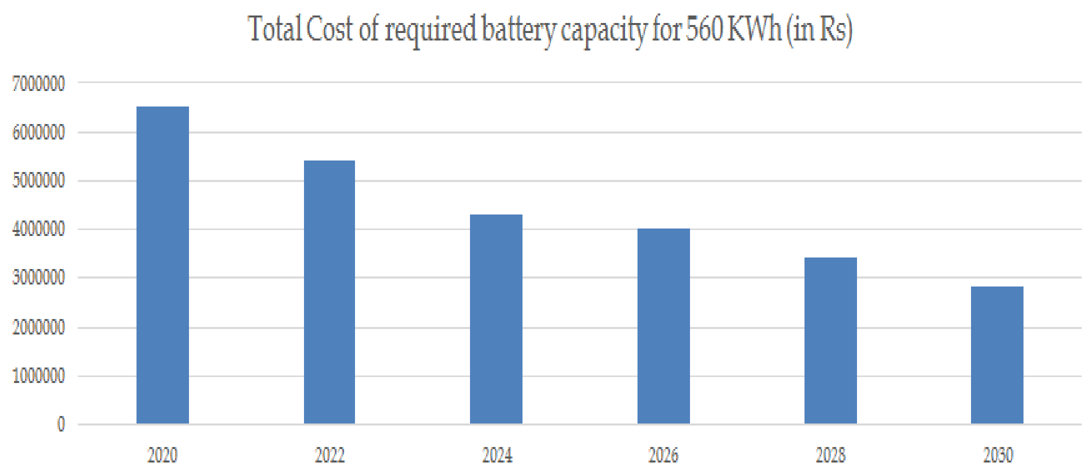



Fig 8.3 BESS price projection

From Fig 8.3, it can be seen that there is 64% decrease in BESS Cost i.e cost has reduced from Rs 65,15,307 in 2020 to Rs 28,24,819 in 2030. One reason for this is that the battery costs depend less on the active material costs and to a greater extent on the production volume of the batteries and are expected to decline as the batteries are mass-produced. The development of manufacturing equipment or processes that will result in decreased line-time requirements for the manufacture of the different components of the cells, primarily the electrodes, will also help reduce the costs. Apart from the anticipated reduction in the manufacturing costs with their mass-production, costs can also come down with better design and integration of the battery packs by making better decisions on the rate capability and pack sizes of batteries.

### 8.2.4 LCOE projection

TPV is addition of TPV of PV system, Wind turbine system, BESS and converter system for respective years. Hereafter LCOE is calculated from TPV of different years using (7.1). In LCOE calculation, project lifetime, annual interest rate, annual inflation rate, nominal interest is same for all the cases and value taken is same as mentioned before in our study. By following this process, LCOE for all cases is calculated from 2020 to 2030 and shown in tabular in Table 8.1

| Year | LCOE (Case 1) (Rs) | LCOE (Case 2) (Rs) | LCOE (Case 3) (Rs) | LCOE (Case 4) (Rs) | LCOE (Case 5) (Rs) | LCOE (Case 6) (Rs) | LCOE (Case 7) (Rs) | LCOE (Case 8) (Rs) | LCOE (Case 9) (Rs) | LCOE (Case 10) (Rs) | LCOE (Case 11) (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind 0% Solar 100% | Wind 10% Solar 90% | Wind 20% Solar 80% | Wind 30% Solar 70% | Wind 40% Solar 60% | Wind 50% Solar 50% | Wind 60% Solar 40% | Wind 70% Solar 30% | Wind 80% Solar 20% | Wind 90% Solar 10% | Wind 100% Solar 0% |
| 2020 | 4.09 | 4.30 | 4.60 | 4.90 | 5.66 | 5.97 | 6.28 | 6.59 | 6.9 | 7.21 | 7.58 |
| 2022 | 3.39 | 3.6 | 3.87 | 4.15 | 4.84 | 5.13 | 5.41 | 5.7 | 5.98 | 6.27 | 6.61 |
| 2024 | 2.77 | 2.95 | 3.19 | 3.43 | 4.03 | 4.27 | 4.52 | 4.77 | 5.02 | 5.26 | 5.55 |
| 2026 | 2.46 | 2.61 | 2.81 | 3.01 | 3.52 | 3.72 | 3.93 | 4.14 | 4.35 | 4.56 | 4.81 |
| 2028 | 2.07 | 2.22 | 2.41 | 2.60 | 3.07 | 3.26 | 3.46 | 3.66 | 3.86 | 4.06 | 4.3 |
| 2030 | 1.64 | 1.77 | 1.94 | 2.11 | 2.51 | 2.68 | 2.85 | 3.03 | 3.2 | 3.37 | 3.58 |

Table 8.1 LCOE Projection for 11 cases from 2020-2030

From Table 8.1 it can be seen that there is a trend from 2020 to 2030, LCOE for all cases goes on reducing. Hence, the cost of energy for HRES will reduce in the coming years and will save consumers money.

## 8.3 Comparison with conventional energy

In this section comparison of the cost of energy of hybrid renewable energy system with the conventional energy system is discussed. Fig 8.4 shows LCOE comparison between our hybrid model system (all 11 cases) and conventional energy (eg: Thermal) sources over the coming decade i.e from 2020-2030. In case 1, entire generation is done by solar source and contribution of wind is zero. Similarly, in last case 11 entire generation is done by wind source. Cost of conventional energy depends upon units consumed. Hence, in our analysis we have considered cost for a residential user consuming 100-300 units of electricity. Cost of conventional energy is Rs 6/unit for a consumer consuming 100-300 units of electricity.

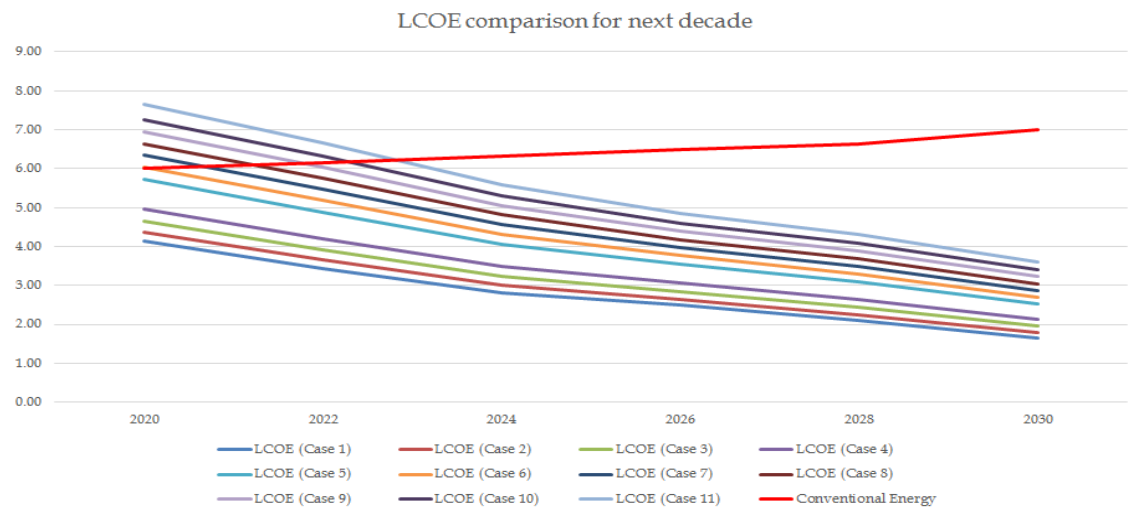



Fig 8.4 LCOE price projection and comparison with CE

From Fig 8.4, it can be seen that cost of conventional energy will slightly increase and become Rs 7/unit in 2030. But the LCOE of non-conventional energy source will go on decreasing from 2020-2030. From the Fig 8.4 it can be seen that in 2020, case 7 to case 11 are costlier as compared to conventional energy source but cost of non-conventional source (PV + Wind in our case) goes on reducing and from 2024, all the 11 cases are cheaper as compared to conventional energy source. In 2030, it can be stated that the hybrid system will cost Rs 3-5/unit cheaper than the conventional energy source hence it will reduce cost of energy. Hence, it can be inferred that cost of energy will significantly reduce in coming future and there is a need to shift to non-conventional energy sources like solar and wind.

# Chapter 9
# Conclusion and future scope

## 9.1 Conclusion

An upward trend is observed in the cost of LCOE as there is reduction in the contribution of PV panel and simultaneously an increase in wind turbine contribution. The reason for this trend is a greater variance of wind power generation than variance of solar power generation, which states that the results are location specific and our location had good amount of solar irradiance than wind according to the data from NREL for a span of 1 year.

1. Size micro-grid based on location:

Various micro grid configurations should be analysed and the best suited one for the considered location must be selected. The results obtained from this study have established that RESs are potential alternatives to meet the power demand of the remote areas where supply power through conventional energy sources is not feasible.

2. Environment friendly:

Renewable energy can economically reduce CO2 emission in the electricity sector and open-up electrification of end-uses with decarbonization strategy.

3. Low cost:

RES cost will be less than conventional energy sources in the near future and hence it will save plenty of money of the consumer which they spend on yearly bills.

4. Serve as an alternative:

RES can be a potential alternative to meet power demand of remote areas where supplying power through conventional energy source is not feasible.

## 9.2 Future scope

The future scope of RES in India is given in Fig 9.1 which clearly states that there will be a drastic increase in the installed capacity where, non-fossil fuel (solar, wind, biomass, hydro & nuclear) based installed capacity is likely to be about 64% of the total installed capacity and non-fossil fuels contribute around 44.7% of the gross electricity generation during the year 2029-30.

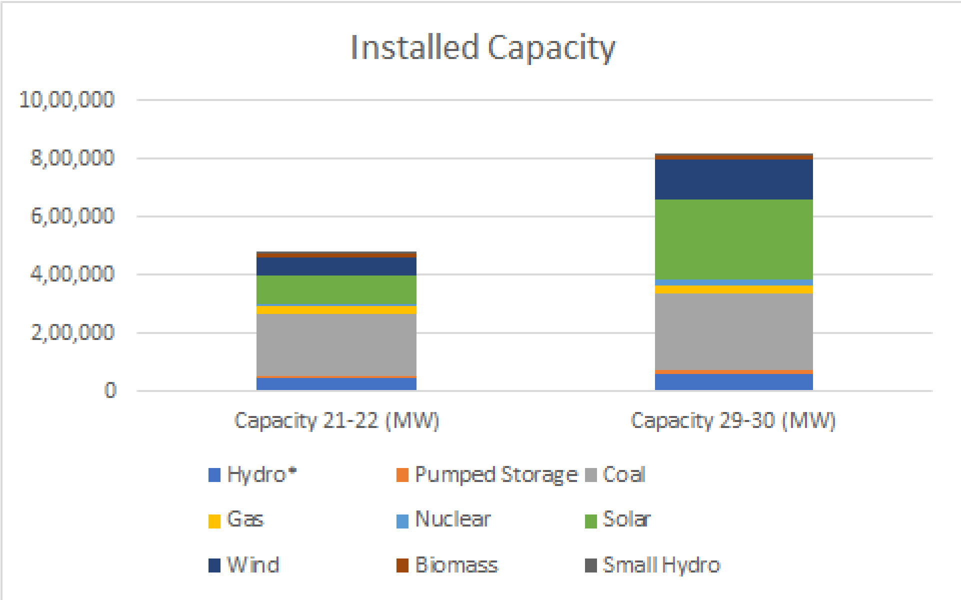



Fig 9.1 Installed capacity projections of conventional and non-conventional energy sources

As shown in Fig 9.1, the projected installed capacity by the end of 2021-22 as per midterm NEP review is 4,76,431 MW (44,989 MW Hydro, 5246 MW PSP, 2,15,773 MW Coal, 25,343 MW Gas, 10,080 MW Nuclear, 5,000 MW small Hydro, 10000MW Biomass, 100,000 MW solar and 60,000 MW wind) and has been considered as the base capacity. Additionally, hydro imports totaling to 2136 MW have been considered till 2021-22. The base year of the study has been considered as 2021-22.

It is seen from the results that renewable energy sources (solar +wind) installed capacity is likely to be about 420 GW (280GW Solar+ 140 GW Wind) by the end of year 2029-30 which is more than 50% of total installed capacity of 817 GW. Looking at the cost projection study done in Chapter 8, it can be observed that in upcoming decade, from 2020 to 2030 there is 64% decrease in BESS cost, 60% decrease in PV system cost, 50% decrease in wind system cost.

In the future, the cost difference between PV-plus-storage assets and thermal assets likely will increase. Therefore, new investments in thermal power plants with lifetimes of 25–30 years may present extreme financial risk. However, concerted policy and regulatory efforts are needed to scale-up India’s RE and storage deployment and achieve the low prices that we estimate are possible. Such efforts could include a clear policy direction to boost domestic renewable system manufacturing via guaranteed demand as well as a roadmap for skill development and the addition of new jobs.

# References


1. https://maps.nrel.gov/wind-prospector
2. https://www.nrel.gov/gis/solar.html
3. Hina Fathima and K. Palanisamy,"Optimized Sizing, Selection, and Economic Analysis of Battery Energy Storage for Grid-Connected Wind-PV Hybrid System",Volume 2015, Article ID 713530
4. "Techno-ecnomic analysis of a PV-wind_Battery-Diesel standalone power system in a remote area", Temitope Adefarati, Ramesh C. Bansal, Jakcson John Justo Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa.
5. "Optimal Placement and Sizing of Renewable Distributed Generation and Capacitor Banks into Radial Distribution Systems", Mahesh Kumar, Perumal Nallagowden and Irravian Elamvazuthi.
6. "Optimal allocation and sizing of PV/Wind/Split-Diesel/Battery hybrid energy system for minimizing life cycle cost, carbon emission and dump energy of remote residential building", A.S.O Ogunjuyigbe.
7. "Optimal sizing and designing of Hybrid Renewable Energy System in Smart Grid Applications", Ali M. Eltamaly and Mohamed A. Mohamed.
8. https://loopsolar.com/datasheet/adani-solar/datasheet-adani-solar-72-cell-300-330-Wp-India.pdf
9. https://en.wind-turbine-models.com/turbines/1640-eocycle-eo20.
10. "Estimating the Cost of Grid-Scale Lithium-Ion Battery Storage in India", authors - Shruti M. Deorah1 , Nikit Abhyankar1.
11. https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019.
12. https://www.pv-magazine.com/2019/06/05/pilot-project-in-israel-embraces-the-energy-grid-of-the-future/
13. https://www.prayaspune.org/peg/

**14.** https://energypost.eu/analysis-shows-wind-and-solar-costs-will-continue-to-fall-dramatically-throughout-the-2020s/

**15.** https://www.iea.org/data-and-statistics/charts/actual-and-forecast onshore-wind-costs-2016-2025

**16.** https://www.irena.org/https://www.irena.org/

**17.** https://www.woodmac.com/our-expertise/focus/Power--Renewables/a-deep-dive-into-chinas-renewables-landscape/

**18.** https://www.nrel.gov/docs/fy12osti/54526.pdf

**19.** https://www.smart-energy.com/renewable-energy/renewables-will-be-cheaper-than-coal-by-2026-in-china-study/

**20.** https://kleanindustries.com/resources/environmental-industry-market-analysis-research/what-happens-when-solar-gets-much-much-cheaper/

**21.** https://www.intechopen.com/books/wind-solar-hybrid-renewable-energysystem/evaluation-of-pv-wind-hybrid-energy-system-for-a-small-island.

**22.** https://energypost.eu/analysis-shows-wind-and-solar-costs-will-continue-to-fall-dramatically-throughout-the-2020s/

**23.** Report On optimal Generation Capacity Mix for 2029-30

**24.** "Evaluation of PV-Wind Hybrid Energy System for a Small Island", Sajid Ali and Choon-Man Jang