

CHAPTER TWO

Literature review

2.1 Introduction:

A hybrid renewable energy system is a system in which two or more supplies from different renewable energy sources (solar-thermal, solar photovoltaic, wind, biomass, hydropower) which used to supply electricity or heat, or both, to the same demand. The most frequently used hybrid system is the hybrid which consists of Photovoltaic (PV) modules and wind turbines [3].

Because the supply pattern of different renewable energy sources intermittent but with different patterns of intermittency, it is often possible to achieve a better overall supply pattern by integrating two or more sources .Sometimes also including a form of energy storage. In this way the energy supply can effectively be made less intermittent, or more firm [3].

Combining renewable hybrid system with batteries as a storage system, to increase duration of energy autonomy, will make optimal use of the available renewable energy resource and this in turn can guarantee high supply reliability. To deal with different weather conditions and to make the system supplies load demand at the worst conditions, this strategy requires large storage capacity and therefore it is very expensive. It is cheaper to supply peaks or to supply demand during periods of cloudy weather or poor wind days with another back up supply (usually diesel generator), although this lowers the proportion of renewable energy used. Selecting appropriate size of the storage system is such that to minimize diesel running time and to maximize fuel savings [3].

Dump loads are recommended to be used in hybrid power systems as secondary loads to provide a sink for excess renewable generated power to keep power balance of the system at all times, also improve the economic return of the system by allowing excess renewable energy to meet an on-site energy needs that would otherwise have to be met with other energy source [3].

2.2 Benefits of a Hybrid System

The main benefits (advantages) of a hybrid system can be summarized as:

- The possibility to combine two or more renewable energy sources, based on the natural local potential of the users.
- Environmental protection especially in terms of CO₂ emissions reduction.
- Low cost – wind energy, and also solar energy can be competitive with nuclear, coal and gas especially considering possible future cost trends for fossil and nuclear energy.
- Diversity and security of supply.
- Rapid deployment - modular and quick to install.
- Fuel is abundant, free and inexhaustible.
- Costs are predictable and not influenced by fuel price fluctuations although fluctuations in the price of batteries will be an influence where these are incorporated [3].

2.3 Scenarios of a Hybrid System

There are many possible configurations of hybrid power systems. One way to classify systems architectures is to distinguish between AC and DC bus systems. DC bus systems are those where the renewable energy components and sometimes even the backup diesel generator feed

their power to a DC bus, to which is connected an inverter that supplies the loads. This is for small hybrid systems. Large power hybrid systems use an AC bus architecture where wind turbines are connected to the AC distribution bus and can serve the loads directly [3].

The configuration used to be evaluated in this thesis has a DC bus which combines the DC output of the PV module, the DC output of the wind turbine and diesel generator is connected to operate in the loss of generation of the solar and wind system, and then convert the total DC voltage into AC voltage using inverter [3].

2.4 Wind Energy:

Wind has been utilized as a source of power for thousands of years for such tasks as propelling sailing ships, grinding grain, pumping water, and powering factory machinery. The world's first wind turbine used to generate electricity was built by a Dane, Poul la Cour, in 1891. It is especially interesting to note that La Cour used the electricity generated by his turbines to electrolyze water, producing hydrogen for gas lights in the local school house. In that regard we could say that he was 100 years ahead of his time since the vision that many have for the twenty-first century includes photovoltaic and wind power systems making hydrogen by electrolysis to generate electric power in fuel cells [4].

2.5 Types of Wind Turbines:

Most early wind turbines were used to grind grain into flour, hence the name "windmill." Strictly speaking, therefore, calling a machine that pumps water or generates electricity a windmill is somewhat of a misnomer. Instead, people are using more accurate, but generally clumsier, terminology: "Wind-driven generator," "wind generator,"

“wind turbine,” “wind-turbine generator” (WTG), and “wind energy conversion system” (WECS) all are in use [4]. For our purposes, “wind turbine” will suffice even though often we will be talking about system components (e.g., towers, generators) that clearly are not part of a “turbine.”

One way to classify wind turbines is in terms of the axis around which the turbine blades rotate, most are:

- Vertical axis wind turbines (VAWT).
- Horizontal axis wind turbines (HAWT) .

2.5.1 Vertical Axis Wind Turbines (VAWT):

The only vertical axis machine that has had any commercial success is the Darrieus rotor, named after its inventor the French engineer G. M. Darrieus, who first developed the turbines in the 1920s [4]. The shape of the blades is that which would result from holding a rope at both ends and spinning it around a vertical axis, giving it a look that is not unlike a giant eggbeater. Considerable development of these turbines, including a 500-kW, 34-m diameter machine, was undertaken in the 1980s by Sandia National Laboratories in the United States [4]. An American company, FloWind, manufactured and installed a number of these wind turbines before leaving the business in 1997 [4]. Figure 2.1 below show the vertical axis wind turbine.

The blades of a Darrieus VAWT have a curved shape and this looks like a shape taken by a spinning rope. This shape is a structurally efficient one, but the unusually shaped blades are difficult to manufacture, transport and install [3]. In order to overcome these problems, straight-bladed VAWTs have been developed: these include the H-type vertical axis and V-type vertical axis wind turbines [3].

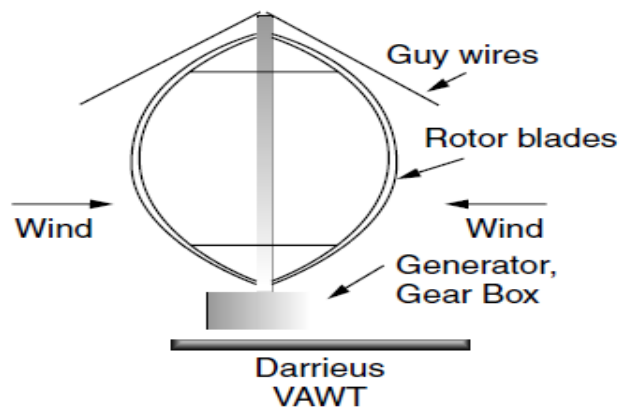


Figure 2.1: Vertical axis wind turbines (VAWT)

The principal advantage of vertical axis machines, such as the Darrieus rotor, is that [4].

- They don't need any kind of yaw control to keep them facing into the wind.
- A second advantage is that the heavy machinery contained in the nacelle (the housing around the generator, gear box, and other mechanical components) can be located down on the ground, where it can be serviced easily.
- Since the heavy equipment is not perched on top of a tower, the tower itself need not be structurally as strong as that for a HAWT.
- The tower can be lightened even further when guy wires are used, which is fine for towers located on land but not for offshore installations.
- The blades on a Darrieus rotor as they spin around are almost always in pure tension, which means that they can be relatively lightweight.

There are several disadvantages of vertical axis turbines:

- The principal one being that the blades are relatively close to the ground where wind speeds are lower.

- Power in the wind increases as the cube of velocity so there is considerable incentive to get the blades up into the faster wind speeds that exist higher up.
- Winds near the surface of the earth are not only slower but also more turbulent, which increases stresses on VAWTs.
- Finally, in low-speed winds, Darrieus rotors have very little starting torque; in higher winds, when output power must be controlled to protect the generator, they can't be made to spill the wind as easily as pitch-controlled blades on a HAWT.



Figure 2.2: A 4 MW, Darrieus-type VAWT, Cap Chat, Quebec, late 1990s.



Figure 2.3: A H- type VAWT built in Wales, rated power 130 Kw

VAWTs have a greater solidity than HAWTs, which usually results in a heavier and more expensive rotor. VAWTs are not at economically competitive with HAWTs [3].

2.5.2 Horizontal Axis Wind Turbines (HAWT):

Almost all wind turbines are of the horizontal axis type, there is still some controversy over whether an upwind machine or a downwind machine is best. A downwind machine has the advantage of letting the wind itself control the yaw (the left–right motion) so it naturally orients itself correctly with respect to wind direction. They do have a problem, however, with wind shadowing effects of the tower. Every time a blade swings behind the tower, it encounters a brief period of reduced wind, which causes the blade to flex. This flexing not only has the potential to lead to blade failure due to fatigue, but also increases blade noise and reduces power output [4].

Upwind turbines, on the other hand, require somewhat complex yaw control systems to keep the blades facing into the wind. In exchange for that added complexity, however, upwind machines operate more smoothly and deliver more power. Most modern wind turbines are of the upwind type [4].

Wind turbines with many blades operate with much lower rotational speed than those with fewer blades. As the rpm of the turbine increases, the turbulence caused by one blade affects the efficiency of the blade that follows. With fewer blades, the turbine can spin faster before this interference becomes excessive and a faster spinning shaft means that generators can be physically smaller in size [4].

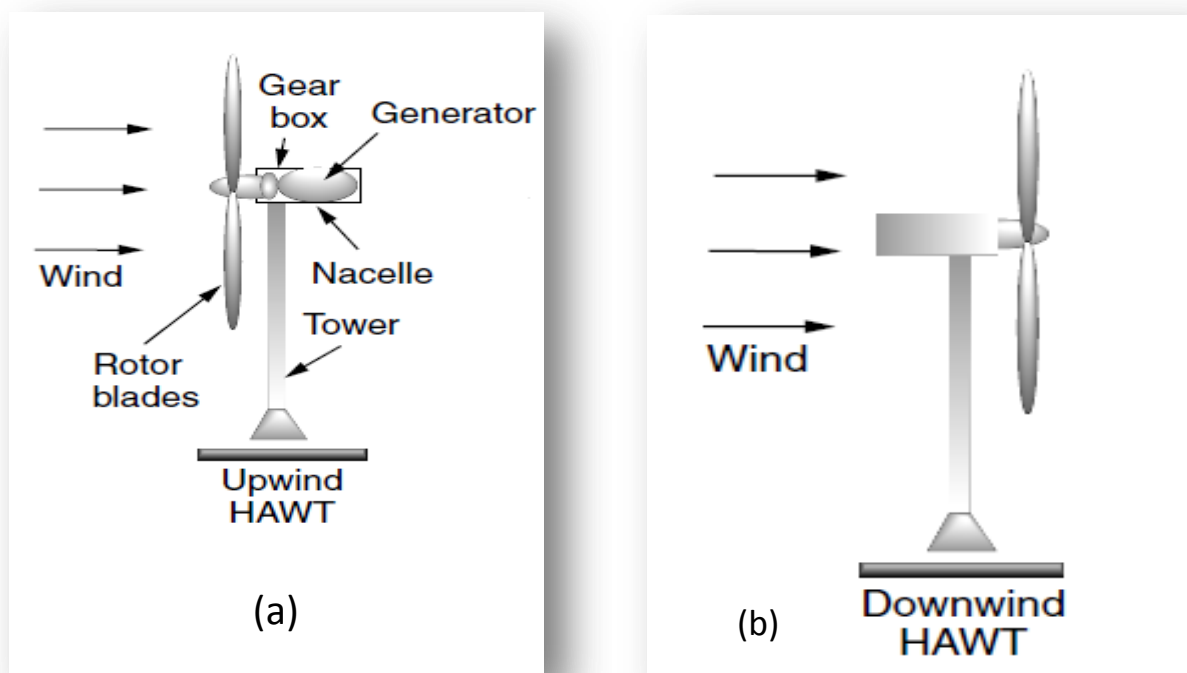


Figure 2.4: Horizontal axis wind turbines (HAWT) (a) upwind machines
(b) down wind machines

Most modern European wind turbines have three rotor blades, while American machines have tended to have just two. Three-bladed

turbines show smoother operation since impacts of tower interference and variation of wind speed with height are more evenly transferred from rotors to drive shaft. They also tend to be quieter. The third blade, however, does add considerably to the weight and cost of the turbine. A three-bladed rotor also is somewhat more difficult to hoist up to the nacelle during construction or blade replacement [4].



Figure 2.5: 2-blade HAWT,30 kW, Pitch Wind Systems AB Company (Sweden).



Figure 2.6: 3-blade HAWT,2MW,Okinawa,New Energy Development Company-(Japan).

2.6 Main Parts of Wind Generators:

There are four main parts to a wind turbine: the base, tower, nacelle, and blades as shown in Figure 2.7. The blades capture the wind's energy, spinning a generator in the nacelle. The tower contains the electrical conduits, supports the nacelle, and provides access to the nacelle for maintenance. The base, made of concrete and steel, supports the whole structure [5].

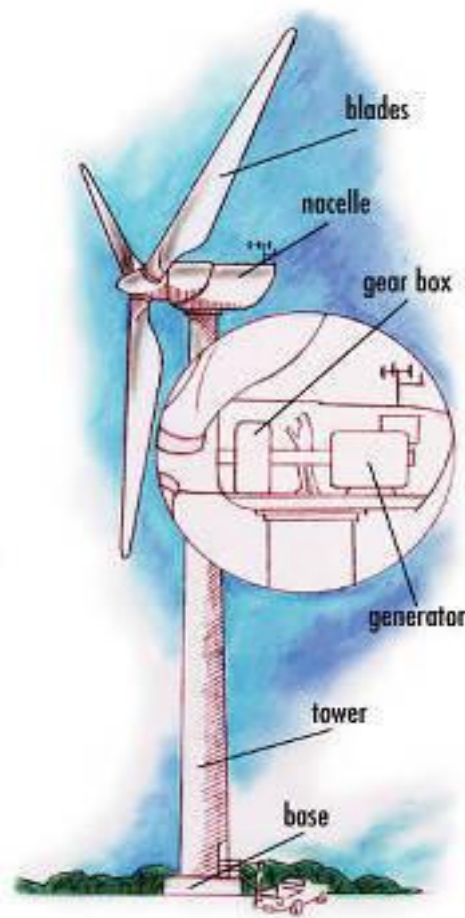


Figure 2.7: the main part of wind turbine

2.7 Power Produced By a Wind Turbine

Each wind turbine has its own characteristic known as wind speed power curve. The shape of this curve is influenced by the blades area, the

choice of airfoil, the number of blades, the blade shape, the optimum tip speed ratio, the speed of rotation, the cut-in wind speed, the shutdown speed, the rated speed, and gearing and generator efficiencies. The power output of a wind turbine varies with wind speed and wind turbine power curve. An example of such curve is shown in Figure 2.8 [3].

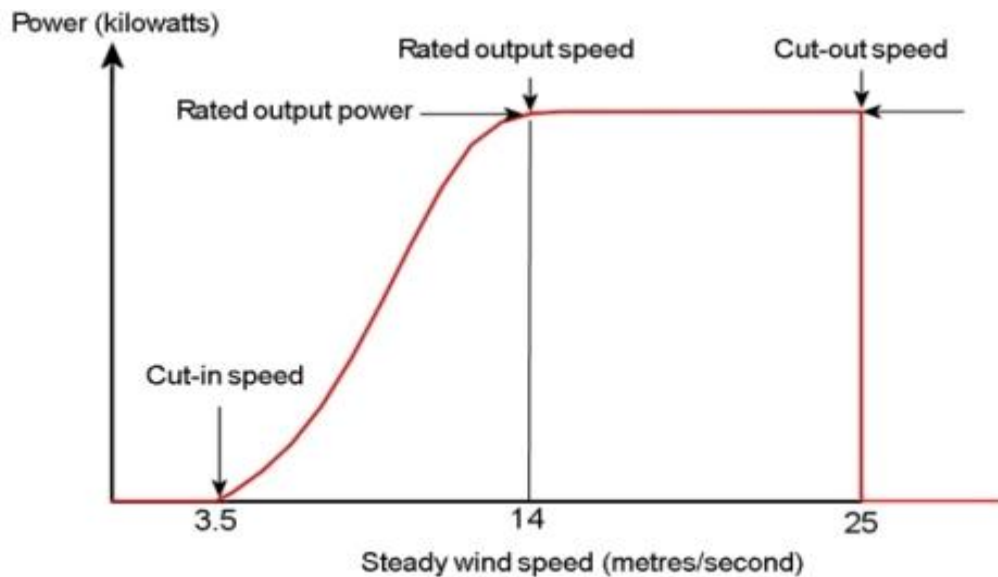


Figure 2.8: wind turbine power curve.

The energy that a wind turbine will produce depends on both its power curve and the wind speed frequency distribution at the site. Wind speed frequency distribution is a graph showing the number of hours for which the wind blows at different wind speeds during a given period of time [3].

Energy produced at any wind speed can be obtained by multiplying the number of hours of its duration by the corresponding turbine power at this wind speed obtained by the turbine's power curve. The total energy produced is calculated by summing the energy produced at all the wind speeds within the operating range of the turbine [3].

The height at which the speed of wind is measured affects the value of the wind speed. As height increases the speed of wind increases,

so it is more valuable to increase the height of wind turbine in respect of power that can be captured, but as height increases the initial capital cost of the tower increases also the maintenance and operation costs increases, so it is a compromise issue [3].

So when calculating the output of wind generator, the measured data of average hourly wind speed must be converted to the corresponding values at the hub height. The most commonly used formula is power law, expressed as:

$$\frac{V}{V_R} = \left(\frac{Z}{Z_R} \right)^\alpha \dots\dots\dots (2.1)$$

Where (V) is wind speed at desired height (Z) ; (V_R) is wind speed at the reference height (Z_R) ; α is the ground surface friction coefficient, the one seventh- power law ratio is used corresponds to most common surfaces.

2.8 Generic Generators Types:

Several generic types of generator are possible candidates in wind turbines. Historically, the squirrel cage, induction generator has been frequently applied commercially. A second popular type is the induction generator with wound rotor, while a third is the current excited, synchronous generator. These types have been synchronized directly to the grid, providing a constant speed solution [6].

This confines the choice of generator to a very few types, which exhibit inherently flexible behavior, notably the induction machines, or where there is an established technology for control, for example, the separately excited synchronous generator [6].

Criteria such as weight of active materials, operational characteristics, applicable type of semiconductor power converter, protection

considerations, service and maintenance aspects, environmental considerations, and list price are all relevant for the assessment [6].

The state-of-the-art of wind turbines seen from electrical point of view includes old and new potential concepts of generators and power electronics based on technical aspects and market trends [6].

- ❖ The squirrel cage induction machine has a very simple and reliable construction and there are no needs of special maintenance, however it has to be supplied with reactive power via the supply terminals although it.
- ❖ The wound rotor induction machine has a weak spot in the presence of the slip rings and brushes; it is more expensive than the squirrel cage machine and requires special maintenance. However, the presence of slip rings makes possible to control from outside the electrical characteristics of the rotor, by means of electric equipment.
- ❖ The synchronous machine is very attractive for direct drive applications although involve synchronous operation. The wound rotor machine is vulnerable to vibrations and the slip rings and brushes require special maintenance.
- ❖ The permanent magnet machine eliminates some disadvantages of the wound rotor machine; however it raises problems concerning the temperature and weight of the magnets and the fault capability.
- ❖ The switched reluctance machines have not yet implemented in wind energy conversion systems. The switched reluctance machine has the advantages of squirrel cage induction machine regarding the simplicity and robustness of the rotor and it is suitable for low speed operation. However it requires a sophisticated power converter and control.

2.9 A Photovoltaic Technology:

A material or device that is capable of converting the energy contained in photons of light into an electrical voltage and current is said to be photovoltaic.

A photon with short enough wavelength and high enough energy can cause an electron in a photovoltaic material to break free of the atom that holds it. If anearby electric field is provided, those electrons can be swept toward a metallic contact where they can emerge as an electric current.

The history of photovoltaics (PVs) began in 1839 when a 19-year-old French physicist, Edmund Becquerel, was able to cause a voltage to appear when heillumined a metal electrode in a weak electrolyte solution (Becquerel, 1839) [4].

2.10 Photovoltaic Construction:

A solar cell is considered the basic part in the photovoltaic system; it is a device that converts light energy into electrical energy by the photovoltaic effect. Solar cells are often electrically connected and encapsulated as amodule. PV modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from the elements (rain, hail). Solar cells are also usually connected in series in modules, creating an additional voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak DC voltage and current.

The photovoltaic cell consists of 6 different layers of materials as shown in Figure 2.9 [3].

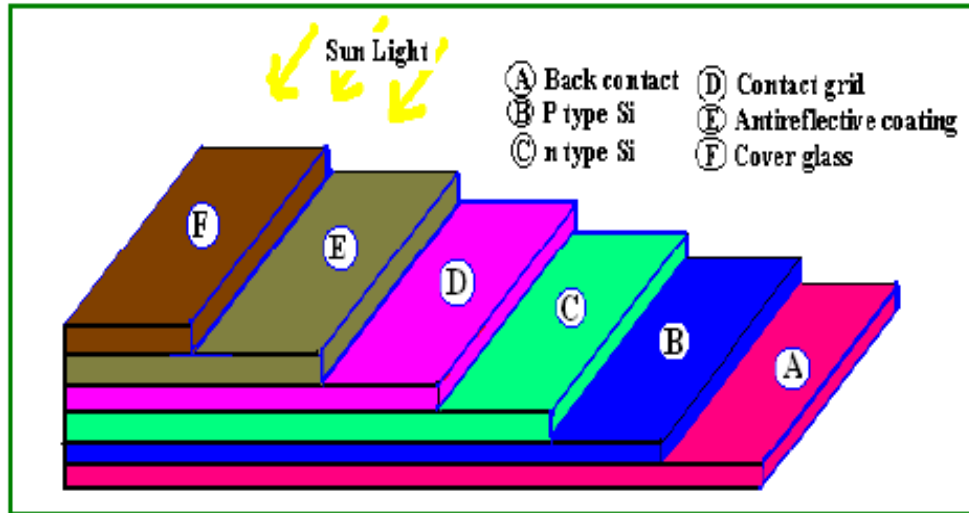


Figure 2.9: silicon PV cell construction

2.11 Main PV Cell Types

The material that is widely used in the industry of PV cells is silicon. Silicon can be found inside the sand in the form of silicon oxide (SiO_2). Depending on the structure of the basic material from which PV cells are made and the particular way of their preparation, PV cells can mainly be categorized as follows [3]:

1- Mono-crystalline:

The efficiency of a single crystal silicon cell varies between 13-16% and it is characterized by a high cost for its manufacture and has a dark blue color.

2- Poly-crystalline:

Its efficiency varies between 10-14% and it is characterized by lower cost silicon which is used for its manufacture and has light blue color.

3- Amorphous (non crystalline) silicon:

This type of photovoltaic cells achieves maximum efficiency not more than 10%. Production cost is much cheaper than what is for the previous two types. Its efficiency degrades with time.

Other types of PV cells use other materials or compounds rather than silicon. Other innovative PV technologies use multi-junction, silicon spheres, or photo electrochemical in manufacturing the PV cells [3] .

2.12 Equivalent Circuit of a Photovoltaic Cell

A simple equivalent circuit model for a photovoltaic cell consists of a real diode in parallel with an ideal current source as shown in Figure 2.10. The ideal current source delivers current in proportion to the solar flux to which it is exposed.

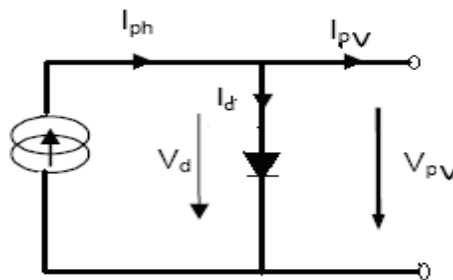


Figure 2.10: The Simplest Equivalent Circuit for a Photovoltaic Cell

If a variable load is connected through the terminals of the PV cell, the current and the voltage will be found to vary. The relationship between the current and the voltage is known as the I-V characteristic curve of the PV cell. The I-V curve for a typical silicon PV cell under standard conditions is shown in figure 2.11[4].

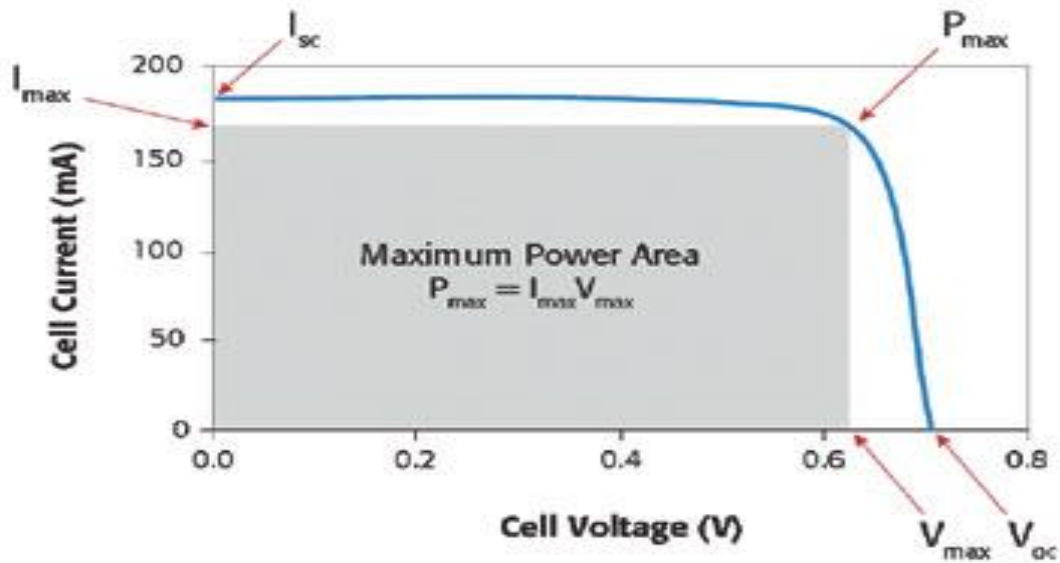


Figure 2.11: I-V characteristic curve of a typical Si cell.

To measure the I-V characteristic of a PV cell and to find the maximum power point, an international standard conditions shall be fulfilled. These standard conditions are: irradiance level that shall be 1000 W/m², the reference air mass that shall be 1.5 solar spectral irradiance distribution, and cell or module junction temperature that shall be of 25°C [3].

Open circuit voltage (V_{oc}) is the voltage appears across the terminals of the PV cell when it is open circuited, while short circuit current (I_{sc}) is the current passes through the short circuit when the terminals of the PV cell are short circuited. The term fill-factor is defined as the ratio between the maximum power delivered by the PV cell and the product of open circuit voltage and the short circuit current of the cell [3].

The cell will deliver maximum power at maximum power point (MPPT) on the I-V characteristic curve which represents the largest area of the rectangular under the I-V characteristic. A technique to utilize effectively the photovoltaic is known as a maximum-power- point tracking (MPPT) method, which makes it possible to acquire as much power as possible from the photovoltaic, this is accomplished by a built

in circuit in the charger controller or in the inverter circuit following the PV module [3].

2.13 Temperature and Solar Radiation Effects

The two most important effects that must be considered are due to the variable temperature and solar radiation. The effect of these two parameters must be taken into account while sizing the PV system [4].

A- Temperature Effect:

This has an important effect on the power output from the cell. The temperature effect appears on the output voltage of the cell, where the voltage decreases as temperature increases. This decrease for silicon cell is approximately 2.3 mV per 1°C increase in the solar cell temperature.

B- Solar Radiation Effect:

The solar cell characteristics are affected by the variation of illumination. Increasing the solar radiation increases in the same proportion the short circuit current.

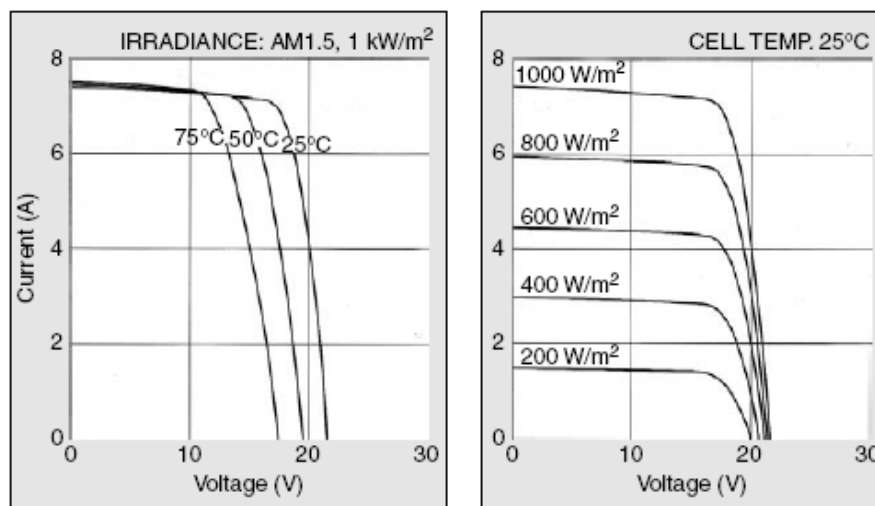


Figure 2.12: I-V characteristic curves under various cell temperatures and irradiance

As can be seen in Figure 2.12, as cell temperature increases, the open-circuit voltage decreases substantially while the short-circuit current increases only slightly. Photovoltaic, perhaps surprisingly, therefore perform better on cold, clear days than hot ones. For crystalline silicon cells, V_{OC} drops by about 0.37% for each degree Celsius increase in temperature and I_{SC} increases by approximately 0.05%. The net result when cells heat up is the MPP slides slightly upward and toward the left with a decrease in maximum power available of about 0.5%/°C. Given this significant shift in performance as cell temperature changes, it should be quite apparent that temperature needs to be included in any estimate of module performance [4].

2.14 Bypass Diodes for Shade Mitigation

In Figure 2.13(a) a solar cell in full sun operating in its normal range contributes about 0.5 V to the voltage output of the module, but in the equivalent circuit shown in Figure 2.13(b) a shaded cell experiences a drop as current is diverted through the parallel and series resistances. This drop can be considerable [4].

The voltage drop problem in shaded cells could be corrected by adding a bypass diode across each cell, as shown in Figure 2.14. When a solar cell is in the sun, there is a voltage rise across the cell so the bypass diode is cut off and no current flows through it as if the diode is not even there. When the solar cell is shaded, however, the drop that would occur if the cell conducted any current would turn on the bypass diode, diverting the current flow through that diode. The bypass diode, when it conducts, drops about 0.6 V. So, the bypass diode controls the voltage drop across the shaded cell, limiting it to a relatively modest 0.6 V instead of the rather large drop that may occur without it [4].

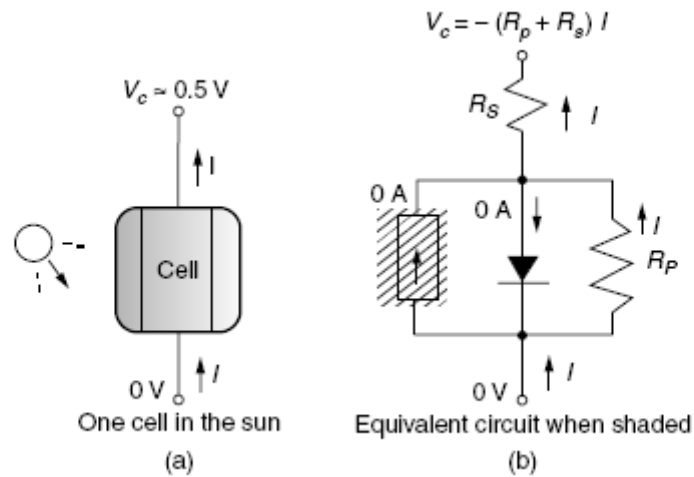


Figure 2.13: equivalent circuit (a) In full sun cell (b) shaded cell

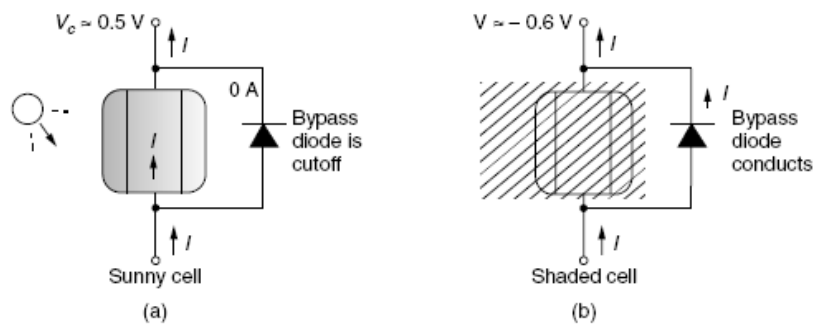


Figure 2.14: Mitigating the shade problem with a bypass diode.

Figure 2.15 helps explain how the bypass diodes do their job. Imagine five modules, wired in series, connected to a battery that forces the modules to operate at 65 V . In full sun the modules deliver 3.3 A at 65 V . When any of the cells are shaded, they cease to produce voltage and instead begin to act like resistors ($6.6 \text{ } \Omega$ per cell in this example) that cause voltage to drop as the other modules continue to try to push current through the string. Without a bypass diode to divert the current, the shaded module loses voltage and the other modules try to compensate by increasing voltage, but the net effect is that current in the whole string drops. If, however, bypass diodes are provided, as shown in Figure 2.15c,

then current will go around the shaded module and the charging current bounces back to nearly the same level that it was before shading occurred [4].

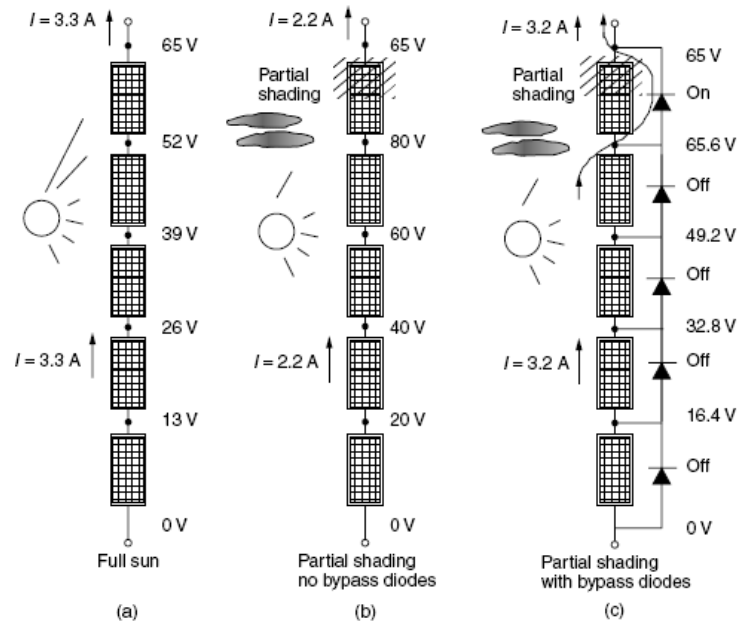


Figure 2.15: Showing the ability of bypass diodes to mitigate shading

2.15 Blocking Diodes

Bypass diodes help current go around a shaded or malfunctioning module within a string. This not only improves the string performance, but also prevents hot spots from developing in individual shaded cells. When strings of modules are wired in parallel, a similar problem may arise when one of the strings is not performing well. Instead of supplying current to the array, a malfunctioning or shaded string can withdraw current from the rest of the array. By placing blocking diodes (also called isolation diodes) at the top of each string as shown in Figure 2.16, the reverse current drawn by a shaded string can be prevented [4].

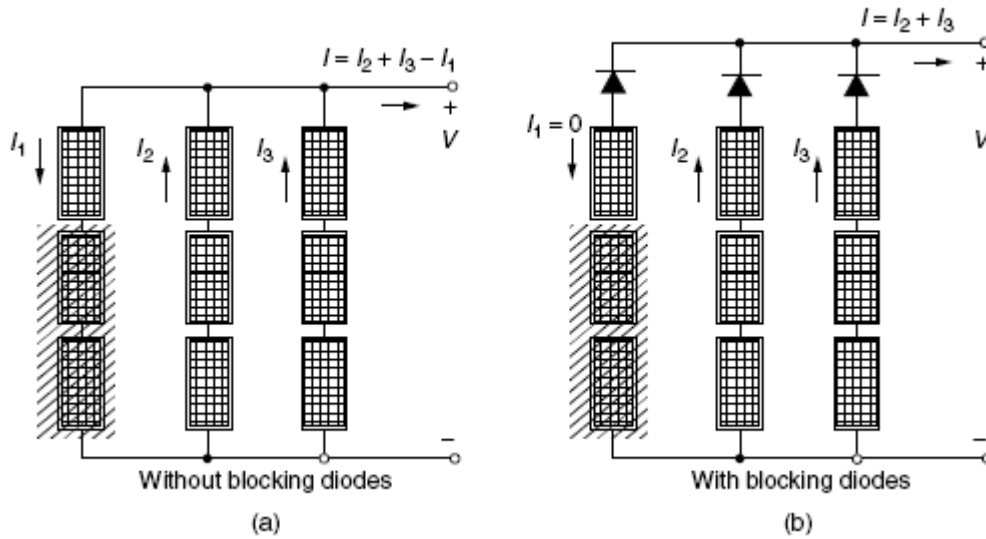


Figure 2.16: Blocking diodes

2.16 Hybrid System Components

The most frequent combination of renewable energy sources for electric power supply is wind and solar photovoltaic. The components and subsystems of a stand alone power supply system based on renewable sources are interconnected to optimize the whole system. The design of a hybrid system will depend on the requirements of the load (isolated or not isolated, rural or urban, DC or AC) and on the power supply system. Off-grid hybrid systems can also incorporate energy storage in batteries to increase duration of energy autonomy. If a permanent electric power supply is required, a backup diesel generator can be connected to the system to provide electric energy for peak loads which can't be covered by the hybrid system [3].

It is so important to determine the appropriate size of hybrid system components. The system shall not be oversized (expensive without increasing performance) or undersized (not capable to operate load).

A- Dump Load

The dump load is a set of parallel load resistances. Each parallel resistance can be turned on or off upon command. In a real application, the dump load may take the form of an electric heater to heat air or water or electrical pump used to store water. The main purpose of the dump load is to guarantee the inverter working normally. It is used to consume the surplus energy generated by the system [3].

B- Plant Management Unit

The purpose of the plant management unit is to control start and stop operation of the diesel generator, control start and stop operation of chargers, and storage and analyze data. It includes all connection and interfaces required [3].