CHAPTER 3

DISTRIBUTED GENERATION

Given enough ANTS, you can move a mountain! This proverb holds good for DG applications for power system.

This chapter deals with starting from definition of DG to classification of DG and brief note on each type to grid benefits with DG has been discussed. Since the work concentrates on wind, solar and hybrid combination of these two, information about wind and solar energy is discussed in detail and also the possible way to overcome the drawbacks of each type by hybrid combination is presented.

3.1 DG - Definition

The earliest power systems were DG systems, which were intended to cater to the requirements of local areas. With the development of technology and increase in demand for energy resulted in the development of large Centralized Grids connecting entire regions and countries. DGs applications in the vicinity of the load had shown greater operational and power quality advantages, in addition to transmission losses reduction. DGs are very appropriate for particular site and specific applications as they require short period of construction and need low investment. It is defined on the basis of size of the plant, which may vary from few KW to MW (10–50 MW). DG options can be classified based on the fuel source as renewable or non-renewable [Ackermann et al., 2001].

In literature, there are many definitions that suggest how large distributed energy generation systems should be, but the basic feature is that the energy generation and load are co-located. Table 3.1 compares various sources and their definitions.

Generally speaking, it is up to interpretation about what defines one system over another, either central or distributed. From the examples provided in table 3.1, it can be noted that all sources other than potentially Sweden will consider distributed systems to be under 100 MW. However, no general definition of power rating can be given to a distributed system as the rating will depend heavily on the design and
application of a specific system. Ackermann et al., [2001] suggest categories for clearly defining various distributed generation capacities:

• *Micro* distributed generation – 1 W to <5 kW
• *Small* distributed generation – 5 kW to < 5 MW
• *Medium* distributed generation – 5 MW to <50 MW
• *Large* distributed generation – 50 MW to <300 MW

**Table 3.1 Various definitions of Distributed Generation**

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Power Research Institute</td>
<td>A few kW to 50 MW</td>
</tr>
<tr>
<td>Gas Research Institute</td>
<td>25 W to 25 MW</td>
</tr>
<tr>
<td>Preston and Rastler</td>
<td>A few kW to over 100 MW</td>
</tr>
<tr>
<td>International Conference on large High Voltage Electric Systems</td>
<td>Smaller than 100 MW</td>
</tr>
<tr>
<td>English and Welsh Market</td>
<td>Smaller than 100 MW</td>
</tr>
<tr>
<td>Sweden</td>
<td>Less than 1.5 MW</td>
</tr>
</tbody>
</table>

(Source: Ackermann et al., 2001)

DG, defined as generation located at or near the load centres, is being recognised as an environment friendly, reliable, and secure source of power which not only has minimal negative social impacts but also serves to promote social welfare. In the recent years due to economical, environmental and political reasons, the traditional power system, characterized by centralized bulk power production and wide/long transmission networks supporting DG.

For a large and dispersed rural country, decentralized power generation systems, where in electricity is generated at consumer end and thereby avoiding transmission and distribution costs, offers a better solution. The concept of DG has been taken as decentralized generation and distribution of power especially in the rural areas.
In India, the deregulation of the power sector has not made much headway but the problem of T&D losses, the unreliability of the grid and the problem of remote and inaccessible regions have provoked the debate on the subject. The DG technologies in India relate to micro turbines, wind turbines, biomass, and gasification of biomass, solar photovoltaic and hybrid systems. In so far as the 18,000 villages in remote and inaccessible areas are concerned, the extension of grid power is not going to be economical. Decentralized plants based on biomass, gasification of biomass, hydel power and solar thermal power and solar photovoltaic are the appropriate solution for these areas.

As people in many of the electrified villages are very much dissatisfied with the quality of grid power, such villages also encouraged to go ahead with the DG Schemes. Knowing the importance of DG, its classification is discussed briefly.

3.2 DG – Classification

Based on the sources used for generation at or near the load centres, they are classified as renewable and non-renewable and the classification is clearly shown with the help of Figure 3.1
Some of the classifications of DGs are discussed in brief as below:

- **Reciprocating Engines**: Reciprocating engines are the most common technology used for distributed generation. They are a proven technology with low capital cost, large size range, fast start-up capability, relatively high electric conversion efficiency and good operating reliability. These characteristics, combined with the engines' ability to start up during a power outage, make them the main choice for emergency or standby power supplies. They are by far the most commonly used power generation equipment under 1 MW. The main drawbacks of reciprocating engines are noise, costly maintenance and high emissions, particularly of nitrogen oxides.

- **Gas Turbines**: Small industrial gas turbines of 1-20 MW are commonly used in combined heat and power applications. They are particularly useful when higher temperature steam is required than can be produced by a reciprocating engine. The maintenance cost is slightly lower than for reciprocating engines, but so is the electrical conversion efficiency. Gas turbines can be noisy. Emissions are somewhat lower than that of reciprocating engines, as Nitrogen Oxides emissions-control technology is commercially available and it is cost-effective.

- **Micro Turbines**: One of the most striking technical characteristics of micro turbines is their extremely high rotational speed. The turbine rotates up to 120000 rpm and the generator up to 40000 rpm. Individual units range from 30-200 kW but can be combined readily into systems of multiple units. Low combustion temperatures can assure very low NO\textsubscript{2} emissions levels. They make much less noise than an engine of comparable size. Natural gas is expected to be the most common fuel, but landfill gas, or biogas can also be used. The main disadvantages of micro turbines at this stage are its short track record and high costs compared with gas engines.

- **Fuel Cells**: Fuel cells are compact, quiet power generators that use hydrogen and oxygen to make electricity. The transportation sector is the major potential market for fuel cells, and car manufacturers are making substantial investments in research and development. Power generation,
however, is seen as a market in which fuel cells could be commercialized much more quickly. Fuel cells can convert fuels to electricity at very high efficiencies (35%-60%), compared with conventional technologies.

- **Photovoltaic Systems:** Unlike the other DG technologies discussed above, photovoltaic systems are a capital-intensive, renewable technology with very low operating costs as there are no fuelling costs. PV systems also are widely used in developing countries, serving rural populations that have no other access to basic energy services. PV systems can be used to provide electricity for a variety of applications in households, community lighting, small businesses, agriculture, healthcare, and water supply. The other half of existing PV capacity is on-grid, mostly as distributed generation.

- **Wind:** Wind generation is rapidly growing in importance as a share of worldwide electricity supply. About 14.158 GW of capacity was installed during the year 2011. Wind power is sometimes considered to be distributed generation, because the size and location of some wind farms makes it suitable for connection at distribution voltages. Most popular DG is wind generation since it is cheapest of all renewable energy sources.

- **Hydro Electric Resources:** Water constantly moves through a vast global cycle, in which it evaporates from oceans, seas and other water reservoirs, forms clouds, precipitates as rain or snow, then flows back to the ocean. The energy of this water cycle, which is driven by the sun, is tapped most efficiently with hydropower.

### 3.3 Grid Benefits of On-Site DG

DGs, depending on location, may offer additional value to the grid in several ways. Some of them are discussed as below.

- On-site production avoids transmission and distribution costs, which otherwise amount to about 30% of the cost of delivered electricity.

- When a transmission system is congested, an appropriately located DG can reduce the congestion and thus can defer the need for an upgrade of transmission system.
• In areas where voltage support is difficult, installation of a DG may improve quality of supply.

• Distributed resources can improve the efficiency of providing electric power. Beyond efficiency, DG technologies may provide benefits in the form of more reliable power for industries that require an uninterrupted service.

• DG supports the entire grid by reducing demand during peak times and by minimizing congestion of power on the network.

• Customer’s electricity bills include the cost of vast transmission grid; the use of on-site power equipment can conceivably provide consumers with affordable power at a higher level of quality.

• Consumers will get power at lower tariff as more power becomes available at lower per unit cost and they will be relieved from frequent power cuts and load shedding.

• Consumers will immensely benefit from better regulation and power quality.

• As on-site DG eliminates need for costly high voltage transmission lines transmission and large distribution lines. The problem of land acquisition for their construction and the related woes of people can be done away with the effect of high voltage transmission lines on the health of the people living near it.

• More employment opportunities both at plant management level and in the manufacturing sector for related machinery will improve living standards of the people.

• Availability of power at low cost will attract more investments, which would be more evenly distributed throughout the country rather than being limited to cities alone.

• As per capita power consumption increases the living standards of people will improve and hence the economic growth of the country.
From the above discussion one can understand the importance of DG implementation to meet the rise in power demand and the new generation has to be necessarily from renewable technology. The study concentrated on wind and solar DG as they are much better and popular than the rest discussed above. Hence a brief discussion is presented on wind energy and solar energy in the following sections.

3.4 Wind Energy

The call for improved renewable energy technologies is increasing due to the global warming. The global warming is caused from green house gases, which comes from burning fossil fuels such as oil or coal. The advent of renewable energy resources is the promising solution to the problems. There are several renewable energy resources for the electrical power system. Wind energy is one of the fastest growing renewable energy resources as it is cheapest clean energy and requires less installation time.

3.4.1 Background

Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. The earth’s surface is made of different types of land and water. These surfaces absorb the sun’s heat at different rates, giving rise to the differences in temperature and subsequently to winds. During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles. Humans use this wind flow for many purposes: sailing boats, pumping water, grinding mills and also for generating electricity. Wind turbines convert the kinetic energy of the moving wind into electricity. Wind energy is one of the cleanest and free energy.

The wind energy is used for a long time in farms to grind grains or pump water in the form of a wind mill. The principle is to convert the kinetic energy from the wind to the mechanical energy. This principle is applied to the wind energy in the power system. A wind turbine captures the kinetic energy from the flowing air and changes
it to the mechanical energy. A generator installed in the wind turbine converts the mechanical energy to the electrical energy.

As shown in Figure 3.2, the kinetic energy of the wind turns the rotor blades of the wind turbine. This results in revolving of the shaft of the generator, which is mounted on the rotor blades. The generator converts the mechanical energy from the rotating shaft to the electrical energy. It is optional to tie the low speed shaft of the rotor blades to the high speed shaft of the generator with a gear box. In some cases, gearboxes are undesirable because they are expensive, bulky, and heavy. A multi-pole generator is an alternative way of a gearless system.

The power cable transmits the electrical power to a transformer. The transformer steps up the low voltages of the generator to the distribution or sub-transmission level of the connected system. The voltages from the generator are typically in a few hundred volts. The wind resource data is an estimation of average and peak wind speeds at a location based on various meteorological data.

3.4.2 Power Extracted from Wind

The range of wind speeds that are usable by a particular wind turbine for electricity generation is called productive wind speed. The power available from wind is
proportional to cube of the wind's speed. So as the speed of the wind falls, the amount of energy that can be got from it falls very rapidly. On the other hand, as the wind speed rises, so the amount of energy in it rises very rapidly; very high wind speeds can overload a turbine. Productive wind speeds will range between 4 m/sec to 35 m/sec.

Wind mills or turbines works on the principle of converting kinetic energy of the wind into mechanical energy. The kinetic energy in air of mass “m” moving with speed $V$ is given by the following in SI units:

$$
\text{kinetic energy} = \frac{1}{2} m V^2 \text{joules.}
$$

(1)

The power in moving air is the flow rate of kinetic energy per second.

$$
\text{Power} = \frac{1}{2} \text{(mass flow rate per second).} V^2
$$

(2)

Let $P =$ Mechanical power in the moving air.

$\rho =$ Air density, kg/m$^3$

$A =$ Area swept by the rotor blades, $m^2$.

$V =$ Velocity of the air, m/s.

Then the volumetric flow rate is $A \cdot V$, the mass flow rate of the air in kg per second is $\rho \cdot A \cdot V$ and then from equation (2) power is given by,

$$
P = \frac{1}{2} (\rho AV) \cdot V^2 = \frac{1}{2} \rho AV^3 \text{ watts.}
$$

(3)

Two potential wind sites are compared in terms of the specific wind power expressed in watts per square meter of area swept by the rotating blades. It is also referred to as the power density of the site, and is given as,

$$
\text{Specific power of the site} = \frac{1}{2} \rho \cdot V^3 \text{ watts per m}^2 \text{ of the rotor swept area.}
$$

(4)

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. All of the upstream wind power cannot be extracted by the blades as some power is left in the downstream air which continues to move with reduced speed.
The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers. By equation (2),

$$ P_0 = \frac{1}{2} \text{mass flow rate per second} \cdot (V^2 - V_0^2) $$

(5)

Where $P_0$ = Mechanical power extracted by the rotor (turbine output power).

$V$ = Upstream wind velocity at the entrance of the rotor blades.

$V_0$ = Downstream wind velocity at the exit of the rotor blades.

The air velocity is discontinuous from $V$ to $V_0$ at the “plane” of the rotor blades in the macroscopic sense. The mass flow rate of air through the rotating blades is therefore derived by, multiplying the density with the average velocity.

$$ \text{Mass flow rate} = \rho \cdot A \cdot \frac{(V + V_0)}{2} $$

(6)

The mechanical power extracted by the rotor, which is driving the electrical generator is

$$ P_0 = \frac{1}{2} \rho \cdot A \cdot \frac{(V + V_0)}{2} \cdot (V^2 - V_0^2) $$

(7)

Simplifying and rearranging,

$$ P_0 = \frac{1}{2} \rho \cdot A \cdot V^3 \cdot \left(1 + \frac{V_0}{V}\right) \left[1 - \left(\frac{V_0}{V}\right)^2\right] $$

(8)

The power extracted by the blades is customarily expressed as a fraction of the upstream wind power

$$ P_0 = \frac{1}{2} \rho \cdot A \cdot V^3 \cdot C_P $$

(9)

Where,

$$ C_P = \frac{(1 + \frac{V_0}{V}) \left[1 - \left(\frac{V_0}{V}\right)^2\right]}{2} $$

(10)

$C_P$ is called as the power coefficient of the rotor or the rotor efficiency. It is the fraction of the upstream wind power, which is captured by the rotor blades. The remaining power is discharged or wasted in the downstream wind.
3.4.3 Geographic Location and Wind Potential

The wind potential is far from exhausted. It is estimated that with the current level of technology, the ‘on-shore’ potential for utilization of wind energy for electricity generation is of the order of 65,000 MW. India also is blessed with 7517 km of coastline and its territorial waters extend up to 12 nautical miles into the sea. Potential areas can be identified on Indian map using wind power density map. C-WET, one of pioneering wind research organization in the country is leading in all such resource studies and has launched its wind resource map and is shown in Figure 3.3.

![Wind Power Density Map of India](https://www.mapsofindia.com)

Source: CEA

**Figure 3.3 Wind Power Density Map of India**

As on June 2011, country wise wind energy generation is shown in table 3.2 and observed that India stands 5th position and all the country wind generation is improving year by year.
According to Global Status Report 2011, Indian company Suzlon was among top ten manufacturers of wind turbine manufacturer’s in the world with world market share of 6.7%. Also major world companies are pouring into the fast evolving wind energy market in India. Some of them like Vestas, GE Wind, Enercon and Gamesa have already opened up their establishments across various cities in India.

The cumulative installed capacity of grid interactive wind energy in India by the end of September 2011 was 14989 MW [MNRE, 2012]. The Table 3.3 gives history of wind installation in India state wise from 2002-2012. It is very clear that more generation is likely towards wind generation.

The potential is far from exhausted. Almost 1000 MW increment per year in generation is observed in the table. Indian Wind Energy Association has estimated that with the current level of technology, the ‘on-shore’ potential for utilization of wind energy for electricity generation is of the order of 65,000 MW. Present report is that 18,000 MW only is generated.
### Table 3.3 Year wise wind power installation of different states of India

<table>
<thead>
<tr>
<th>State</th>
<th>Karnataka</th>
<th>Andhra Pradesh</th>
<th>Gujarat</th>
<th>Kerala</th>
<th>Madhya Pradesh</th>
<th>Maha rashtra</th>
<th>Rajasth an</th>
<th>Tamil Nadu</th>
<th>Total in MW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Up to Mar 2002</strong></td>
<td>69.3</td>
<td>93.2</td>
<td>181.4</td>
<td>2.0</td>
<td>23.2</td>
<td>400.3</td>
<td>16.1</td>
<td>877.0</td>
<td>1662.5</td>
</tr>
<tr>
<td>2002-03</td>
<td>55.6</td>
<td>0.0</td>
<td>6.2</td>
<td>0.0</td>
<td>0.0</td>
<td>2.0</td>
<td>44.6</td>
<td>133.6</td>
<td>242.0</td>
</tr>
<tr>
<td>2003-04</td>
<td>84.9</td>
<td>6.2</td>
<td>28.9</td>
<td>0.0</td>
<td>0.0</td>
<td>6.2</td>
<td>117.8</td>
<td>371.2</td>
<td>615.2</td>
</tr>
<tr>
<td>2004-05</td>
<td>201.5</td>
<td>21.8</td>
<td>51.5</td>
<td>0.0</td>
<td>6.3</td>
<td>48.8</td>
<td>106.3</td>
<td>675.5</td>
<td>1111.7</td>
</tr>
<tr>
<td>2005-06</td>
<td>143.80</td>
<td>0.45</td>
<td>84.60</td>
<td>0.0</td>
<td>11.40</td>
<td>545.10</td>
<td>73.27</td>
<td>857.55</td>
<td>1716.17</td>
</tr>
<tr>
<td>2006-07</td>
<td>265.95</td>
<td>0.80</td>
<td>283.95</td>
<td>0.0</td>
<td>16.40</td>
<td>485.30</td>
<td>111.90</td>
<td>577.90</td>
<td>1742.05</td>
</tr>
<tr>
<td>2007-08</td>
<td>190.30</td>
<td>0.0</td>
<td>616.36</td>
<td>8.50</td>
<td>130.39</td>
<td>268.15</td>
<td>68.95</td>
<td>380.67</td>
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</tr>
<tr>
<td>2008-09</td>
<td>316.0</td>
<td>0.0</td>
<td>313.6</td>
<td>16.5</td>
<td>25.1</td>
<td>183.0</td>
<td>199.6</td>
<td>431.1</td>
<td>1484.9</td>
</tr>
<tr>
<td>2009-10</td>
<td>145.4</td>
<td>13.6</td>
<td>197.1</td>
<td>0.8</td>
<td>16.6</td>
<td>138.9</td>
<td>350.0</td>
<td>602.2</td>
<td>1564.6</td>
</tr>
<tr>
<td>2010-11</td>
<td>254.1</td>
<td>55.4</td>
<td>312.8</td>
<td>7.5</td>
<td>46.5</td>
<td>239.1</td>
<td>436.7</td>
<td>997.4</td>
<td>2349.3</td>
</tr>
<tr>
<td>2011-12</td>
<td>46.4</td>
<td>7.7</td>
<td>160.9</td>
<td>0.0</td>
<td>0.0</td>
<td>83.2</td>
<td>153.4</td>
<td>381.9</td>
<td>833.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1773.20</td>
<td>199.20</td>
<td>2337.30</td>
<td>35.10</td>
<td>275.90</td>
<td>2400.0</td>
<td>1678.50</td>
<td>6286.0</td>
<td>14985.1</td>
</tr>
</tbody>
</table>

Source: Windpowermonthly.com

The unexploited resource availability has the potential to sustain the growth of wind energy sector in India in future. In terms of wind power installed capacity, India is ranked 5th in the World. Today India is a major player in the global wind energy market. But the forecasting predictions do say that wind annual growth rate will reduce in the upcoming years due to revolution in solar PV technology.

### 3.5 Solar Energy

Solar power is the generation of electricity from sunlight. This can be directly obtained from photo-voltaic (PV) or indirectly from concentrating solar power (CSP), where the sun's energy is focused to generate power. The evolution of PV cell has a history starting from 18th century.
3.5.1 PV Working Principle

Photovoltaic effect is a basic physical process through which solar energy is converted into electrical energy directly. The physics of a PV cell or solar cell is similar to the classical p-n junction diode. Solar cells are devices which convert solar energy directly into electricity, either directly via the photovoltaic effect, or indirectly by first converting the solar energy to heat or chemical energy.

The most common form of solar cells are based on the PV effect in which light falling on a two layer semi-conductor device produces a photo voltage or potential difference between the layers. This voltage is capable of driving a current through an external circuit and thereby producing useful work.

The amount of power available from a solar cell device is determined by

- The type and area of the material.
- The intensity of the sunlight.
- The wavelength of the sunlight

Solar cell consists of two types of material, often p-type silicon and n-type silicon. Light of certain wavelengths is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charges (holes) from the negative charges (electrons) within the photovoltaic device. The holes are swept into the positive or p-layer and the electrons are swept into the negative or n-layer. Although these opposite charges are attracted to each other, most of them can only recombine by passing through an external circuit outside the material because of the internal potential energy barrier. As shown in Figure 3.4, power can be produced from the cells under illumination, since the free electrons have to pass through the load to recombine with the positive holes.

![Figure 3.4 Schematic of Photo Voltaic Effect](image-url)
Solar cells in the market can be classified into two main categories - crystalline silicon cells and thin-film cells. Crystalline silicon cells can be further divided into mono-crystalline cells and poly-crystalline cells [Figure 3.5]. Thin-film cells include the amorphous silicon cells, copper indium diselenide cells (CIS) and cadmium-telluride cells (CdTe).

The performance of a solar cell is expressed in terms of its energy conversion efficiency, i.e. the efficiency in converting the energy in sunlight into electricity. The earliest silicon solar cells had efficiencies of just a few percents. Nowadays commercial solar cells can approach almost 20% in efficiency, while special-made cells and experimental cells can exceed 30%.

For the majority of applications multiple solar cells need to be connected in series or in parallel to produce enough voltage and power. Individual cells are usually connected into a series string of cells to achieve the desired output voltage. The complete assembly is usually referred to as a module and manufacturers basically sell modules to customers.

An array is a structure that consists of a number of PV modules, mounted on the same plane with electrical connections to provide enough electrical power for a given application. Arrays range in power capacity from a few hundred watts to hundreds of kilowatts. The connection of modules in an array is similar to the connection of cells in a single module.
To increase the voltage, modules are connected in series and to increase the current they are connected in parallel. Matching is again very important for the overall performance of the array. The formation of cell to module to array is shown in Figure 3.6.

![PV cell, PV module and PV array](image)

**Figure 3.6 PV cell, PV module and PV array**

### 3.5.2 Electrical Properties of PV Modules

Each PV module can be characterized by its performance curve, i.e. the current-voltage curve (I-V curve). The performance of solar module is tested under standard testing conditions (STC) as defined in the IEC 60904 standards: cell temperature of 25 degrees Celsius, incident solar irradiance of 1000 W/m², spectral distribution of the light spectrum with an air mass (AM) = 1.5.

![I-V characteristics of a PV module](image)

**Figure 3.7 I-V characteristics of a PV module**
Three points on the I-V curve are important in defining the performance of a PV module, i.e. the maximum power point, the short-circuit current and the open-circuit voltage.

- The maximum power point (MPP) is the point on the I-V curve at which the PV module works with maximum power output.
- The short-circuit current (Isc) is the maximum current output of a module.
- The open-circuit voltage (Voc) is the maximum output voltage of a module.

Power is the product of voltage times current. Therefore, on the I-V curve, the maximum-power point (MPP) occurs where the product of current time's voltage is a maximum. No power is produced at the short-circuit current with no voltage or at open-circuit voltage with no current. So maximum power generated is expected to be somewhere between these two points. Maximum power is generated at only one place on the power curve, at about the “knee” of the curve. This point represents the maximum efficiency of the solar device at converting sunlight into electricity.

In Figure 3.8 (a), I-V characteristics of a PV module for constant irradiance of 1000 w/m² with various temperatures are shown. It is observed that at 25°C maximum power is generated by the PV cell. Where as in Figure 3.8 (b), I-V characteristics of a PV module for constant temperature 25°C of with various irradiances are shown and it is obvious that more the irradiance more the output power. Figure 3.9 shows the PV characteristic in which MPPT for different irradiance case studies. Based on these specifications suitable module is chosen depending upon the application.

![Figure 3.8(a) I-V characteristics of a PV module (various temperatures, constant irradiance)](image)

![Figure 3.8(b) I-V characteristics of a PV module (various irradiances, constant temperature)](image)
3.5.3 Solar Energy Scenario

Indian solar installations are driven by Jawaharlal Nehru National Solar Mission (JNNSM) with a goal to install 20 GW of solar power by 2022. India has already installed about 825 MW during 2011 and is set the pace to install over 1 GW by 2012. JNNSM and most states uses the reverse auction process to select projects. India went quickly from almost no installations three years ago to 1 GW and is one of the most promising future solar markets along with China and Japan.

According to Ministry of New and Renewable Energy solar photovoltaic installations in India have crossed the 1,000 MW or 1 GW mark. At the end of June 2012, India had grid interactive solar PV installed capacity of 1,030.66 MW. Most of the capacities are installed at Gujarat. In addition, India has 85.21 MW of off-grid solar PV systems, counting only those that are higher than 1 kW. Renewable Energy in India crossed another milestone in the first quarter of the current year 2012. Total grid interactive renewable energy installations have crossed 25,000 MW.

The Karnataka State, through Karnataka Power Corporation Limited (KPCL), is ready to establish 10 solar power plants at Shimoga, Kaginele, Mandy, Bijapur, Haveri, Mysore and Tumkur, under the JNNSM. In fact, the state is set to become the country’s solar power hub. It has in the pipeline 10 solar power projects with a total capacity of 100 MW, operated on the basis of public-private-partnership.

India’s first-ever 3 MW solar photovoltaic power plants were erected by the Karnataka Power Corporation Limited (KPCL), the state-owned power generating
company. It has been set up at a cost of Rs 59.5 crore. The 3 MW solar photovoltaic plants set up in Kolar district provides energy to 500 pumpsets of 10 HP each which benefits about 1,000 farmers.

Rajasthan has the most barren land with 2,595 ha, followed by Gujarat with 2,295 ha and Andhra Pradesh with 2,056 ha. Maharashtra, Madhya Pradesh and Karnataka have 1,718 ha, 1,351 ha and 788 ha respectively. If this barren lands used for the power generation by PV technology most of the power demand is met throughout the year.

As seen from the Figure 3.10 Rajasthan, the largest state in India receives maximum solar radiation intensity in India. Thus it is clear that solar power projects are commercially viable in most parts of India.

**Figure 3.10 Solar radiations in different parts of the country**

The National Solar Mission also has the following additional objectives:

- To create favourable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.
• To promote programs for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022.
• To achieve 15 million sq. meters solar thermal collector area by 2017 and 20 million by 2022. To deploy 20 million solar lighting systems for rural areas by 2022.

Under the plan, incentives vary, depending on whether the project is off-grid or grid connected.

1. Grid connected solar projects - these systems are typically supported by high feed-in-tariff. The first phase of the solar mission saw the tariffs being decided by a reverse bidding process. The rates quoted by the winners were in the range Rs 10.9-12.7/kWh for solar PV and 10.49 to 12.24/kWh for CSP.

2. Off-grid solar projects - for solar PV projects that are off the grid, incentives have been provided primarily in the form of capital subsidies (30% for non-priority regions and 90% for priority regions), accelerated depreciation and in some cases, access to soft loans (5% interest rate).

Outside of the central schemes under the National Solar Mission, several state governments have announced their own incentive schemes for solar PV. Many Indian states are firming up their individual state schemes under the National Solar Mission. Of these, only Gujarat, Rajasthan and Karnataka have so far announced their schemes formally. As the duo -wind and PV are complimentary to each other several researches concentrated on the combination of DGs to overcome intermittent nature of these renewable sources.

3.6 Hybrid Energy System

Hybrid energy is a combination of two or more energy sources for producing electricity. There are many sources of combining renewable energy sources to produce power but very common combination is biomass- wind fuel cell and photovoltaic - wind. The hybrid energy sources can help farmers to run their tube wells to provide water to their irrigation land. Combining two or three energy sources to form one combinational source is capable of generating efficient energy to power a house or a small industrial unit.

Nevertheless, different renewable energy sources can complement each other, multi-source hybrid alternative energy systems have great potential to provide higher quality
and more reliable power to customers than a system based on a single resource. Because of this, hybrid energy systems have caught worldwide research attention.

There are many combinations of different alternative energy sources and storage devices to build a hybrid system. Due to natural intermittent properties of wind and photovoltaic power, stand-alone wind and/or PV renewable energy systems normally require energy storage devices or some other generation sources to form a hybrid system.

Solar panels are too much costly and the production cost of power by using them is generally higher than the conventional process, it also not available in the night/in cloudy days, similarly Wind turbines can’t operate in high or low wind speeds.

If these renewable sources are combined into one hybrid power generating system the drawbacks discussed can be avoided partially/completely, depending on the control units. As the one or more drawbacks can be overcome by the other sources hybrid generation is becoming trend in DGs. In this study Wind and Solar combination is considered as hybrid study and estimation of new PV plant with the existing wind farm is proposed.

Figure 3.11 shows the system configuration for the proposed hybrid alternative energy system. This system can be considered as a complete “green” power generation system because the main energy sources are environmentally friendly. However, when connected to a utility grid, operation and performance requirements, such as voltage, frequency and harmonic regulations, are imposed on the system.

Figure 3.11 Proposed hybrid systems