## UNIT-VI :NETWORK INTEGRATION ISSUES
## INDIAN WIND GRID CODE

### 1. Introduction

India today stands fifth in the world with an installed capacity of 10242.5 MW of wind power (as on March 2009) which constitutes 7% of the total 1,52,000 MW connected to the grid. This has grown from 3.5% in 2004 to the present capacity it is today.

Wind turbines are installed in areas with sufficient wind power density (> 200 W/ sq.m at 50 m hub height level) with provision to connect to the grid. Areas with good wind power density are not necessarily places with a strong grid, as they are mainly concentrated in rural areas away from locations with major generating stations. However, in the initial days due to the low penetration of wind energy in the grid, impacts on the overall power system were limited to local effects. Local impacts like voltage fluctuations, flicker, reactive power absorption were observed at the point of connection to the grid. With the exception of penalties by state electricity boards for VAR drawl from the grid, there were no technical regulations to govern the connection of the wind turbines to the grid. However, with the increasing penetration of wind turbines, as high as 42 % in terms of installed capacity in states like Tamil Nadu, the need was felt to establish a standard operating practice for the wind turbines . This has lead to the draft Grid code for wind turbines to establish the guidelines specific to wind turbines.

### 2. Grid behaviour of wind turbines

Important aspects which determine the grid behaviour of wind turbines are that majority of these are fixed speed turbines consisting of induction generators. This is unlike the conventional generators which are synchronous generators / alternators and have characteristics different from the induction generators. Machines with induction generators need capacitor banks for VAR support, otherwise reactive power will be drawn from the grid. The drawl of reactive power affects the voltage profile at the point of connection to the grid. However, wind turbines of variable type, which use wound rotor or permanent magnet synchronous generators, do not need a reactive power support. They may have to deal with issues like harmonics generated by the power converters, which has to be kept under control.

Another major characteristic is the behaviour of the wind turbine during system faults/ disturbances. The wind turbines are designed to disconnect from the grid during system faults, when the voltage at the point of connection drops beyond a certain percentage of the nominal value If wind turbines are to remain connected to the grid during system fault, a source of reactive power must be able to sustain the wind turbine in the generation mode during such fault conditions.

The variable nature of wind, which is talked of as one of the drawbacks of wind energy is also an important grid aspect. Wind generation cannot be scheduled due to its unpredictability.

Moreover, different manufacturers follow different operating standards and the system behaviour in the absence of any grid code will be unpredictable.

### 3. World scenario

Internationally the countries who are leaders in terms of installations have framed grid codes for wind. USA, Germany, Spain, Denmark, China, Nordic Countries Canada, Ireland have enforced their grid codes. Each of these grid codes have a common framework dealing with issues specific to wind, however the regulations take into the nature of the grid, installed capacity, penetration of wind, high wind potential zones etc. For instance, the Danish grid code has been formulated keeping in mind the high penetration of wind power in the country.

The grid codes for wind, in general deal with the following issues:

- Active power control
- Frequency
- Voltage and reactive power issues
- Fault ride through capability
- Protection
- Power quality issues like flicker, harmonics etc.

### 4. Grid code requirements

***Active power control***

This is the ability of the wind turbine generators to regulate the active power output of the wind turbine according to system requirements. Active power control of wind turbines is to ensure a stable frequency in the system, to prevent overloading of transmission lines, to avoid large voltage steps and in-rush currents during start up and shut down of wind turbines. In a wind turbine, the power output is a function of the wind speed and the power fed into the grid by the turbine is irrespective of the frequency of the grid. However, with this feature the active power controller will take into account not only the wind speed, but also the requirements of the grid. The wind turbines will also have to regulate the in rush currents during start up.

During a fault, if the turbine were to stay on line, the active power output has to be reduced in a controlled manner to prevent tripping of the generator. All the same, the active power output should be brought back to the pre fault value after the fault is cleared.
The rate at which the power is ramped up after a system fault or during start up should not cause significant power surges.

***Frequency requirements***

System frequency is a major indicator of the power balance in the system. A decrease in generation vis-a-vis the demand causes the frequency to drop below the nominal frequency and vice versa. In India, the frequency varies from 48.5- 51.5 Hz due to the power imbalance. This imbalance can be mitigated by primary control and secondary control of conventional synchronous generators. During an increase of load, the energy stored in these synchronous generators can balance the power for 1- 30 s, this is the primary control. The secondary control, employed with in a time span of 10 – 15 min. is by governor action which increases the input to the generator and stabilizes the system frequency.

Low penetration of wind turbines does not affect the system frequency. High penetration of wind turbines can have a significant impact on the grid. Even so, the wind turbines may not be able to contribute to primary control. The power output of the wind turbine can be regulated during high frequency, if need be. However, during low frequencies the output of the wind turbine cannot be controlled to contribute more power to the grid.

***Voltage and reactive power issues***

Wind turbines with induction generators need reactive power support. Capacitor banks are the preferred method of reactive power compensation in wind farms, though dynamic VAR support devices like the STATCOM are available. If not properly compensated reactive power drawl from the system can cause increased losses, overheating and de- rating of the lines. Doubly fed induction generators and synchronous generator based wind turbines do not have any constraints with respect to reactive power. Thus, the behavior of different types of wind turbines can be standardized by means of the grid code.

***Fault / low voltage ride through***

This refers to the ability of the wind turbine to remain connected to the grid without tripping from the grid for a specified period of time during a voltage drop at the point of connection. The period of fault ride through depends on the magnitude of voltage drop at the Point of Common Coupling (PCC) during the fault and the time taken by the grid system to recover to the normal state.

During system disturbances, if generators of large generating capacity connected to the grid continue their operation, this aids the system in returning to normal operation. On the other hand, disconnection of such a generator would further aggravate the disturbance and may lead to a system collapse. If the fault causes loss of a conventional generating unit, the system would need sufficient spinning reserve to cover the loss of the generator. Hence the need for fault ride through capability.

During a fault that causes a voltage drop at the wind turbine terminals, the reactive power demand of induction generators increases. Unless a reactive power support is available at the generator terminals, the reactive power will be drawn from the grid. This will reduce the thermal capacity of the conductors connecting the turbine to the grid, to transfer active power and cause further drop in voltage at the point of common coupling.

***Wind farm protection***

In case of large wind farms connected to the grid, wind turbines are required to remain connected to the grid within specified voltage and frequency limits. High short circuit currents, under voltages and over voltages during and after the fault can damage the wind turbine. The relay protection system of the wind turbine should take in to account:

- Normal operation of the system and support to network during and after the fault.
- Secure wind farms from damage originating from faults in the network.

Wind turbines are required to be equipped with under frequency and over frequency protection, differential protection of the generator transformer, and back up protection. The protection system requirements have been mentioned in some of the grid codes, while others have not exclusively mentioned about wind farm and system protection.
Grid codes require that wherever low voltage ride through schemes and frequency protection schemes are applied on the wind turbines, the settings should be done in proper coordination with the transmission system protection relaying.

***Data requirements***

Monitoring of large wind farms to obtain up-to-date information on the real time status of the wind farm is essential. This will help in tracking the dynamic changes that the wind farms will undergo. The system operator can change the set point according to the operating conditions.

**Power quality issues like flicker, harmonics etc**

Flicker is defined as the visual fluctuations in the light intensity as a result of voltage fluctuations and is caused by wind turbines, both during continuous operations and switching operations. Human eye is most sensitive to frequencies in the range 1- 10 Hz. The flicker from wind turbines is mainly caused by the effect of tower shadow, which lies in the range of 1-2 Hz. Power fluctuations due to wind speed fluctuations lie in the frequency range of < 0.1 Hz and hence are less critical to flicker. Flicker in variable speed turbines is found to be lower than that of fixed speed wind turbines due to smoothening of the power fluctuations.

During switching operation, the generator cuts in and the large in-rush current of the generator is limited by the soft starter. A few seconds after the generator is connected, capacitors are switched in for reactive power compensation. These power fluctuations, both active and reactive power, during switching operation cause flicker. However, for variable speed turbines such in rush currents do not arise.

Harmonics are generated by variable speed turbines with power converters, like doubly fed generator and full variable speed wind turbine. Induction generator based wind turbines which are directly connected to the grid, do not have harmonic issues.

The grid codes specify limits for flicker and harmonics due to their impact on the grid. Flicker is a main concern for fixed speed wind turbines connected to weak grids. As regards, harmonics, many grid codes do not speak of limits for harmonics in their grid codes. IEC 61400-21 recommends measurement of harmonic emissions only for variable speed turbines. IEEE STD- 519-1992 is followed by many countries for grid integration of turbines.

Voltage imbalance is another power quality issue which can affect the performance of induction generators. The effect is severe during fault conditions. Most of the grid codes impose the same voltage requirements for unbalance as for conventional generators.

## 5. Indian Wind Grid Code

The draft Indian Wind grid code addresses issues related to the wind energy plant as an addendum to the existing Indian Electricity Grid Code (IEGC).

The IEGC lays down the rules, guidelines and the standards to be followed by the various agencies and participants in the system to plan, develop and operate the power system in an efficient, reliable, economic and secure manner. The IEGC broadly covers the planning code for inter state transmission, the connection conditions (minimum technical and design criteria which are complied with by the transmission utility), operating code for the regional grid and scheduling and dispatch code for conventional generators. The IEGC would be suitably amended to incorporate the criteria to be complied with for wind turbine generators and any additional features would be a part of a supplement to the IEGC.

The following are proposed in the draft Indian Wind Grid Code:

***Planning Code for transmission systems evacuating wind power***

Wind power evacuation shall feature as a part and parcel of the overall grid planning.

The transmission utility / transmission system operator shall consider both short term and long term expected wind generation in the region. The planning criterion should consider the following scenarios:

i. System peak load with high wind generation
ii. System light load with high wind generation
iii. Local light load with high wind generation

The high wind generation shall be classified as a percentage of the overall wind farm capacity, based on the voltage level to which it is connected. For instance, wind farms connected below 66 kV levels may reach their peak capacity during the windy months as wind turbines see the same wind over a smaller geographical spread; this must be taken care of during the transmission planning.

The N-1 contingency criteria may be adapted for planning of transmission lines wind farms connected above 220 kV or of capacity 100 MW and above at 220 kV levels. The underlying idea is that N-1 contingency planning does not make economic sense for smaller wind farms and loss of generation of small wind farms does not have a significant impact on the grid.

The Wind power addition plan for every five years issued by the Ministry of New and Renewable Energy shall be considered for planning of transmission lines. Wind farm owner shall also give the requisite planning data to the transmission utility.

***Connection code for wind farms***

Wind farms shall maintain certain minimum technical standards for grid connection with respect to the following:

***Transmission voltage range***

The wind farms must be capable of normal operation for the following voltage ranges. The limits are taken from the standards set for conventional generators in the IEGC / state grid codes:

*Table 1: Voltage withstand limits for wind farms*

| Voltage (kV) | | | |
|---|---|---|---|
| Nominal | % Limit of variation | Maximum | Minimum |
| 400 | +5% to -10% | 420 | 360 |
| 220 | +11% to -9% | 245 | 200 |
| 132 | +10% to -9% | 145 | 120 |
| 110 | +10% to -12.5% | 121 | 96.25 |
| 66 | +10% to -9% | 72.5 | 60 |
| 33 | +5% to -10% | 34.65 | 29.7 |

***Voltage unbalance***

Voltage unbalance, defined as the ratio of the deviation between the highest and lowest line voltage to the average of the three line voltages, can cause negative sequence current to flow in the rotor of the wind turbine. As per the Grid Standard (CEA) followed, the following limits have been specified:

*Table 2: Voltage unbalance limits for wind farms*

| Voltage level (kV) | Unbalance (%) |
|---|---|
| 400 | 1.5 |
| 220 | 2 |
| <220 | 3 |

***Reactive power capability***

The wind farms shall be able to maintain a power factor of 0.95 lagging to 0.95 leading at the grid connection point. Wind farms at higher voltage levels (66 kV) shall maintain the following characteristics (refer figure 1):

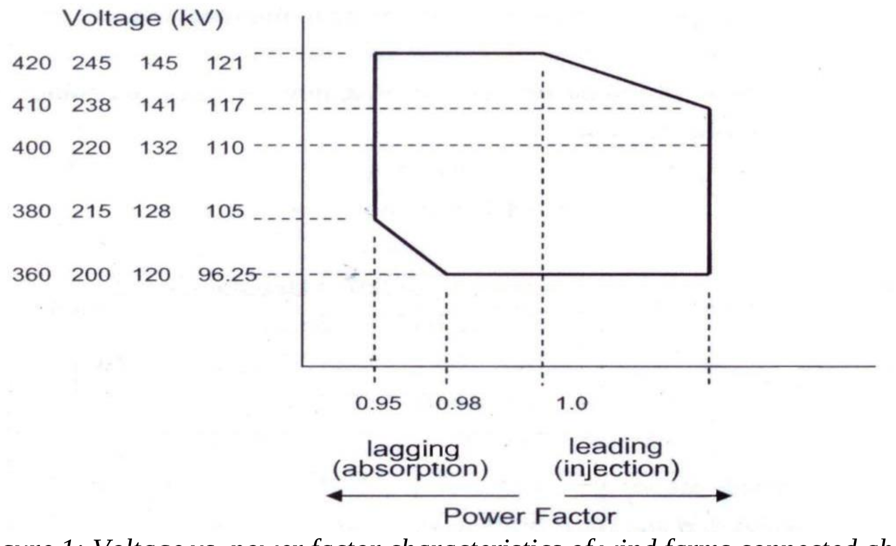



*Figure 1: Voltage vs. power factor characteristics of wind farms connected above 66 kV*

At system voltages higher than nominal, the requirement is a lagging power factor, whereas at lower voltages, the wind farm can operate at leading power factor injecting reactive power to the grid.

***Frequency tolerance range***

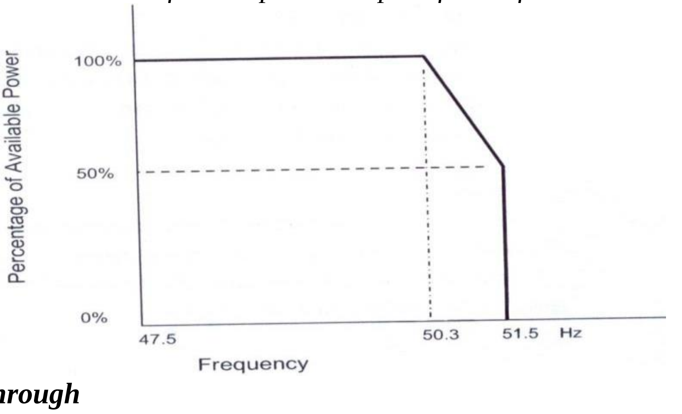
The frequency tolerance range for wind farms is 47.5 – 51.5 Hz. Beyond this, the frequency tolerance shall be manufacturer specific. Wind farms shall be able to withstand change in frequency up to 0.5 Hz/sec.

*Active power control*

For wind farms at high voltage levels (66 kV), active power control of the wind farm output shall be possible on system operator's request.

The active power response of wind farms to frequency should be such that the power injection into the grid is limited at frequencies above nominal.

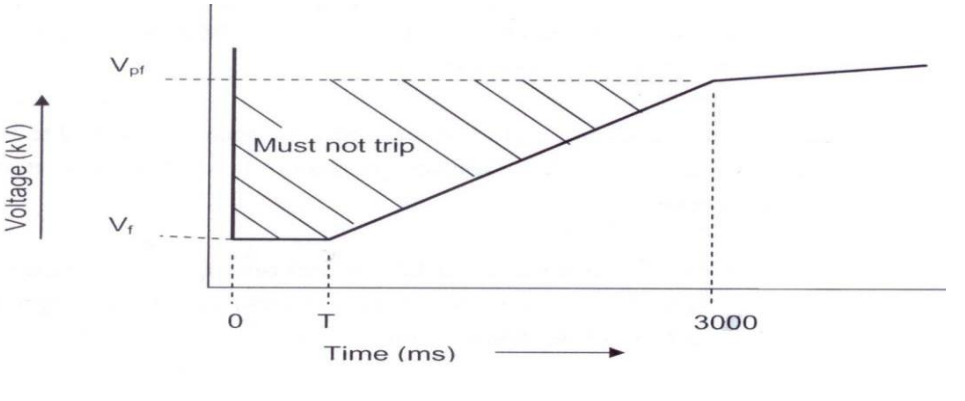
*Figure 2: Variation of active power output of wind farms with respect to frequency*




***Low voltage ride through***

Wind farms connected at 66 kV and above shall have low voltage ride through capabilities. The operating characteristics are depicted below (refer figure 3):

*Figure 3: Fault ride through characteristics*




*$V_f$ : 15% of nominal system voltage*

*$V_{pf}$ : Minimum Voltage for normal operation of the wind turbine*

*Table 3: Fault clearing time and voltage limits*

| Nominal system voltage (kV) | Fault clearing time, T(ms) | $V_{pf}$ (kV) | $V_f$ (kV) |
|---|---|---|---|
| 400 | 100 | 360 | 60.0 |
| 220 | 160 | 200 | 33.0 |
| 132 | 160 | 120 | 19.8 |
| 110 | 160 | 96.25 | 16.5 |
| 66 | 300 | 60 | 9.9 |

The fault ride through requirement brings the wind farms at par with the conventional generators, which have this feature. The fault clearing times are as specified in the IEGC / state grid codes. However, the timeline for implementing the same shall be based on the penetration levels of wind farms, the additional cost involved and usefulness in terms of grid management strategies.

***Protection schemes for wind farm protection:***

The minimum requirement with respect to wind farm protection are:

i) under/over voltage protection
ii) under/over frequency protection
iii) over current and earth fault protection
iv) load unbalance (negative sequence) protection
v) differential protection for the grid connecting transformer
vi) capacitor bank protection
vii) tele-protection channels (for use with distance protection) between the grid connection point circuit breaker and user connection point circuit breaker.

***Operating code for wind farms***

The wind farm shall adhere to the operating code for safety and reliable operation of the grid.

*Voltage at the grid connection point*

*Table 4: Operating voltage limits for wind farms*

| Voltage (kV) | | | |
|---|---|---|---|
| Nominal | % Limit of variation | Maximum | Minimum |
| 400 | +5% to -10% | 420 | 360 |
| 220 | +11% to -9% | 245 | 200 |
| 132 | +10% to -9% | 145 | 120 |
| 110 | +10% to -12.5% | 121 | 96.25 |
| 66 | +10% to -9% | 72.5 | 60 |
| 33 | +5% to -10% | 34.65 | 29.7 |

***Frequency of operation for wind farms***

The operation of the wind turbine shall be as shown in figure 2. Wind turbine shall not be started above 51.5 Hz.

***Reactive power and voltage control***

The requirement with respect to reactive power and voltage control will be as mentioned in the IEGC.

i) VAR drawl from the grid at voltages below 97 % of nominal will be penalized.
ii) VAR injection into the grid at voltages below 97 % of nominal will be given incentive.
iii) VAR drawl from the grid at voltages above 103 % of nominal will be given incentives.
iv) VAR injection into the grid at voltages above 103 % of nominal will be penalized.

As such VAR drawal from the grid when voltage is below 95 % of nominal and injection into the grid when voltage is 105 % above nominal shall be minimize by the wind farm operator. The charges for VAR exchange shall be specified by the Central / State Electricity regulatory Commissions.

***Ramp rate limits***

Ramp rate limits aims at regulating the active power generated from the WTG and minimizing the sudden variations in generated power due to variations in the wind.
The ramp rate limits specified for wind farms of 50 MW and above are:

*Table 5: Ramp rate limits for wind farms*

| **Wind Farm Installed Capacity (MW)** | **10 min Maximum Ramp(MW)** | **1 min Maximum Ramp(MW)** |
|---|---|---|
| 50-150 | Installed Capacity/1.5 | Installed Capacity/5 |
| >150 | 100 | 30 |

The ramping down of wind generators would be as per the request of the system operator.

***Power Quality***

The assessment of power quality of wind farms is done as per the requirement of IEC 61400-21: Wind Turbine Generator Systems, Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines”

As regards voltage flicker limits, the IEC 61000-3-7 shall be followed. IEC 61000-4-15 gives the guidelines on measurement of flicker.
The harmonic content will be governed by Total harmonic distortion of voltage, $V_{THD}$

$$V_{THD} = \sqrt{\sum_{n=2}^{n=50} \frac{V_n^2}{V_1^2}} \times 100$$

Where Vn: n$^{th}$ harmonic of voltage
V1: fundamental frequency (50 Hz) voltage

The harmonic content of the supply current is given by:

$$I_{THD} = \sqrt{\sum \frac{I_n^2}{I_1^2}} \times 100$$

Where In: nth harmonic of current
I1: fundamental frequency (50 Hz) current
The limits for the harmonic contents are as follows:

*Table 6: Voltage harmonic limits*

| System Voltage (kV) | Total Harmonic Distortion (%) | Individual Harmonic of any Particular frequency (%) |
|---|---|---|
| 765 | 1.5 | 1.0 |
| 400 | 2.0 | 1.5 |
| 220 | 2.5 | 2.0 |
| 132 | 3.0 | 2.0 |

*Table 7: Current harmonic limits*

| Voltage level | <69 kV | >69 kV |
|---|---|---|
| ITHD | 5.0 | 2.5 |

***Operation during transmission congestion***

During network congestion, wind farms shall operate as per instructions of system operator. Wind shall be backed down as a last resort and shall be considered like overflowing reservoir in Merit Order Dispatch

The demand estimation for operational purposes and demand management shall be as described in the IEGC / state grid codes. Wind energy forecasting shall be considered for demand estimation. The demand management shall take into account variable nature of wind.

***Forecasting***

Wind energy forecasting will become a necessity with increase in penetration of wind power. Scheduling of other generating plants can be carried out based on the forecast data for wind.

Centralised forecasting facility will be a requisite in an area with aggregated capacity of 200 MW and above. The forecast will be for the following time intervals:

i) Day ahead forecast**:** Wind power forecast with an interval of one hour for the next 24 hours for the aggregate wind farms. This will help in assessing the probable wind energy that can be scheduled for the next day.

ii) Hourly forecast: Wind power forecast with a frequency of one hour and interval of 30 minutes for the next 3 hours for the aggregate wind farms. This helps in minimizing the forecasting error that can occur in the day ahead forecasting.

Scheduling of other generators shall consider available wind generation for the duration. The spinning reserve shall be necessary to account for sudden loss of wind generation, based on the wind power forecast information.

As mentioned earlier, the forecasting will be implemented after considering factors like the penetration level of wind farms, cost and tariff.

The Indian Wind Grid Code has been designed keeping in mind the growth of wind energy in the power sector scenario over the past years. Today, wind constitutes the largest share of the 12 % capacity of renewable energy sources in the country.

As such, the framing of the grid code has been timely, as it will bring ‘Wind’ at par with the conventional generators. The technical requirements for small wind farms have been kept minimal and have been limited to operating voltage limits, frequency tolerance limits, reactive power drawal and protection schemes.

Conditions like fault ride through capability and forecasting that are stringent in the present context have been specified for larger wind farms and will be implemented in due course of time taking into account the penetration levels of wind energy, cost of implementation, tariff structure and usefulness in terms of grid management strategies.

## hybrid and isolated operations of solar PV and wind systems

According to many renewable energy experts, a small "hybrid" electric system that combines home wind electric and home solar electric (photovoltaic or PV) technologies offers several advantages over either single system.

In much of the United States, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when you need it.

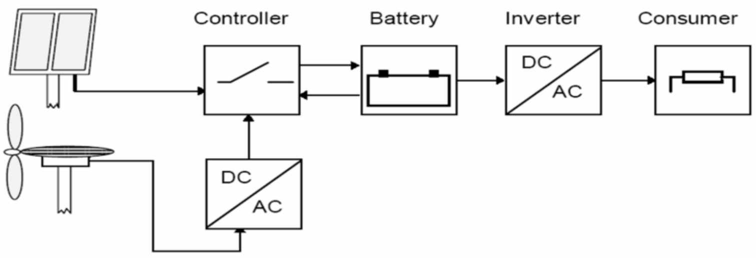
Many hybrid systems are stand-alone systems, which operate "off-grid" -- not connected to an electricity distribution system. For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel. If the batteries run low, the engine generator can provide power and recharge the batteries.

Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically. An engine generator can also reduce the size of the other components needed for the system. Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days.

- Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and / or economics.
- Incorporating heat, power, and highly efficient devices (fuel cells, advanced materials, cooling systems, etc.) can increase overall efficiency .
- Conserve energy for a hybrid system when compared with individual technologies.
- Achieving higher reliability can be accomplished with redundant technologies and/or energy storage.

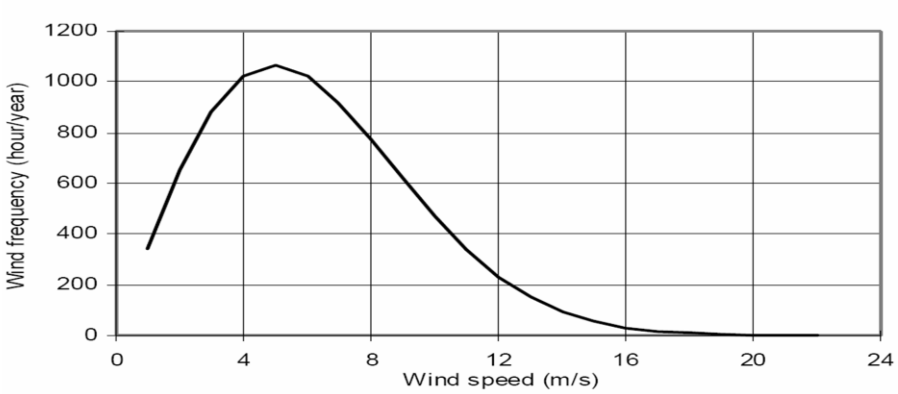
- Some hybrid systems typically include both, which can simultaneously improve the *quality* and *availability* of power.
- Hybrid systems can be designed to maximize the use of renewable.
- Resulting in a system with lower emissions than traditional fossil-fueled technologies.
- Hybrid systems can be designed to achieve desired attributes at the lowest acceptable cost, which is the key to market acceptance

**Wind/PV Hybrid System**

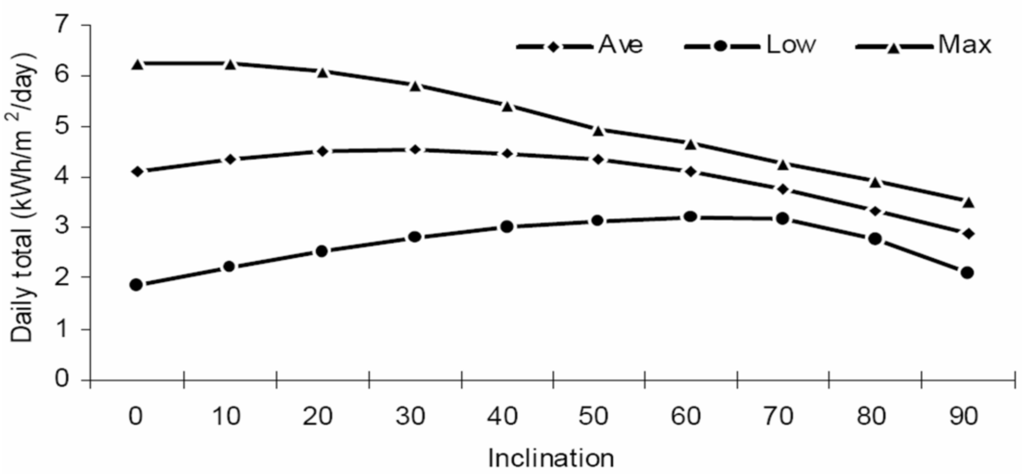



*Schematic diagram of a typical hybrid energy system containing solar and wind sources.*

- 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 above.
- 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 system, whose block diagram is shown in Fig, above, consists of 12 photovoltaic (PV) panels.
- which can provide a total power of 900 W, and a wind generator that can produce a maximum power of 2200 W.
- The hybrid PV-wind generator system has been designed to supply continuous power of 1.5 kW and should has 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.
- Controls the charge and discharge processes of the batteries.
- Protects wind generator from over speeding by connecting a dummy load to its output.




- Initiates the operation of a diesel generator or connects the system to the electric grid (if available), when the renewable energy sources fail to produce sufficient electric energy.
- Provides continuous and uninterruptible electric power (220 V, 50 Hz) to a 1.5-kW house load.




Local solar radiation information: high, low and average values of daily solar radiation calculated over one year