HYBRID ENERGY SYSTEMS

UNIT-V

- Hybrid Energy Systems,
- Need for Hybrid Energy Systems,
- Range and types of Hybrid systems,
- Hybrid Solar PV/Wind Energy System,
- Architecture of Solar-Wind Hybrid System and
- Grid connected issues.

Hybrid Energy Systems,

- The renewable energy technologies include power generation from renewable energy sources, such as wind, PV(photovoltaic), MH (micro hydro), biomass, ocean wave, geothermal and tides. I
- the deployment of the above energy systems are their benefits, such as supply security, reduced carbon emission, and improved power quality, reliability and employment opportunity to the local people.
- Since the RE resources are intermittent in nature therefore, hybrid combinations of two or more power generation technologies, along with storage can improve system performance.
- **Hybrid Renewable Energy System (HRES) combines two or more renewable energy resources with some conventional source (diesel or petrol generator) along with storage, in order to fulfill the demand of an area.**

Methodology

It is essential to have a well-defined and standardized frame work/steps taken for hybrid system-based power generation for rural electrification. These steps are as follows:

Demand Assessment:

Using accurate load forecasting of remote villages, the load demand can be fetched. During load survey, following factors may be considered:

- Demand for street lighting
- Number of houses, schools, health centers, commercial establishment and their energy requirement
- Number of small scale industries and their energy demand
- Miscellaneous demand

Resource Assessment:

Resource assessment can be done by calculating potential available in wind, MHP, solar, Biomass, Biogas, and other renewable energy resources using meteorological data available.

Need for Hybrid Systems

- As convention fossil fuel energy sources diminish and the world‘s environmental concern about acid deposition and global warming increases, renewable energy sources (solar, wind, tidal, biomass and geothermal etc) are attracting more attention as alternative energy sources.
- These are all pollution free and one can say eco friendly.
- These are available at free of cost in India, there is severe power shortage and associated power quality problems.
- The quality of the grid supply in some places is characterized by large voltage and frequency fluctuations, scheduled and un-scheduled power cuts and load restrictions.
- Load shedding in many cities in India due to power shortage and faults is a major problem for which there is no immediate remedy in the near future since the gap between the power demand and supply is increasing every year.
- To meet the demand and for the sake of continuity of power supply, storing of energy is necessary.
- The term hybrid power system is used to describe any power system combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either.

- one of the energy sources is a conventional one (which necessarily does not depend on renewable energy resource) powered by a diesel engine, while the other(s) would be renewable viz. solar photovoltaic, wind or hydro.
- The design and structure of a hybrid energy system obviously take into account the types of renewable energy sources available locally, and the consumption the system supports. For example, the hybrid energy system presented here is a small-scale system and the consumption of power takes place during nights.
- The wind energy component will make a more significant contribution in the hybrid system than solar energy.
- Although the energy produced by wind during night can be used directly without storage.
- Battery is needed to store solar and wind energy produced during theday.
- In addition to the technical considerations, cost benefit is a factor that has to be incorporated into the process of optimizing a hybrid energy system.
- In general, the use of wind energy is cheaper than that of solar energy. In areas where there is a limited wind source, a wind system has to be over-dimensioned in order to produce the required power, and these results in higher plant costs. It has been demonstrated that hybrid energy systems (renewable coupled with conventional energy source) can significantly reduce the total life cycle cost of a standalone power supplies in many off-grid situations.
- Numerous hybrid systems have been installed across the world, and expanding renewable energy industry has now developed reliable and cost competitive systems using a variety of technologies.
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Hybrid energy systems, which combine two or more energy generation sources (like solar and wind) or integrate a source with storage (like solar plus batteries), are essential for modernizing the power grid and increasing energy independence.
The primary needs driving their adoption include:

1. Addressing Intermittency of Renewables

Renewable sources like **solar** and **wind** are **intermittent**—they only generate power when the sun shines or the wind blows.A standalone solar plant produces nothing at night.
A hybrid system, such as **Solar + Wind + Battery Storage**, can use the battery to supply power when neither source is active, or use the wind to generate power when the sun isn't out, ensuring a more **stable and reliable** power supply.

2. Improving Power Quality and Stability

Integrating multiple sources helps to smooth out rapid power fluctuations, which are common with single, large renewable sources.
Energy storage (batteries) acts as a buffer, absorbing excess power during peaks and releasing it during dips, thereby stabilizing the grid frequency and voltage.

3. Economic Optimization

Hybrid systems often lead to a lower **Levelized Cost of Electricity (LCOE)** by maximizing the use of shared infrastructure.They can share the same transmission lines, power electronics (inverters/converters), and land, reducing the overall capital and operational expenditure compared to two separate, uncoordinated systems.

4. Meeting Diverse Load Requirements

Different energy sources can be optimized for various load profiles throughout the day. Solar is excellent for meeting high daytime cooling demands. Batteries are perfect for meeting the evening peak demand (the "duck curve").This coordination allows the system to be tailored more precisely to the consumer's needs.
In essence, hybrid energy systems are necessary because they combine the **sustainability** of renewable energy with the **reliability** and **dispatchability** (on-demand availability) typically associated with traditional power plants.

RANGE AND TYPE OF HYBRID SYSTEMS

- Although hybrid energy systems are open, they can have the characteristics of a closed system if a subsystem with the function of —monitoring‖ is introduced as a feedback between output (consumer) and input (controller).
- As inputs of particular hybrid system cannot be changed. However, the load may be changed.
- With a backup system as another energy source the system can be designed as a partial closed-loop feedback system.
- There are various possibly to make combination of different energy sources.
- Selection of energy source for hybrid system is mainly depends upon **availability at the place where it going to stabilized.**
- solar energy is available almost all the places and infrastructure for power generation is rugged. Hence need low maintenance so it is smart to choose to have PV one of the energy sources in hybrid system.
- Wave and tidal energy available only at sea shore and need large capital investment and more maintenance, therefore not compatible for household hybrid system.
- Wind energy source is also a good choice but more preferable for open land hybrid system and status of wind throughout the year is also important.
- India has monsoon climate hence has enough potential of wind energy.
- Biomass energy is good option but it needs regular feeding to continuously operate.
- Biomass with grid hybrid system is broadly used in sugar mill in India.
- In residential applications, biomass can be used for space heating or for cooking. .

RANGE AND TYPE OF HYBRID SYSTEMS

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- Selection of energy source for hybrid system mainly depends upon **availability at the place where it going to stabilized**

  1. <u>Classification by Energy Source Combination</u>
- The most common hybrid systems combine two or more generation sources, often pairing an intermittent renewable with a controllable or stable source.

Hybrid System Type	Components Combined	Primary Use Case
Solar-Wind (PV-Wind)	Solar Photovoltaic (PV) Panels + Wind Turbine	Ideal for maximizing generation by using **complementary resources** (solar during the day, wind often at night/in winter).
Renewable-Fossil Fuel	Solar/Wind + Diesel Generator (DG) or Natural Gas	Common in **remote or off-grid** areas. The renewable source saves fuel, and the generator provides reliable backup power during low wind/sun conditions.
Renewable-Storage	Solar/Wind + **Battery Energy Storage System (BESS)**	Essential for grid stability and demand management. The battery stores excess renewable energy for use during peak demand (evening).
Multi-Renewable	Geothermal + Solar or Hydro + Wind	Used in areas with diverse natural resources to create a highly **diversified and stable** portfolio.

- **Classification by Configuration (How they Connect)**
- The way components are wired together affects efficiency, cost, and control complexity. Hybrid systems typically use either AC or DC coupling.
- ***A. DC Coupled Hybrid System***
- **Configuration:** All power generation sources (Solar PV, Wind, etc.) are connected to a common **DC Bus (Direct Current)**.
- **Key Feature:** The DC bus directly feeds the **Battery Storage** and then connects to a central inverter. This is the simplest and most efficient way to charge batteries from solar, as it avoids extra conversion losses.
- **Best Used For: Off-grid or small systems** where battery storage and DC loads are the priority.
- ***B. AC Coupled Hybrid System***
- **Configuration:** Each power source (Solar, Wind, Grid) has its own dedicated **inverter** and is connected to a common **AC Bus (Alternating Current)**.
- **Key Feature:** It is easier to integrate into an existing grid-tied system. The inverters communicate to manage power flow. Charging the battery requires a separate AC-to-DC conversion step.
- **Best Used For: Large-scale, grid-tied commercial or utility projects** where each source needs independent control.
- ***C. AC-DC Hybrid (A Hybrid of Hybrids)***
- **Configuration:** Uses a combination of both AC and DC buses. For example, the solar array might DC-couple directly to the battery, while the wind turbine and diesel generator AC-couple to the load.

Classification by Operating Scale

Types of the systems

- Wind/PV Hybrid System
- PV/Hydro Hybrid System
- Biomass-PV-Diesel Hybrid System
- Hybrid PV diesel system

1. Classification by Energy Source Combination

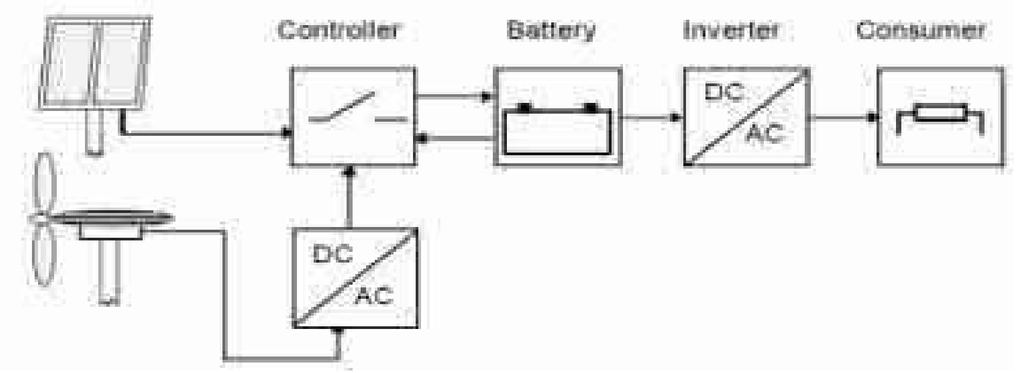
Hybrid System Type	Components Combined	Primary Goal / Application
Solar-Wind (PV-Wind)	Solar Photovoltaic (PV) Panels + Wind Turbine	**Intermittency Reduction:** Maximize energy capture by utilizing complementary resources (solar peaks in the day, wind often peaks at night/in winter).
Renewable-Storage	Solar/Wind + **Battery Energy Storage System (BESS)**	**Grid Stability & Dispatchability:** Store excess renewable energy to supply the load during peak demand periods or non-generation hours.
Renewable-Fossil Fuel (SWDH)	Solar/Wind/Battery + **Diesel/Gas Generator**	**Remote/Off-Grid Power:** Minimize expensive fuel use while maintaining 100% power reliability in remote locations.
Hydro-Solar	Hydroelectric Turbine + Solar PV	**Water Resource Management:** Solar generation during dry periods when water levels are low, saving water for higher-value hydro use or for when solar is unavailable.
Geothermal-Solar	Geothermal Power Plant + Solar PV	**Efficiency:** Use solar to meet variable power demands while the geothermal plant provides a stable, $24/7$ baseline load.

2. Classification by Electrical Connection (Wiring Architecture)

A. DC Coupled Hybrid System
Architecture: All DC sources (Solar PV, sometimes wind rectifiers) connect directly to a shared **DC Bus** (common wiring path). The battery also connects here.
Efficiency: Highest for charging batteries from solar because it avoids multiple DC-to-AC-to-DC conversions.
Best Used For: Small-to-medium **off-grid** systems where minimizing component count and maximizing battery charging efficiency are key.
B. AC Coupled Hybrid System
Architecture: All sources (Solar inverter, Wind inverter, Grid) connect to a shared **AC Bus**.
Flexibility: Highest for adding new AC-based sources (like diesel or grid connection) and retrofitting storage to existing systems.
Best Used For: Large-scale, grid-tied commercial or utility projects. Requires each source to have its own inverter.
C. AC/DC Hybrid Coupled System
Architecture: A complex system that uses both AC and DC buses, connected by a **bi-directional inverter/converter**.
Performance: Combines the **high efficiency** of DC coupling (for solar-to-battery) with the **high flexibility** of AC coupling (for grid and other generators).
Best Used For: Advanced Microgrids and large-scale, utility-level power plants that manage multiple generation technologies and battery storage simultaneously.

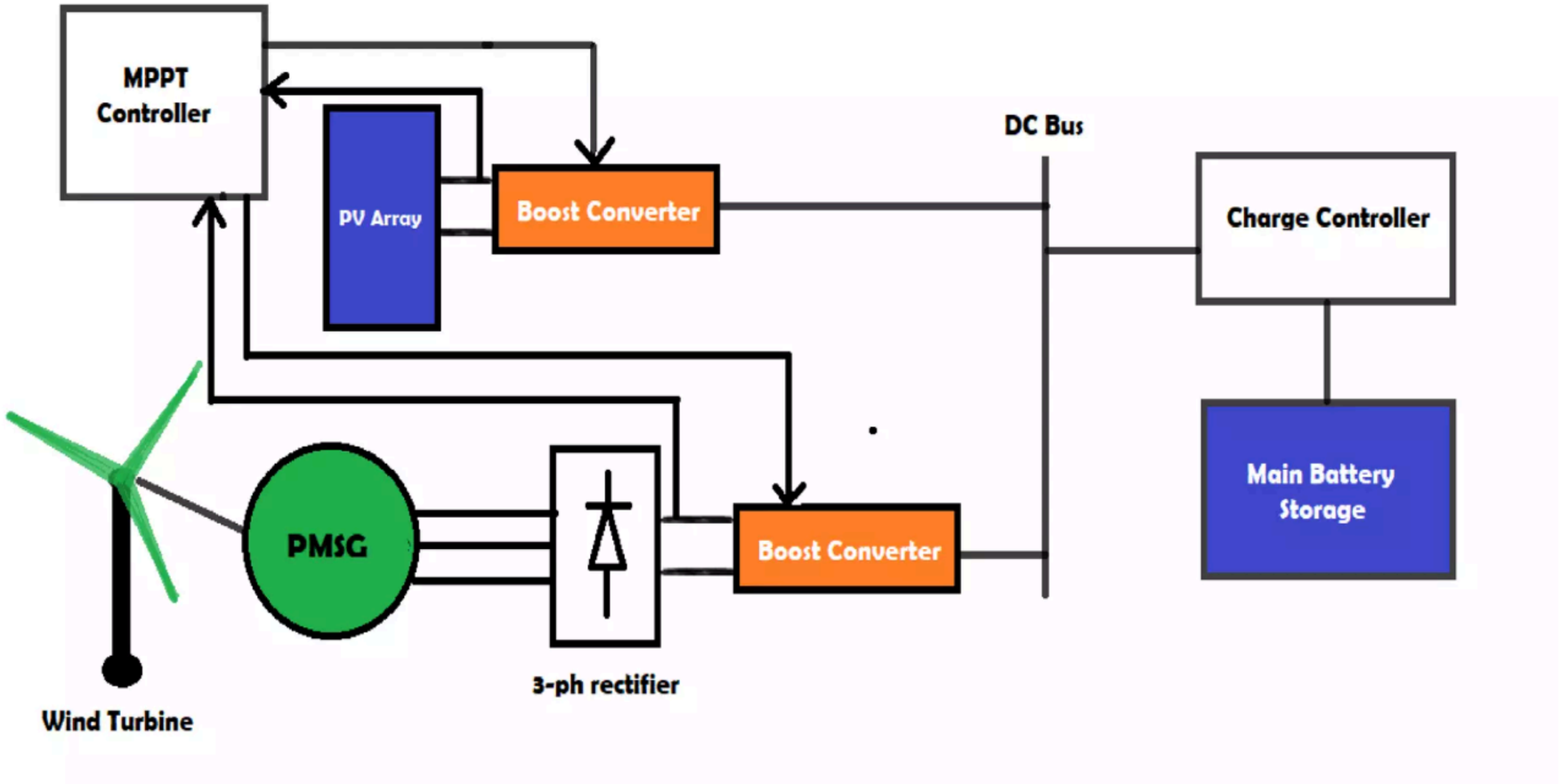
Wind/PV Hybrid System

- A typical hybrid energy system consists of solar and wind energy sources.
- The principle of an open loop hybrid system of this type is shown in Figure.
- The power produced by the wind generators is an AC voltage but have variable amplitude and frequency that can then be transformed into DC to charge the battery.
- The controller protects the battery from overcharging or deep discharging.
- As high voltages can be used to reduce system losses, an inverter is normally in traduced to transform the low DC voltage to an AC voltage of 230V of frequency 50 Hz.
- The hybrid PV-wind generator system has been designed to supply continuous power of 1.5 kW and should have the following capabilities:



- **Maximizes the electric power produced by the PV panels or by the wind generator by detecting and tracking the point of maximum power stores the electric energy in lead-acid batteries for a stable repeater operation.**
- **Control of the charge and discharge processes of the batteries protects wind generator from over speeding by connecting a dummy load to its output.**

Architecture of Solar–Wind Hybrid System



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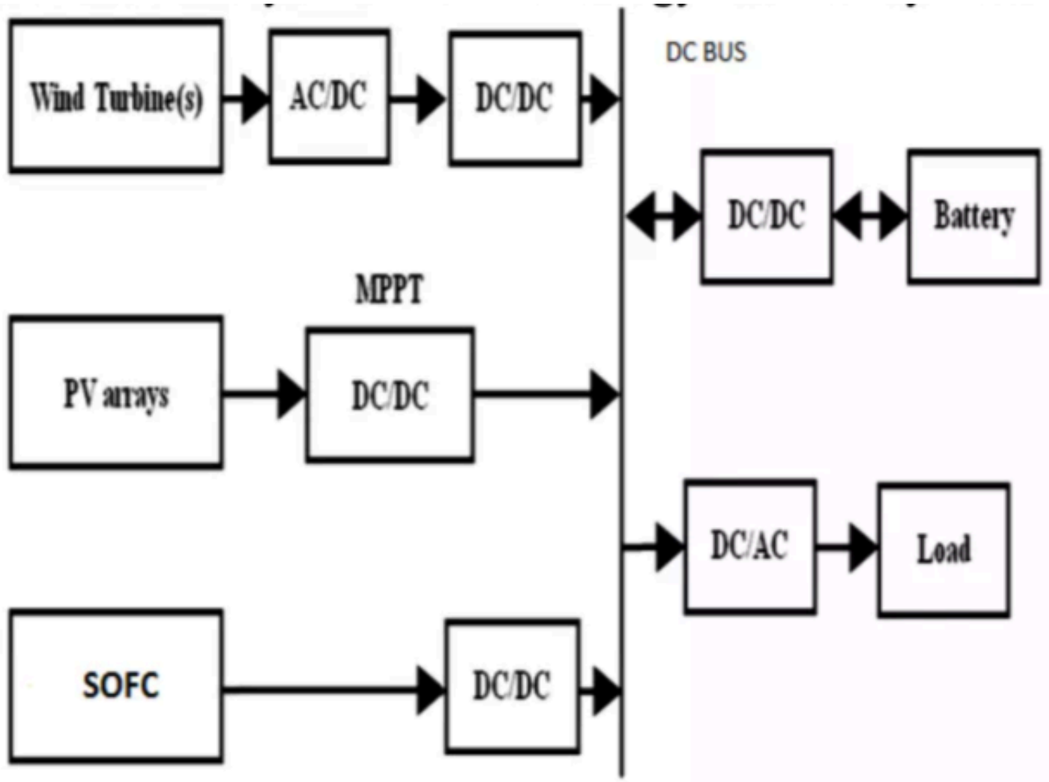


Fig.1.1 Schematic of a hybrid solar-wind-fuel cell system

Components and Functionality

1. Renewable Energy Sources

PV Array (Solar Panels): Converts sunlight directly into **DC (Direct Current)** electricity.

Wind Turbine: Rotational energy from the wind is captured and drives a **PMSG (Permanent Magnet Synchronous Generator)** to produce **AC (Alternating Current)** electricity, often with variable frequency and voltage.

2. Power Conditioning for Wind

PMSG (Permanent Magnet Synchronous Generator): The generator connected to the wind turbine, which produces three-phase AC power.

3-ph rectifier (Three-phase rectifier): Converts the variable-frequency AC output from the PMSG into **DC** electricity.

3. Power Maximization and Regulation

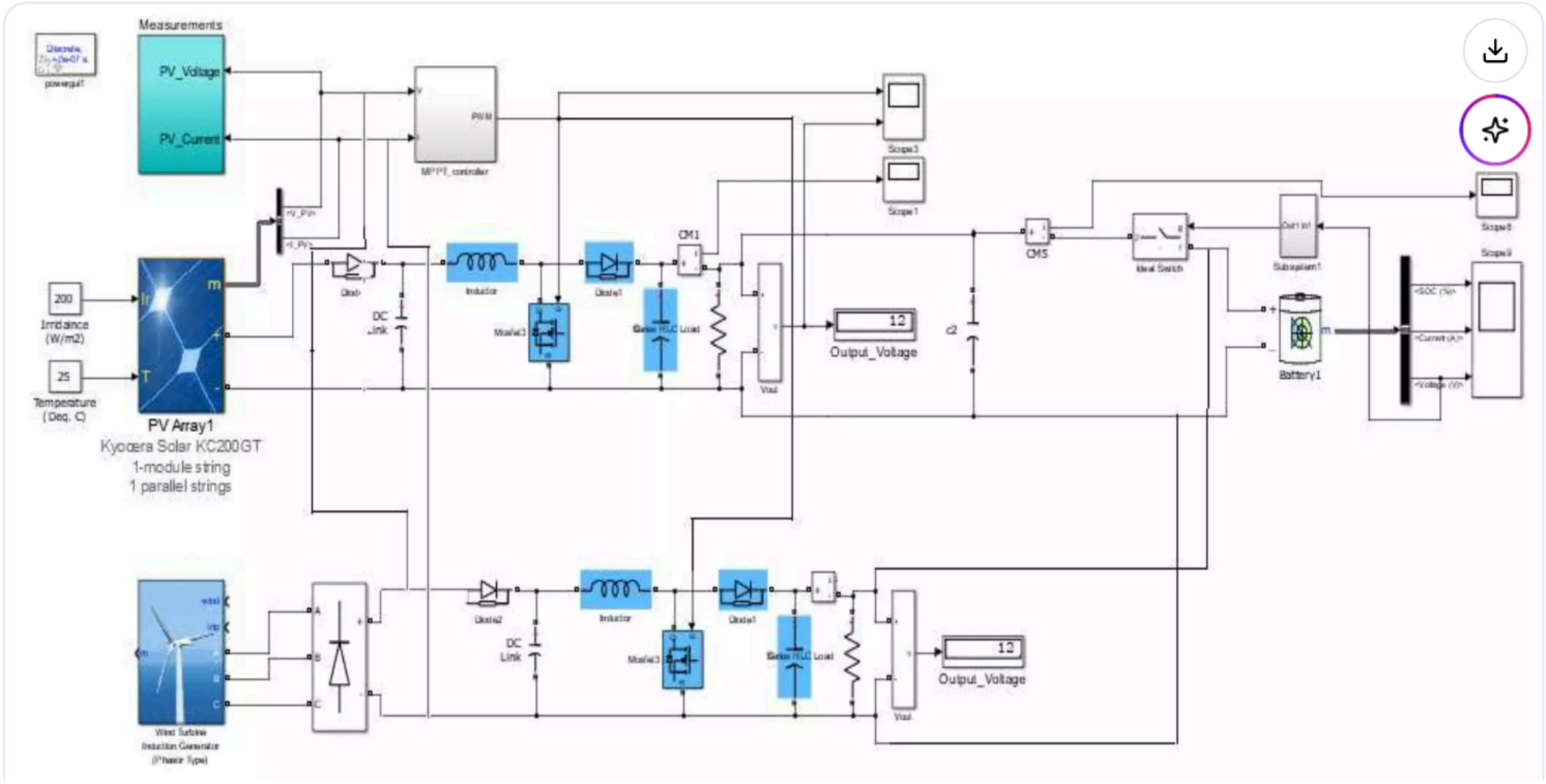
MPPT Controller (Maximum Power Point Tracking Controller): This is a crucial component for the **PV Array**. Its function is to continuously adjust the operating point (voltage and current) of the solar panels to extract the **maximum possible power** under varying conditions (sunlight intensity, temperature). It typically uses a feedback loop to sense the output of the PV array and adjust the duty cycle of the connected boost converter. The controller is also shown monitoring and potentially regulating the wind power conversion path as well.

Boost Converter (DC-DC Converter): Two separate boost converters are used, one for the solar path and one for the wind path. A **boost converter** is a type of DC-to-DC power converter that steps up (increases) the input voltage to a higher output voltage.

PV Path Boost Converter: Takes the DC output from the PV array (regulated by the MPPT controller) and steps up its voltage to match the voltage level of the **DC Bus**.

Wind Path Boost Converter: Takes the rectified DC output from the wind system and steps up its voltage to match the **DC Bus** voltage.

- **4. System Bus and Storage**
- **DC Bus**: This is a common point where power from both the solar and wind sources is aggregated. All components operating on DC connect to this bus.
- **Charge Controller**: This component is essential for **battery health and safety**. It regulates the voltage and current flowing into the **Main Battery Storage** from the DC Bus. Its primary functions are:
  - **Overcharge Protection**: Prevents the battery from being overcharged, which can damage the battery.
  - **Over-discharge Protection**: (Often integrated or handled by an inverter/load management system, though not explicitly shown) Prevents the battery from being completely drained.
- **Main Battery Storage**: Stores the electrical energy generated by the PV array and the wind turbine for later use (e.g., at night or during low wind/sun periods).


Measurements
PV_Voltage
PV_Current
MPPT_controller
PWM
Scope3
Scope1
Scope8
Scope9
CM1
CM5
Ideal Switch
Subsystem1
Battery1
200
Irradiance (W/m2)
25
Temperature (Deg. C)
Ir
T
m
+
-
PV Array1
Kyocera Solar KC200GT
1-module string
1 parallel strings
DC Link
Inductor
Diode
Diode1
Diode2
Mosfet3
Vout
12
Output_Voltage
C2
Wind Turbine Induction Generator (Phasor Type)
A
B
C

HYBRID RENEWABLE ENERGY SYSTEMS

- Hybrid renewable energy system (HRES) combines two or more renewable energy sources like wind turbine and solar system.
- PV modules produce outputs that are determined mainly by the level of incident radiation.
- As the light intensity increases, photocurrent will be increased and the open-circuit voltage will be reduced.
- The efficiency of any photovoltaic cell decreases with the increasing temperature which is non-uniformly distributed across the cell.
- The solar output power can be smoothed by the distribution of solar power in different geographical areas

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- The solar output power can be smoothed by the distribution of solar power in different geographical areas.
- Wind turbines (WTs) are classified into two types: horizontal-axis WT (HAWT) and vertical-axis WT (VAWT).
- The highest achievable extraction of power by a WT is 59% of the total theoretical wind power.

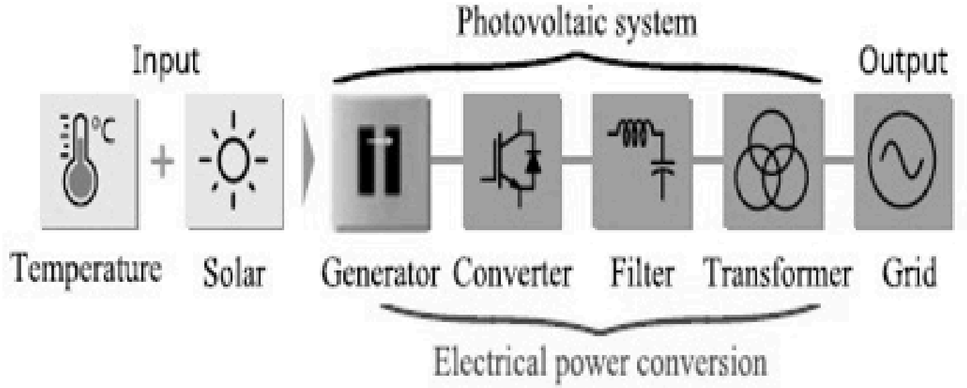

Fig 1.Architecture of Solar PV System.

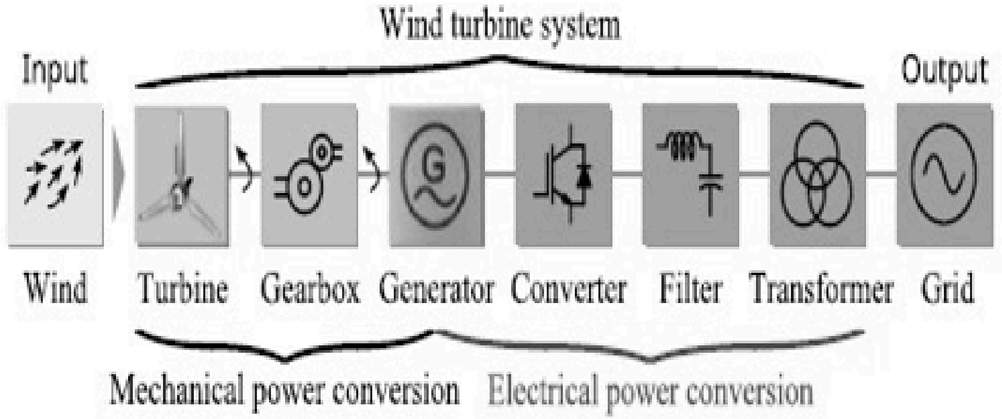

Fig 2.Architecture of Wind Power System.

HYBRID SOLAR PV-WIND SYSTEMS

Hybrid solar PV and wind generation system become very attractive solution in particular for grid connected applications. Combining the two sources of solar and wind can provide better reliability and their hybrid system becomes more economical to run since the weakness of one system can be complemented by the strength of the other one.

The integration of hybrid solar and wind power systems into the grid can further help in improving the overall economy and reliability of renewable power generation to supply its load.

Similarly, the integration of hybrid solar and wind power in a stand-alone system can reduce the size of energy storage needed to supply continuous power.

- Hybrid solar-wind systems can be classified into two types:
- grid-connected and stand-alone.
- hybrid grid-connected and stand-alone solar PV and wind energies faces various challenges.
- Due to the nature of hybrid solar PV and wind energies, optimization techniques can play a good role in utilizing them efficiently.
- Graphic construction methods, linear programming, and probabilistic approach are few examples of optimization techniques that have been developed for techno-economically optimum hybrid renewable energy system for both types.

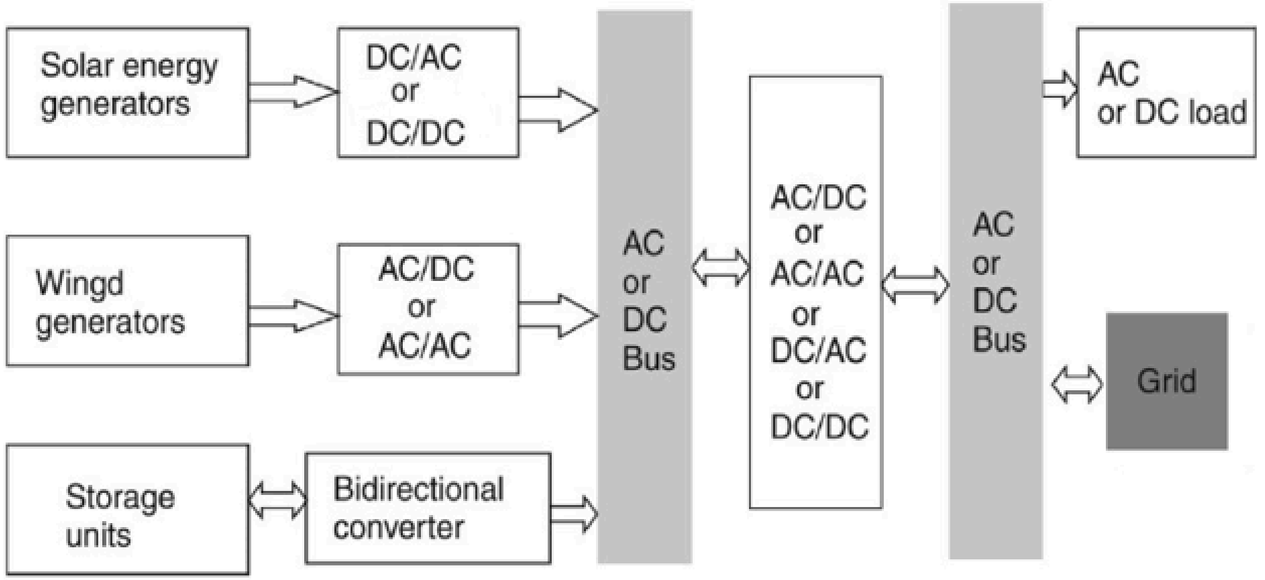

Fig 3. Basic component of solar–wind hybrid renewable energy system.

- **Advantages Of Hybrid Systems**
  - A hybrid energy system can make use of the complementary nature of various sources, which increases the overall efficiency of the system and improve its performance (power quality and reliability).
  - For instance, combined heat and power operation, e.g. MT and FC, increases their overall efficiency [3]&[4-6]or the response of an energy source with slower dynamic response (e.g. wind or FC) can be enhanced by the addition of a storage device with faster dynamics to meet different types of load requirements
  - Lower emissions: hybrid energy systems can be designed to maximize the use of renewable resources, resulting in a system with lower emissions.
  - Acceptable cost: hybrid energy systems can be designed to achieve desired attributes at the lowest acceptable cost, which is the key to market acceptance.
- They provide flexibility in terms of the effective utilization of the renewable sources

ISSUES WITH HYBRID RENEWABLE ENERGY SYSTEMS

1. Though a hybrid system has a bundle of advantages, there are some issues and problems related to hybrid systems. Most of hybrid systems require storage devices which batteries are mostly used. These batteries require continues monitoring and increase the cost, as the batteries life is limited to a few years. It is reported that the battery lifetime should increase to around years for the economic use in hybrid systems
2. Due to dependence of renewable sources involved in the hybrid system on weather results in the load sharing between the different sources employed for power generation, the optimum power dispatch, and the determination of cost per unit generation are not easy.
3. The reliability of power can be ensured by incorporating weather independent sources like diesel generator or fuel cell.
4. The stability issue. As the power generation from different sources of a hybrid system is comparable, a sudden change in the output power from any of the sources or a sudden change in the load can affect the system stability significantly.
5. Individual sources of the hybrid systems have to be operated at a point that gives the most efficient generation. In fact, this may not be occur due to that the load sharing is often not linked to the capacity or ratings of the sources. Several factors decide load sharing like reliability of the source, economy of use, switching require between the sources, availability of fuel etc. Therefore, it is desired to evaluate the schemes to increase the efficiency to as high level as possible.

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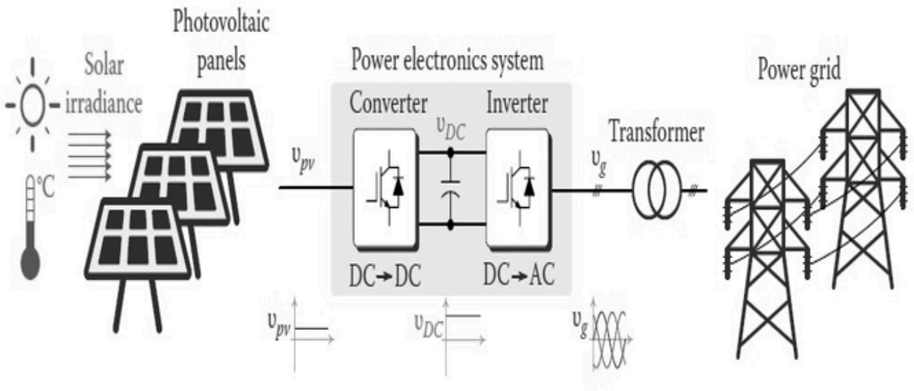
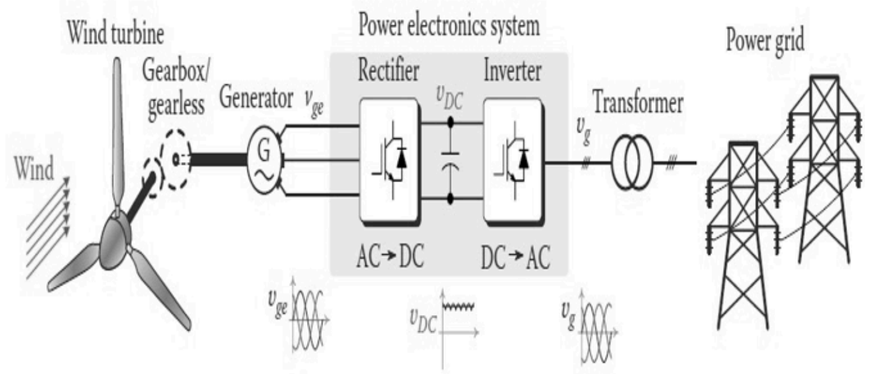
GRID CONNECTED SYSTEMS

- Different grid connected configurations are shown in figure 4. The choice of the layout for particular location depends upon geographical, economical, and technical factors
- Grid connected PV energy conversion system shown in Fig.4(a). The DC energy source from solar PV system is passed through power electronics system and converted DC into AC before being delivered to the main AC bus bar. An inverter, main, takes the responsibility of feeding the ac grid from this dc power.
- Grid connected wind turbine energy conversion system shown in Fig.4(b), The AC Power from wind turbine passed through appropriate power electronic devices, before being connected to the grid. Here conversion takes place from AC to DC and DC to AC. finally connected to AC Power Grid.

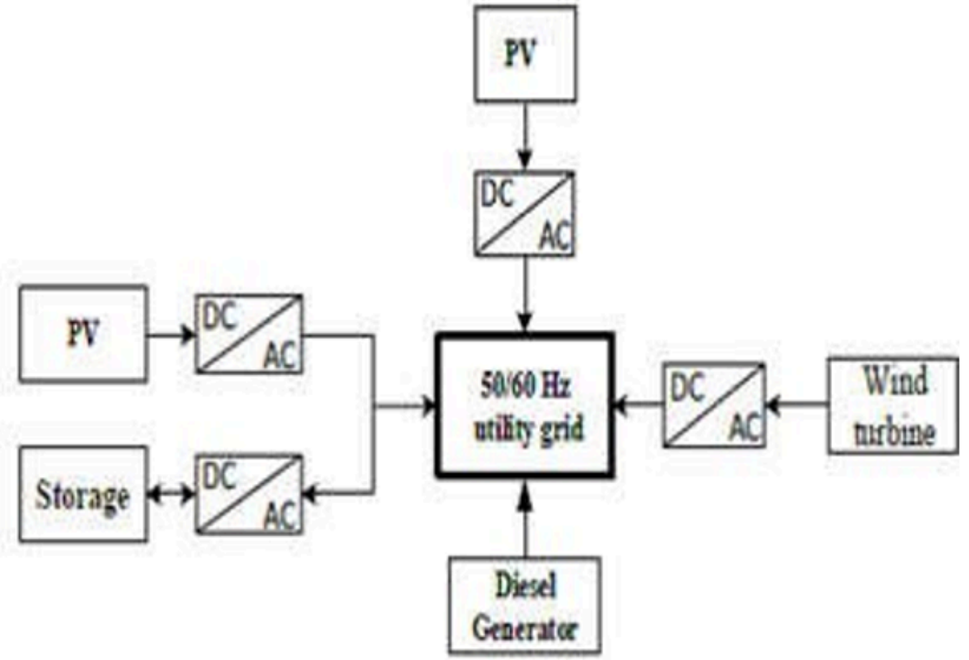


a. Grid Connected PV energy conversion system



b. Grid Connected Wind energy conversion system

- Grid connected PV-wind energy conversion system shown in Fig. 4(c), the power sources do not need to be installed close to each other, and they do not need to be connected to one main bus. The sources are distributed in different geographical locations and connected to the grid separately



c. Grid Connected distributed AC Bus Solar-Wind turbine energy conversion system

Fig 4. Different grid connected configurations

- **ISSUES, CHALLENGES AND POSSIBLE SOLUTIONS**

Renewable energy sources are intermittent in nature hence it is therefore a challenging task to integrate renewable energy resources into the power grid. Some of
the challenges and issues associated with the grid integration of various renewable energy sources particularly solar photovoltaic and wind energy conversion systems[19]. Further these challenges are broadly classified into technical and non-technical and described below.

Technical Issues: The following are the technical issues are described as

Power quality:

Harmonics,
Frequency and voltage fluctuation.

Power fluctuation:

Small time power fluctuations,
Long time or seasonal power fluctuations.

Storage,

Protection issues

Optimal placement of RES,

Islanding

Apart from aforesaid technical issues some of the nontechnical issues are also presented in this paper.

Non- Technical Issues

Lack of technical skilled man power
Less availability of transmission line to accommodate RES
RES technologies are excluded from the competition by giving them priority to dispatch which discourage the installation of new power plant for reserve purpose.

Challenges	Solutions
Voltage fluctuation due to variations in wind speed and irregular solar radiation	Series and shunt active power filters. Power compensators such as fixed/switched capacitor or static compensator. Less sensitive customer's equipment to power disturbance/ voltage distortions and utilities line conditioning systems
Frequency fluctuation for sudden changes in active power by loads	PWM inverter controller for regulating three-phase local AC bus voltage and frequency in a microgrid.
Harmonicsby power electronics devices & nonlinear	PWM switching converter and appropriate filters.
Intermittent energy's impacts on network security	Accurate statistical forecasting and scheduling systems. Regression analysis approaches and algorithms for forecasting weather pattern, solar radiation and wind speed. Increase or decrease dispatchable generation by system operator to deal with any deficit/surplus in renewable power generation. Advanced fast response control facilities such as Automatic Generation Control and Flexible AC Transmission System.
Synchronization	The most popular grid synchronization technique is based on phase- locked loop. Other techniques for synchronization include detecting the zero crossing of the grid voltages or using combinations of filters coupled with a non-linear transformation.

1.**Converters losses:** The loss involved with electrical power converters are actually reduced to some sufficient stage; on the other hand, it should be guaranteed that there's minimal quantity of electrical power reduction within these converters.

2.**Life-cycle:**The life-cycle associated with storage units, such as batteries along with UCs, should be improved upon by means of innovative systems

3.Disposal of storage equipment: The convenience connected with storage space products, like power packs and also other storages, is among the significant problems for producers

4.**Renewable energy sources:** Photovoltaic and other renewable energy options require break-through systems for removing much more quantity of use full strength. The poor effectiveness involving a solar PV is often an important barrier inside stimulating its use

5.**Control unit:** With the entire supplement associated with unique turbines inside developing a hybrid renewable energy system raises the strain about power alteration devices. Any possible hybrid renewable energy system requires the feasible associated with right keeping track of design system that will record important info to its productive functioning. Each time almost any mismatch inside the power generation in addition to desire exists the system may open the circuit breakers with regard to much better safety in addition to functioning

6.**Grid control:** For controlling different generators which are linked to the hybrid renewable energy system, to the function of saving power and carry through the load demand a development of a small grid system required

7.**Manufacturing cost:** This making price tag of renewable energy sources needs a significant lessening considering that the higher capital price tag causes an elevated payback time. cost lessening will supply a motivation on the marketplace to be able to apply like devices

8.**Load management:** The particular renewable resources tend to be independent of the load variations and as such suitable energy management should be designed, in order that the prolonged existence on the hybrid renewable energy system can be increased. Big deviation inside the load could even result in a whole system fall

9.**Stability:** Hybrid renewable energy system depends on weather conditions so that theirs is needed to carry out transient analysis of the system for varying constraint like solar radiation, wind velocity, load demand

10.**Government support :**For reducing the cost of components, production costs of generation and wide deployment of Hybrid renewable energy system network, it is essential to give subsidy on renewable energy goods from central to the state government .