Grid Parity and Solar Electricity for Homes

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Abstract: Although the discovery of the photovoltaic effect is over hundred years ago its application globally has been slow to take off because of its high price/kW ratio compared with the grid. Efforts to achieve price parity with the grid include the development of higher efficiency cells with materials other than silicon being employed. The Feed-In-Tariffs (FITs) is a cost effective way of popularizing solar electricity. The connection of the modules in an array for the panel can either be made in series to achieve the desired voltage or in parallel for the current level. The capacity of solar panel required to charge a 12V battery bank ranges from 14V to 17V with the upper limit reserved for hot environments since cell generated voltage drops with increasing temperature. The charge controller is a desirable feature introduced in the solar electric circuit to protect the battery bank. Before the DC stored in the battery bank can be used in a home wired for an AC supply, it has to go through an inverter. Ideally, the surge capacity of the inverter should be stated. It is recommended that the whole solar panel be electrically well grounded.
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1. Introduction:

The search for alternative and sustainable energy resources has been instrumental to the revival of interest universally in photovoltaic (PV) technology as one source that can contribute to solving the ever dwindling fossil derived energy availability problem and as well, reduce our individual carbon footprint. The discovery of the photovoltaic effect was over a hundred years ago but widespread application of this technology has been very slow in taking off. In recent years however, photovoltaic technology has been gaining ground steadily as an alternative and sustainable way to produce electricity. The first use of solar modules to power satellites was in 1958 and today, solar power technology is still the primary source of energy in space stations. The widespread use of solar cells in space applications may be attributed to their higher power-to-weight ratio compared with any of the other competing technologies. However, this success was also responsible in the sluggish progress in global applications because space users were willing and ready to pay a premium for the best possible cells available. As a result therefore, the semi-conductor industry had no incentive to invest in low-cost solutions albeit with reduced efficiency that might potentially reduce instead of increase their profit margin. The status quo where the price of cells was determined largely by the semiconductor industry reigned until the move to integrated circuits in the 1960s led to the availability of larger boules at lower relative prices and correspondingly a fall in the price of the resulting cells. However these had limited effect on prices for the estimated cost of the cell in 1971 was still as high as $100/W (Perlin, 2002).

Solar cells use light energy, photons from the sun to generate electricity through the photovoltaic effect. The structural load carrying member of a module can either be the top layer or the back layer. The majority of modules use wafer-based crystalline silicon cells or thin film cells based on cadmium telluride or silicon. The conducting wires that take the current off the cells may contain silver, copper or other conducting (but generally not magnetic) transition metals (Jacobson, 2009). Most solar modules are currently produced from silicon PV cells. These are typically categorized into either mono-crystalline or multi-crystalline (polycrystalline) cells. There is also the amorphous or thin film modules that are produced in rigid and flexible forms. While the thin film modules have lower efficiencies, (usually 7-10%), they offer certain advantages which include less power loss than the others in hotter environments.

This study is interested in looking at the efforts to achieve price parity with the grid together with the essential components and the associated configuration required to supply solar electricity to homes.

2. Price Parity

Before solar electricity can compete effectively with the grid, the price/kW has to be comparable with that of the grid. Price parity of photovoltaic electricity with the grid is likely to be reached in stages and this is expected to be achieved first in areas that have abundant sunshine and high costs of electricity. Such areas may include California and parts of Japan. Report holds it that grid parity has already been reached in Hawaii and other islands that otherwise use diesel fuel to produce electricity. The forecast for reaching grid parity in the US has variously been set for 2015 (Brown, 2011). The General Electric support this forecast and speaking through its chief Engineer in a conference in 2007, went further to qualify the prediction by stating that what is meant is grid parity without subsidies in sunny parts of the United States (Wynn, 2011).

On the same issue of price parity with the grid, work has been on-going to develop solar panels whose $/W cost ratio is comparable to grid values. Some of these studies include the high-efficiency multi-junction cells originally developed for special applications such as satellite and space exploration that are now being employed in terrestrial concentrators (Swanson, 2011). These multi-junction cells consist of multiple thin films produced using metalorganic vapour phase epitaxy. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge , and $GalnP_2$ (Spectrolab, 2011). Each type of semiconductor will have a characteristic band gap energy which, loosely speaking, causes it to absorb light most efficiently at a certain colour, or more precisely, to absorb electromagnetic radiation over a portion of the spectrum. The semiconductors are carefully chosen to absorb nearly in all solar spectrum, thus generating electricity from as much of the solar energy as possible.

GaAs based multi-junction devices are the most efficient solar cells developed to date. In October 2010, the publication, (Optics, 2011) reported that triple junction metamorphic cell produced by Spire Semiconductor reached a record high of 42.3% conversion efficiency.

Other efforts to reduce cost of the Solar cell include the work on Dye-sensitized solar cells (DSSCs) developed by prof Michael Gratzel in 1991 at the Swiss Federal Institute of Technology (EPFL) from low-cost materials that do not need elaborate equipment to manufacture. If the claim that the DSSCs can be made in a DIY fashion is proven, there will be the possibility to produce more of this type of solar cells. In bulk, it should be significantly less expensive than older solid state cell designs. DSSCs can be engineered into flexible sheets, even although its conversion efficiency is said to be less than the best thin film cell, its price/performance ratio should be high enough to allow it to compete favourably with fossil fuel electricity generation.

Depending on construction, solar cells produce electricity from a range of frequencies of the sun, but usually cannot cover the entire solar range (specifically, ultraviolet, infrared and low or diffused light). As a result, much of the incident sun energy is wasted by solar cells, and they can give far higher efficiencies if illuminated with monochromatic light. Therefore another design concept is to split the light into different wavelength ranges and direct the beams onto different cells tuned to those ranges. This has been projected to be capable of raising efficiency by 50%. The use of infrared photovoltaic cells has also been proposed to increase efficiencies, and perhaps produce power at night.

Solar conversion rate (solar panel efficiencies) can vary from 5-18% in commercial products, typically lower than the efficiencies of the cells in isolation. Panels with conversion rates around 18% are in development. This high efficiency photovoltaic development incorporates the flexible CIGS (Copper Indium Gallium di-Selenide) technology that uses no silicon at all, and can be made into panels with or without discrete cells (altEU, 2011) and (Empa, 2011) .

2.1 The FITs Scheme

Because of high installation cost when compared with electricity provided by the national grid, the use of PV system has been limited to places where there is no practical source of electric power but where sunshine is in abundant supply. Remote applications such as cabins, caravans, boats and small electronic devices benefit from electricity supplied from PV modules where grid service is not available. Tying the PV module to national grid is beginning to gain popularity especially in countries where the Feed-In-Tariffs (FITs) are practiced. In this arrangement, the PV module owner sales the extra electricity produced to the grid utility. This is a very cost-effective way to bring solar electricity into everyday lives. Where the FITs are practiced, the advantage of available solar energy together with the associated incentive grants offered by governments can be enjoyed while still being assured that when the solar electricity is not available the utility grid is there to provide.

2.2 Factors Affecting Performance

There is a small voltage across a conducting diode called the forward voltage drop and its value varies according to the type of diode used. (Strong and Scheller, 1993) have quoted a value of about 0.75V for a silicon diode and 0.5V for a Schottky diode. For a normal silicon diode, the value quoted by (Piggott, 1997) is 0.7V. The forward voltage drop of a diode is almost constant whatever the current flowing through, therefore it has a very steep characteristic (current-voltage graph). The diode is used to prevent reverse flow from the battery bank to the solar modules in the night. When a reverse voltage is applied a perfect diode does not conduct, but all real diodes leak a very tiny current of a few µA. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction. However, all diodes have a maximum reverse voltage (usually 50V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction and this can lead to a breakdown.

Depending on the latitude, there is an optimum tilt angle for any solar panel installation. In the Northern Hemisphere, a tilt angle equal to the latitude will yield the best all year-round production. A tilt angle equal to the latitude of the location *minus* 15 degrees will favour summer production, while an angle equal to the latitude *plus* 15 degrees will favour winter production (altEU, 2011).

One of the biggest environmental factors affecting solar electricity production is shading. PV modules are very sensitive to shade. For example, if shaded by as much as a leafless tree branch, a PV module could lose up to 80% of its output. When selecting a site for solar panel installation, a location with the least possible shade during the hours between 9 AM and 3 PM should be chosen.

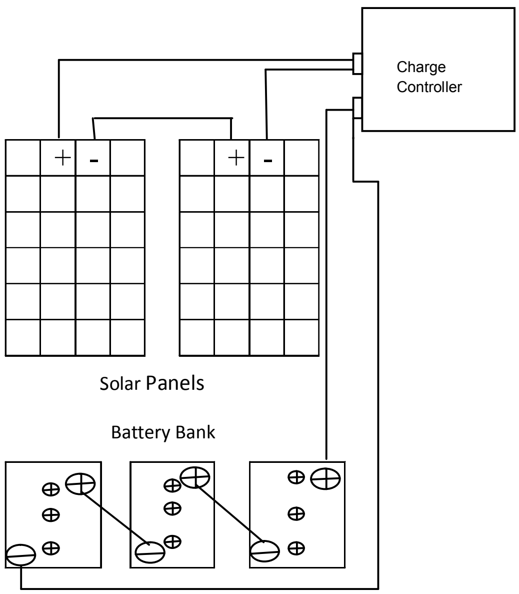

Figure 1. Battery Bank and Solar Panel Connection (Schematic)

3. Solar Electricity for Homes:

In a typical solar electricity supplied home, the system may comprise – a PV array (PV modules connected together), a charge controller, a battery bank, a DC fuse box, an inverter, and a 240V circuit breaker among others. In figure 1 the essential components of the PV system are shown schematically.

An array of solar cells converts solar energy into usable amount of direct current (DC) electricity. To achieve this, when the sun shines, photons in sunlight hit the solar panel and are absorbed by the silicon semiconducting materials. Then the negatively charged electrons are knocked loose from their atoms, allowing them to flow through the cells and produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction and thus produce DC electricity. In order not to overcharge the battery bank, the charge controller regulates the current flow from the solar modules to the battery bank. The charge controller may also have the responsibility if so configured, to stop reverse flow when the battery is not being charged. The electricity stored in the battery bank may be distributed through a DC fuse box to power low voltage DC appliances. For a property wired for normal 120V or 240V, the battery bank supplies the electricity through the inverter. The inverter converts the DC voltage to the appropriate AC.

3.1 System Components

In use, the cells must be connected electrically to one another to produce the module. The modules are similarly connected together to produce an array of modules of solar panel. The electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. Cells must also be protected from mechanical damage and moisture (Davis, 2011). Most solar panels are rigid, but semi-flexible ones, based on the thin-film cells, are also available.

In operation, these cells may require separate diodes to avoid reverse currents at night and when partial or total shading occurs. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics that make the provision of these diodes unnecessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to control this by providing good ventilation behind the panels

There are two main methods of using these panels to provide electric power to homes, cabins and offices and these are the stand-alone battery based systems referred to as 'off-grid' and the utility-interactive known as grid-tied systems.

3.1.1 The Modules

The module is made up of cells that are joined in series by soldering. Each of the cells generates about 0.55V. These cells are sandwiched between two plates. The module is covered by an impact resistant transparent glass at the front and plastic sheet at the back. The module is finally framed for rigidity and mounting. Since the module performance is affected by the surrounding environment, for a 12V battery bank, the module voltage should range from 14V to 17V. The 17V should be used in hot climates where the cells could get hot with temperature and generate at lower voltage. Module voltage higher than the battery voltage rating is required to make up for the losses. The lower range of the module voltage rating, 14V may operate sluggishly as the battery charging approaches the full charge level. However, this type can be used in simple systems without the need for a charge controller and therefore are sometimes referred to as self regulating modules.

If the module is aluminum framed, the mounting bracket and screws should not be made of dissimilar metal in order to avoid setting off electrostatic reaction followed by oxidation. In this situation, it is advisable to use aluminium or stainless steel brackets and screws. If steel brackets are to be used there must be a proper separation between the aluminium frame and the steel bracket by plastic or rubber washer. In mounting the modules provision must be made for grounding. A driven ground rod should be attached if panels are metal mounted to the ground. For a wooden mount, all modules must be wired to the ground and the removal of any module must not break the grounding of any other module. Figure 2 and figure 3 show the different ways of connecting the modules in array of solar panel.

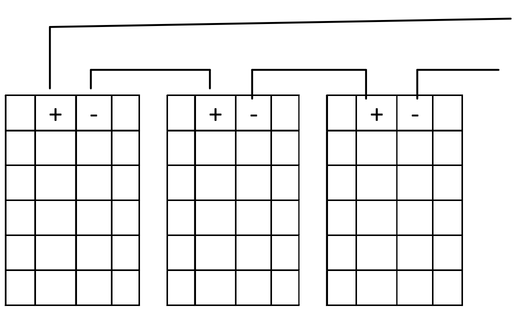

Figure 2 Series Connection of Solar Modules

Figure 2 shows schematically the connection in series of array of three modules each 12V to yield a sum total of 36V in the solar panel.

Similarly, Figure 3 is a solar energy panel consisting of an array of three modules each of 12V connected in parallel for a 12V system

A small system operating only few lights and an appliance such as a radio may just use a 12V DC. In the automobile industry 12V DC is common so sourcing fittings and appliances for use in the home will not be difficult. Appliances with high power requirements however are not suitable for the 12V

DC system because of the associated high current requirement.

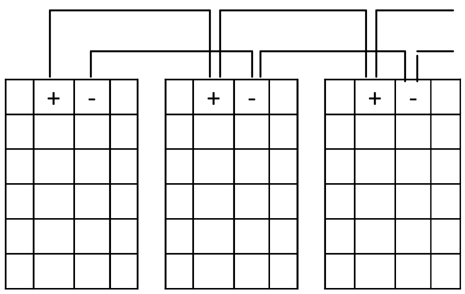

Figure 3 Parallel Connection of Solar Modules

In order to reduce losses, high current systems use cables that are not only too large but also too expensive. As an example, to supply no other appliances than lights, 10 and 12 gauge cables must be specified.

3.1.2 Charge Controller

The charge controller in a PV electricity generating system is a voltage regulation device which matches and protects both the battery banks and the PV module. Without the charge controller, the deep cycling lead acid battery which is normally used would soon reach a state of overcharge which could ruin the batteries. If only part of the current is shunted, the remainder trickles through to maintain the batteries 100% fully charged. When the battery bank is fully charged the electricity generated is dumped. In the night it is the duty of the charge controller, if so configured, to ensure that no reverse flow occurs as this could damage the PV modules. A conventional circuit board or a sealed solid state charge controller may be used. As the full solid state unit has no relay it is therefore recommended for environment where it will be subjected to extremes in weather conditions especially in areas where sparks and arcing are rampant (Solar Inc, 1998). Blocking diodes are often used to prevent reverse flow at night but each diode consumes about 0.7V while charging the batteries. For a conventional charge controller, when the battery bank is being charged, the relay is closed but is kept open at night after the controller has sensed low voltage from the modules.

3.1.3 Battery Bank

Deep cycling battery banks are recommended. Maintenance free batteries may be used for PV systems. These batteries come in different forms including sealed liquid electrolyte, captive electrolyte and gel cell. The latter group needs no addition of water and normally does not release gas. This group of batteries will of course release gas through the pressure relief vent if the charge controller fails and the batteries are charged at above the maximum recommended charging voltage. Should this ever happen however, there is no way of replenishing the lost water. The ordinary maintenance free batteries, unlike the standard deep cycle batteries, do not tolerate being left discharged for a long period of time. On the other hand, if the standard deep cycle battery is left discharged for a long period of time, it is possible to restore the battery by being overcharged for some period and losing a significant quantity of water which can later be replaced. To mix good and bad batteries in a bank is frowned at since the good ones can only operate at the level of the bad ones. The automobile battery is not usually designed for deep cycling since it will be ruined by complete discharge and recharging cycles that occur in a solar energy generating system.

The deep cycle batteries that may be used are those usually referred to as the electric vehicle, golf cart, marine or fork lift batteries. This class of batteries is available in the 6V and 12V sizes. The 6V size may weigh as much as 30kg and a rating of 180-220A-h at 20 hour discharge rate. Another important parameter to look for is the cycle which could be given as 600 80% discharge or so.

3.1.4 The Inverter

Homes are normally AC wired and to be able to use DC electricity from the battery bank, conversion to AC would be necessary. The conversion from DC to AC is achieved through the inverter. The inverter switches the current on and off while also reversing the flow to produce alternating current at the battery bank voltage. The resulting alternating current is pushed through a step up transformer to yield the standard 240V or 120V. This off and on switching must be carried out at the precise speed to produce either 50Hz for the 240V or 60Hz for the 120V standard. Unlike utility current, the resulting inverter current produces square wave. The standard utility wave is sinusoidal. Square waves are not very useful except for resistive loads that produce light and heat. The inverter is therefore made to produce a modified square wave in which the width and height change according to the load thus approximating the sine wave (see figure 4).

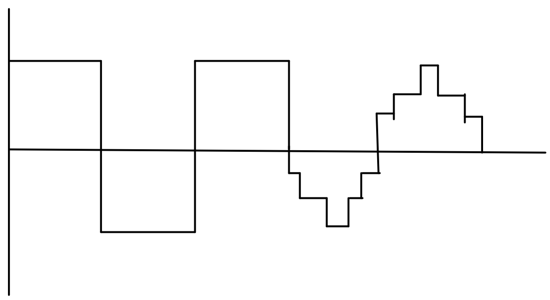

Figure 4. Square and Modified Square Current (Schematic).

The extent of synchronisation of the different current and voltage waveforms defines the power factor. For a resistive load such as light bulb, all that is required of the inverter is to maintain steady voltage and current. The current waveform and the voltage waveform in a reactive load such as an inductor motor are different. When an inverter powers reactive and non-reactive loads, the waveform of the inverter is changed by the reactive load and this creates an interference in the other appliance. An inductor motor draws momentarily about three times its rated power on start up. Inverters are usually rated for the continuous power output but good makes also state the surge ability.

3.1.4 Safety

Although low voltage, the violent arcing that occurs when a 12V battery is accidentally short circuited is a reminder to all that PV installations should be adequately fused. The battery bank has the potential to dump its whole supply instantaneously if short circuited. Any circuit from the battery should be fused and the fuse should be located close to the battery to reduce the chance of short circuiting occurring between the battery and the fuse. When DC circuits are switched off, current arcs are produced and persist through the air while the two contacts are still near each other. Therefore a DC rated switch or circuit breaker is spring loaded to help accelerate the disconnection movement. For an AC circuit, the arcing may not occur because the current changes direction 50/60 times every second. For DC current, a fuse designed to prevent arcing when it blows is needed. The whole circuit should be adequately earthed/grounded. It is necessary to have the batteries well ventilated with spacing between batteries in the bank of at least 6mm. The inverter should be located as close as possible near the main battery terminals and in any case, should not be longer than 1.2m. The battery bank should also be vented to the outside.

Other than incandescent light, polarities should never be reversed to any DC appliance. If in doubt, test with a voltmeter first. All wires must be adequately sized for the current to be carried. During installation, the modules should first be covered with opaque sheet to prevent power generation at this stage.

4. Conclusion

1. Universal application of solar technology was stalled for a long time because the semiconductor industry had no incentive to invest in low-cost solutions since space users were willing and ready to pay a premium for the best possible cells available.
2. Solar cells produced today are mostly mono-crystalline and polycrystalline silicon cells.
3. Efforts to achieve price parity with the grid include choosing the semiconductors carefully so as to absorb the magnetic radiation in all solar spectra and tuning the cells to absorb from solar light split into different ranges.
4. Exceeding the maximum reverse voltage of a diode can lead to system breakdown.

5. PV modules are sensitive to shading therefore shades should be avoided while choosing the location of the solar panels.
6. The provision of a diode may not be necessary for the monocrystalline silicon cell since the p-n junction may have adequate reverse current characteristics.
7. A 12V battery bank requires solar panel capacity between 14V – 17V when charging. The range upper limit suits hot environments since the cell voltage generated drops with temperature.
8. It is useful for a manufacturer to state the surge capacity of the inverter in addition to the normal rated capacity.
9. Any circuit from the battery should be fused and the fuse should be located close to the battery in order to reduce the chances of short circuiting occurring between the battery and the fuse.

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