A CASCADED INVERTER FOR TRANSFORMERLESS SINGLE PHASE GRID CONNECTED PHOTOVOLTAIC SYSTEMS

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A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

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CERTIFICATE

This is to certify that the thesis entitled "**A Ccascaded inverter for transformerless single phase grid connected photovoltaic systems.**", submitted by **Mansing Hembram (Roll. No. 109EE0272)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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Dedicated to

my parents

ABSTRACT

The design and control issues associated with the development of single phase grid-connected photovoltaic system incorporating a multi-level cascaded inverter are discussed in this paper. The advantages of transformer less inverter over a full-bridge inverter in combination with a line frequency transformer which is a common topology has been described in this report. Attractive features of multi-level inverters have been studied and descriptive details of photovoltaic system along with control and grid synchronization has been given this paper. Simulation results are presented to demonstrate the suitability of the control method.

CONTENTS

List of Figures:

Chapter 1

Introduction

1.1 Photovoltaic System: An Overview

In the recent past, various different inverter topologies have been proposed or are currently utilized for low power, single-phase grid-connected photovoltaic (PV) systems. A full-bridge inverter in combination with a line-frequency transformer is a familiar and common topology. The transformer, however, is not a necessity or requirement and inverters avoiding transformers provide various advantages. Inverters without transformers outmatch those with presence of transformers in respect to higher efficiency, reduced cost, weight, embodied energy, and minuscule size.

Apart from beneficial and preferential transformerless concepts, multilevel inverters assure better solutions, as these inverters have the capability of producing ``stepped" output voltage waveforms, which tends to approach the sinusoidal waveform better than waveforms brought out by conventional full-bridge inverters. Multilevel inverters therefore require less filter effort on the AC side, which makes the inverter cheaper, lighter and more compact. In order to generate the "multi-level" (stepped) output voltage waveform, different DC voltage levels are required, which can be rendered by dividing a PV array in appropriate sub-arrays.

1.2 PV Energy System in Indian Scenario:

More than 80% of its oil is imported by India; therefore it has a great dependency on external sources for all-round development. With exhausting fossil reserves across the world, there has been a threat to India's future energy security. Hence, the Indian government is investing heavy money on development of alternative sources of energy such as solar, small hydroelectric, biogas and wind energy systems besides the conventional nuclear and large hydroelectric systems.

The distribution of power generation from various sources according to the Ministry of New and Renewable Energy, Government of India as on 31.01.2011 is shown in Table1.1.

TABLE 1.1: DISTRIBUTION OF POWER GENERATION IN INDIA FROM DIFFERENT SOURCES

Technology	Capacity Installed (MW)	Percentage of Total Installed Capacity
Thermal	93,838	54.20
Hydro	37,367	21.69
Renewable	18,842	10.94
Gas	17,456	10.13
Nuclear	4,780	2.77

From the year 2002 onwards, renewable grid capacity as a percentage of total capacity has changed rather increased drastically by about four times. In April 2002, energy which are renewable based power generation put in capacity was 3497 MW which was around 3% of the total installed capacity in the country. India presently stands among the top five nations of the globe in terms of renewable energy capacity with an installed base of over 19000 MW of grid interactive renewable power which is about 11% of our aggregate installed capacity.

Though the solar power generation concept is popular among space applications, it is yet to get its important place in domestic applications due to high costs connected with generation of electricity from the solar arrays. Howsoever, the Ministry of New and Renewable Energy (MNRE), Government of India has already taken up various measures to focus on the generation of solar energy in Indian energy sector. India specifically should use the chance of altitudinous solar insolation levels than many of the nations in the world to tackle solar power. The approximated potential of solar energy that can be tackled on the surface is 50MW/sq.km.

The ministry of new and renewable energy has highlighted specially of wind power generation as it is more financially beneficial on a wide scale electricity production. Howsoever, solar is a popular alternative where wind energy has to be transmitted at length from generation site to the customers.

The Indian solar merchandise foremost comprises solar water heaters, solar cookers, etc. With new and better technology of solar cells, there has been a rapid increase in the consumption of this energy system in several organizations such as Indian rails. The railways are utilizing them for electrification of tracks, manned level crossings, canteens, etc. The new technology architectural designs make provision for photovoltaic cells and required circuitry for itself sufficient power generation with artistic design.

The present contribution of solar energy power generation through photovoltaic systems is 37.66MW (upto 31.03.2011). The approximated power generation from solar was given by MNRE as 200MW by the last of 2011. The MNRE has sanctioned Jawaharlal Nehru National Solar Mission, whose commitment is to create and implement the solar energy technologies in the nation to achieve parity with the grid tariff by 2022. To accomplish the goal of 20 GW by 2022, the mission is determined on maximizing the production of grid-connected solar energy of 1000MW by 2013. The Ministry issued guidelines for (i) new grid projects through NVVN, (ii) small grid projects through IREDA, (iii) off-grid solar applications and utilities; and (iv) technical performance and domestic content necessities of solar projects, to operationalize the Solar Mission. Projects under each of the variable schemes have been approved for implementation, resulting to capacity aggregation of more than 17 MWp during the year and approval of 804 MW of grid connected projects and 32 MW of off-grid projects.

Therefore, at the outset, the mission is focussed on encouraging off-grid power generation for houses which decreases the reliance on the grid. The solar energy designers will be bunched up with the conventional power in the form of compact energy transmission. The suggested solar power generation for the financial year 2011-2012 is set by the mission at 150MW.

Hence, several projects are taken up all over the country by MNRE and the state government departments such as Maharashtra Energy Development Agency to tackle solar power through photovoltaic cell systems and solar thermal systems. The financial and economical help to such projects is being encouraged by the government through Indian Renewable Energy Development Agency (IREDA), a public sector company with a motto "ENERGY FOR EVER".

A low power stand-alone solar generation system of capacity of 250KWh per month would cost around Rs.5 lakhs (as per taxes in year 2010-11). The current cost of electrical power generation from solar thermal and solar photovoltaic energy systems is ₹15.31 and ₹17.91 per unit, respectively as given by Central Electricity Regulatory Commission.

1.3 System performance and components:

The system performance is relied on insolation and energy, tracking of the sun, shading and dirt, temperature and efficiency, monitoring, performance factors, module life. The various components of photovoltaic systems include trackers, inverters and monitoring systems.

1.4 System description:

When preventing the use of transformer in the given topology there is no methods of increasing the inverter output voltage Vinv to the required RMS grid voltage value. Therefore, high DC bus voltages are required to guarantee the power flow from the two PV sub-arrays to the grid. The system can only function when the addition of the DC bus voltages VPVA1+VPVA2 is more than the total amplitude of the grid voltage at all moment. This constraint decides the minimum power rating of the system. Most crystalline PV modules present on the merchandise today have 36 cells in series and operating voltages of about17 V at 258C and 1000 W/m2. Howsoever, when the temperature rises, the operating voltage can fall to as less as 12 V per module. Owing to this nature, at least 14 crystalline 36-cell-PV modules in series are needed for each of the two sub-arrays allowing for system power ratings of 1.3 kW and above.

1.5 Control System description:

The two main tasks of the system control are:

i. the energy transferred from the PV arrays to the grid should be maximum,

ii. the harmonic distortion during the generation of a sinusoidal current Igrid should be less, even also under presence of grid voltage harmonics.

The control of the system consists of a MPPT, a DC bus voltage controller, the current reference value generation and current controller. A control signal is generated by each controller which contains the information whether Iinv needs to be raised or lowered. Along with the information which mode the inverter operates in, the control signal is needed to derive the switching signals for the each switches of the inverter.

1.6 Switching sequence:

A single full-bridge has 16 inverter states, of which four allow bi-directional current flow and a fixed inverter output voltage.The task is to choose the states so that:

i. each switch should be stressed in the same way in order to get equal losses in each switch and with that an equal temperature distribution;
ii. the switching frequency should be less. To achieve this, conducting switches should be kept on as long as needed or possible;
iii. over one period the amount of power derived from both arrays should be the same. Both sources have to be loaded in a symmetric fashiom;
iv. the presence of ripple on the DC bus capacitors should be low since with increasing ripple losses also increase. To achieve a low ripple the two sources are required to be discharged continuously.

1.7 The benefits of solar electricity:

i. Cut your electricity bills: sunlight is free, so once you've paid for the initial installation your electricity costs will be reduced.

ii. Get paid for the electricity you generate: the government's Feed-In Tariffs pay you for the electricity you generate, even if you use it.

iii. Sell electricity back to the grid: if your system is producing more electricity than you need, or when you can't use it, you can sell the surplus back to the grid.

iv. Cut your carbon footprint: solar electricity is green, renewables energy and doesn't release any harmful carbon dioxide] or other pollutants. A typical home solar PV system could save over a tonne of carbon dioxide per year – that's more than 30 tonnes over its lifetime.

Chapter 2

Photovoltaic Systems

2.1 Photovoltaic Systems:

2.1.1 Photovoltaic Cells:

Photovoltaic (PV) cells, or solar cells, take advantage of the photoelectric effect to produce electricity. The building blocks of all PV systems are PV cells because they are the devices that convert solar energy into electrical energy.

Usually known as solar cells, individual PV cells are electricity-producing devices made of semiconductor materials. PV cells come in many sizes and shapes, from smaller than a postage stamp to several inches across. They are more often than not connected together to form PV modules that may be up to several feet long and a some feet wide.

Modules, in turn, can be united and connected to constitute PV arrays of various sizes and power output. The modules of the array form most of the part of a PV system, which can let in electrical connections, mounting hardware, power-conditioning equipment, and batteries that store solar energy for use when the sun is not bright.

When sunlight falls on a PV cell, there may be reflection, absorption, or passing right through. But only the absorption of light generates electrical energy. The energy of the absorbed light is transposed to electrons in the atoms of the PV cell semiconductor material. With their newfound energy, these electrons flee from their natural positions in the atoms and transmute part of the electrical flow, or current, in an electrical circuit. The force, or voltage, needed to drive the current through an external load is provided by a special electrical property of the PV cell—what is called a "built-in electric field".

2.1.2 Photovoltaic Module:

The voltage produced by a single solar cell is very less, about 0.5V. So a large number of solar cells are combined both in series and parallel connections to achieve the desired result. In case of partial shading, diodes are required to avoid reverse current in the array. Good ventilation behind the solar panels are rendered to avoid the practicability of less efficiency at high temperatures.

2.1.3 Photovoltaic arrays:

A photovoltaic array (or solar array) is a linked collection of solar panels. One module can seldom raise enough power to meet needs of a home or a business, so the modules are linked together to constitute an array. Most PV arrays make use of an inverter to convert the DC power brought about by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are first and foremost combined in series to attain the desired voltage; the individual strings are then combined or connected in parallel to permit the system to create more current. Solar panels are usually mensurated under STC (standard test conditions) or PTC (PVUSA test conditions), in watts. Commonly panel ratings vary from a little less than 100 watts to somewhat over 400 watts. The array rating comprises a summation of the panel ratings, in watts, kilowatts, or megawatts.

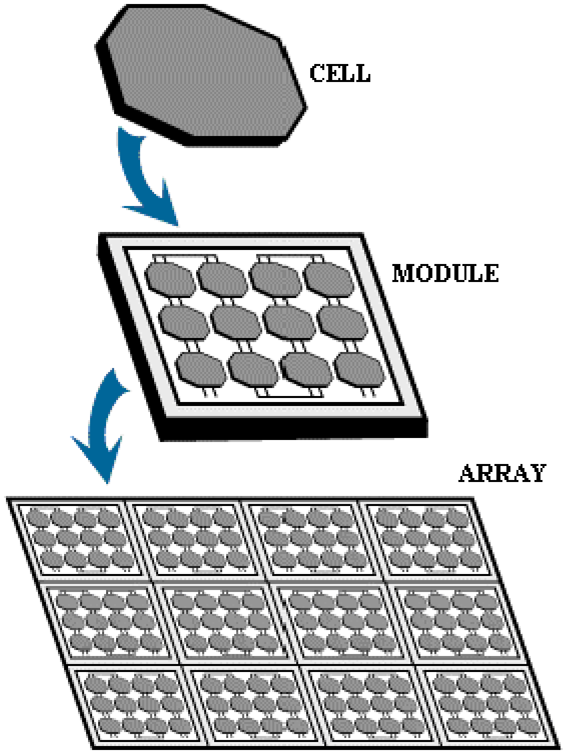


Fig 2.1 Photovoltaic Array

2.1.4 How PV cells are made?

The process of constructing orthodox single- and polycrystalline silicon PV cells starts with very unclouded semiconductor-grade polysilicon - a material made from quartz and used thoroughly throughout the electronics industry. The polysilicon is then warmed to melting temperature, and small amounts of boron are added to the melt to make a P-type semiconductor material. Next, an ingot, or block of silicon is created, usually using one of two methods: 1) by growing a clean crystalline silicon ingot from a seed crystal drawn from the molten polysilicon or 2) by casting the molten polysilicon in a block, creating a polycrystalline silicon material. Individual wafers are then sliced from the ingots using wire saws and then bore upon to a surface etching process. After the wafers are cleared nicely, they are positioned in a phosphorus diffusion furnace, making a thin N-type semiconductor layer around the complete outer surface of the cell. Then, an anti-reflective coating is employed to the top surface of the cell, and electrical contacts are acted upon on the top (negative) surface of the cell. An aluminized conductive material is wedged on the back (positive) surface of each cell, regenerating the P-type properties of the back surface by supervening upon the diffused phosphorus layer. Then each cell is electrically tested, sieved based on current output, and electrically brought togather to other cells to form cell circuits for tacking togather in PV modules.

2.1.5 Working of PV cells:

Photovoltaic (PV) cells consists of at least 2 semi-conductor layers. One layer having a positive charge, and the other having a negative charge.

Sunlight comprises little particles of solar energy called photons. When a PV cell is exposed to the sunlight, majority of the photons are reflected, pass right through, or absorbed by the solar cell.

When enough photons are absorbed by the negative layer of the photovoltaic cell, electrons are freed from the negative semiconductor material. Due to the manufacturing process of the positive layer, these freed electrons naturally migrate to the positive layer creating a voltage differential, similar to a household battery.

When the 2 layers are joined to an external load, the electrons move through the circuit producing electricity.Individual solar energy cell generates only 1-2 watts. To raise power output, cells are featured in a weather-tight package known as a solar module. These modules (from one to several thousand) are then wired up in series and/or parallel with each another, into something called a solar array, to make the wanted voltage and amperage output needed by the given project.

Due to plentily availability of silicon, the semi-conductor material that PV cells are firstly created of, and the practically unlimited resource in the sun, solar power cells are very eco-friendly. They burn no fuel and have absolutely no mobile parts which reckons them nearly maintenance free, clean, and silent.

2.1.6 Mathematical model PV cell:

$$V_c=(A \times K \times T_c/e) \ln (I_{ph}+ I_o-I_c/I_o)-R_s \times I_c$$

The symbols used are:

Vc= cell output voltage

Tc= reference cell operating temperatures

Rc= series resistance of cell

Iph= photocurrent functions of irradiation level and junction temperatures.

Io= reverse saturation current of the diode

Ic= cell output current

K=Boltzman constant(1.38 x 10^-23 j/k)

E= electron range(1.602 x 10^-19C)

2.2 System performance:

2.2.1 Insolation and energy:

Solar insolation consists of direct radiation, diffuse radiation and reflected radiation (or albedo). At noon on a cloudless day at the earths equator, the power of the sun is about 1 kW/m², on the Earth's surface, to a plane perpendicular to the sun's rays. As such, PV arrays can make the sun traverse through each day to greatly intensify energy collection. The tracking devices add cost, and require maintenance, therefore it is more common for PV arrays to have fixed mounts that tilt the array and face solar noon in the direction of south in the Northern Hemisphere or in the direction of north in the Southern Hemisphere. The tilted angle from horizontal, can be altered for season, but if fixed, should be set to give optimal array output during the peak electrical demand portion of a typical year for a stand alone system. This optimal module tilt angle is not needfully identical to the tilted angle for maximum annual array energy output. The optimization of the a photovoltaic system for a particular environment can be as complex as issues of solar flux, soiling, and snow losses should be taken into consideration. In addition, previous work has shown that spectral effects can play a vital role in optimal photovoltaic material selection.

2.2.2 Tracking the sun:

Trackers and sensors to hone the performance are usually seen as optional, but tracking systems can raise viable output by up to 45%.PV arrays that approach or exceed one megawatt mostly utilize solar trackers. Considering for clouds, and the fact and figure that most of the world is not on the equatorial region, and that the sun sets in the evening, the correct approximation of solar power is insolation – the average number of kilowatt-hours per square meter per day.

For large systems, the energy gained by making use of tracking systems can outperform the added complications (trackers can increase efficiency by 30% or more). For very large systems, the added maintenance of tracking is a significant detriment. Tracking is not essential for flat panel and low concentration cogitated photovoltaic systems. For high concentration concentrated photovoltaic systems, dual axis tracking is a required.

Pricing trends alter the balance between adding greater extent stationary solar panels versus having lesser panels that track. When solar panel prices drop, trackers become a less fascinating option.

2.2.3 Shading and dirt:

Photovoltaic cell electrical output is highly nociceptive to shading. When even a little part of a cell, module, or array is shaded, while the remaining is in sunlight, the output falls drastically owing to internal 'short-circuiting' (the electrons reversing course through the shaded portion of the p-n junction). If the current drawn from the series string of cells is no higher than the current that can be generated by the shaded cell, the current (and so power) produced by the string is restricted. If enough voltage is made available from the remaining cells in a string, current will be forced through the cell by falling apart the junction in the shaded portion. This breakdown voltage in standard cells is between 10 and 30 volts. Instead of contributing to the power generated by the panel, the shaded cell absorbs power, turning it into heat. Since the reverse voltage of a shaded cell is much greater than the forward voltage of an illuminated cell, one shaded cell can take up the power of most of the cells in the string, disproportionately altering panel output.. It is important that a PV installation is not shaded by greenery or other obstructions. Most modules have bypass diodes between each cell or string of cells that lower the effects of shading and only decline the power of the shaded part of the array. The important task of the bypass diode is to prevent hot spots that form on cells that can cause further destruction to the array, and cause fires. Sunlight can be absorbed by dust, snow, or other impurities at the surface of the module. This can minimize the light that falls on the cells. In general these losses summed over the year are little. Maintaining a clean module surface will enhance output performance over the lifetime of the module

2.2.4 Temperature:

Module output and life are also degraded by increased temperature. Allowing ambient air to flow over, and if possible behind, PV modules reduces this problem.

2.2.5 Module efficiency:

In 2012, solar panels available for consumers can have an efficiency of up to about 17 percent, while commercially available panels can go as far as 27 percent.

2.2.6 Monitoring:

Photovoltaic systems are required to be monitored to examine breakdown and optimize their operation. Several photovoltaic monitoring strategies depending on the output of the installation and its nature. Monitoring can be executed on site or remotely. It can evaluate production only, fetch all the data from the inverter or convey all of the data from the communicating equipment (probes, meters, etc.). Monitoring tools can be commited to supervision only or offer externalfunctions. Individual inverters and battery charge controllers may comprise monitoring using manufacturer specific protocols and software. Energy metering of an inverter may be of restricted accuracy and not appropriate for revenue metering needs. A third-party data acquisition system can look into multiple inverters, using the inverter manufacturer's protocols, and also get weather-related information. Independent smart meters may evaluate the aggregate energy generation of a PV array system. Various measures such as satellite image analysis or a solar radiation meter (a pyranometer) can be used to approximate total insolation for comparison. Data collected from a monitoring system can be viewed remotely over the World Wide Web.

2.2.7 Performance factors:

Uncertainties in revenue over time associate usually to the measure of the solar resource and to the performance of the system itself. In the best of cases, uncertainties are typically 4 percent for year-to-year climate variability, 5 percent for solar resource estimation (in a horizontal plane), 3 percent for estimation of irradiation in the plane of the array, 3 percent for power rating of modules, 2 percent for losses due to dirt and soiling, 1.5 percent for losses due to snow, and 5 percent for other sources of error. Identifying and reacting to manageable losses is critical for revenue and O&M efficiency. Monitoring of array performance may be portion of contractual agreements between the array owner, the builder, and the utility procuring the energy produced. In the past, a method to create "synthetic days" using readily present weather data and verification using the Open Solar Outdoors Test Field make it feasible to predict photovoltaic systems performance with high degrees of accuracy This method can be used to then determine loss mechanisms on a local scale - such as those from snow or the effects of surface coatings (e.g. hydrophobic or hydrophilic) on soiling or snow losses. Access to the Internet has allowed a further improvement in energy monitoring and communication. Dedicated systems are available from a number of vendors. For solar PV system that use microinverters (panel-level DC to AC conversion), module power data is automatically given. Some systems permit setting performance warns that trigger phone/email/text warnings when limits are attained. These solutions provide data for the system owner and the installer. Installers are capable of monitoring multiple installations, and see at-a-glance the status of their complete installed base.

2.2.8 Module life:

Effective module lives are usually 25 years or more. The payback period for an investment in a PV solar installation varies vastly and is commonly less necessary than a calculation of return on investment. While it is typically calculated to be between 10 and 20 years, the payback period can be far shorter with incentives.

2.3 Maximum Power Point Tracking:

MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum power available from PV module during certain conditions. The voltage at which PN module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.

Typically PV module produces power with maximum power voltage of around 17V when measured at a cell temperature of 25degree celcius, it can drop it around 15V on a very hot day and can also rise to 18V on a very cold day.

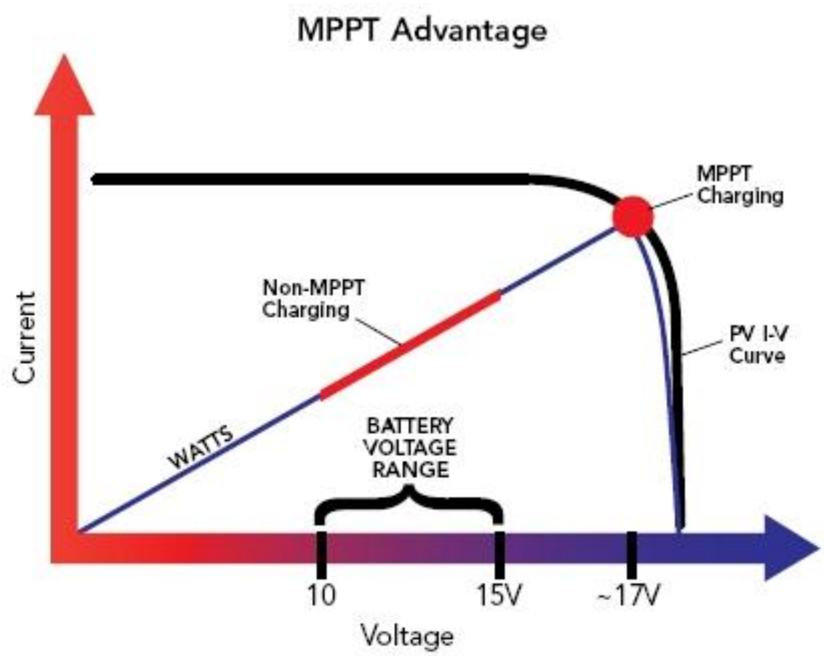


Fig 2.2 Maximum Power Point Treacker

2.3.1 How MPPT Works?

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). That is to say MPPT checks output of PV module , compares it to battery voltage and then fixes what is best power that PV module can produce to charge the battery and concerts it to best voltage to get maximum current into battery, It can also supply powers to a DC load, which is connected directly to battery .

MPPT is most effective under these conditions:

i. Cold weather, cloudy or lazy days: Normaly, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.
ii. When battery is deeply charged: MPPT can extract more current and charge from the battery if the state of charge in the battery lowers.

2.3.2 Conventional charge controller:

When a conventional charge controller is charging a discharged battery, it simply connects the module to the battery. This forces the modules to operate at the battery voltage, typically not the ideal voltage at which the modules are able to obtain maximum power**.**

Consider a PV module at 25 degree celcius and insolation of 1000W/m^2 of insolation at stp of power rating 75W.

MPPT controller calculates the voltage at which the module is able to produce maximum power i.e. 17V to extract full 75W regardless of present battery voltage.

A high DC-DC converter converts the 17V module voltage at the controller of input To the battery voltage at the output.

If the system were 100% efficient, wiring and all, the battery charge current would be:

(Vmodule/Vbattery) x Imodule

A charge current increases of 42% would be achieved by harvesting the module power that would have been behind by conventional controller and turning it into usable charge current. Charge current varies with operating conditions.

i. Greater difference between Vmodule and Vbattery charge current increases.
ii. Cooler PV module cell temperature tend to produce higher Vmp.
iii. A highly discharge battery produces high Vmp.

2.4 Reliability:

The reliability of PV arrays is an pivotal factor in the cost of PV systems and in costumer acceptance. Howsoever, the building blocks of arrays, PV cells, are regarded "solid-state" devices with no mobile portions and, therefore, are greatly reliable and long-lived. Hence, reliability evaluations of PV systems are normally highlighted not on cells but on modules and whole systems.

Reliability can be bettered through fault-tolerant circuit design, which includes making use of several redundant features in the circuit to control the effect of partial failure on overall module yield and array power demeaning. Degradation can be ascertained by dividing the modules into a large number of parallel solar cell networks known as branch circuits. This type of design can also better module losses due to broken cells and other circuit imperfections. Bypass diodes or other corrective steps can overcome the bad effects of local cell hot-spots. However, today's component failure rates are very low enough that, with multiple-cell interconnects, series/paralleling, and bypass diodes, it is very much possible to achieve high levels of reliability.

2.5 Considerations:

The technology utilized in photovoltaic (PV) systems is well-developed and there are significant improvements and modifications occurring frequently, primarily in generation processes. The systems are very much reliable and have been well tested in space and other terrestrial applications.

The elementary obstacle to enormous use of photovoltaic systems is their high initial cost. Intermittent price reductions have been happening. In some off-grid locations as short distance as one quarter mile, photovoltaic systems should be cost effective versus the costs of running power lines into the property and the consequent continual electric charges.

However, of greater interest to homeowners is the potential of decentralized PV systems located at residences providing power to the house and to the centralized power grid when PV power exceeds the home’s necessities. The grid provides power to the house when the PV’s are not producing power in this case particularly.

Electric power generation options are presently commencing to be compared on a basis that includes “externalities.” Externalities are the “hidden” costs related with a power source that are not answerable for the price of the power produced. These hidden costs reckons destruction to the environment caused due to sourcing, processing, transporting, using, and disposal aspects of a power source. The operational costs and externalities related with the conventional fuel mix (coal, oil, nuclear, natural gas) used for producing electricity are not marginally lower than the “full” costs related with photovoltaic systems and, in most of the cases, outgo the costs of PV’s. The use of PV’s is very less polluting than other fuel choices.

The basic strategy for use of PV’s as the electrical power source for household applications is decreasing the need for electricity. Refrigerators, air conditioners, electric water heaters, electric ranges, electric dryers, and clothes washers are all large users of electricity. Highly energy conserving alternatives and gas appliances are now available to greatly reduce electrical load.

2.6 Module Performance Measurements:

PV module performance is evaluated with peak watt ratings. The peak watt (Wp) rating is decided by calculating the maximum power of a PV module under favorable laboratory conditions of relatively high light, favorable air mass, and low cell temperature. But these conditions are not common in the real world. Hence, researchers may use a different procedure, known as the NOCT—or normal operating cell temperature—rating. In this method, the module first equilibrates with a specified ambient temperature so that maximum power is evaluated at a nominal operating cell temperature. This NOCT rating results in a lesser watt value than the peak-watt rating, but it is probably more real.

However, neither of these procedures is designed to indicate the performance of a solar module under real operating conditions. Another method, the AMPM Standard, involves considering the whole day rather than "peak" sunshine hours. This standard, which is meant to address the practical user's requirements, is based on the details of a standard solar global-average day (or a practical global average) in terms of light levels, ambient temperature, and air mass.

Solar arrays are developed to give specified amounts of electricity under certain environmental conditions. The below said factors are normally taken when deciding array performance: characterization of solar cell electrical performance, determination of degradation factors related to array design and assembly, conversion of environmental considerations into solar cell operating temperatures, and calculation of array power output capability.

The amount of electricity required may be decided by any one, or a combination, of the following performance criteria:

i. **Power output:**

Power output is the power (in watts) available at the power regulator, specified either as peak power or average power produced during one day.

ii. **Energy output:**

The energy (watt-hour or Wh) output. This indicates the amount of energy produced during a certain period of time. The parameters are output per unit of array area (Wh/m2), output per unit of array mass (Wh/kg), and output per unit of array cost (Wh/$).

iii. **Conversion efficiency:**

This parameter is defined as: energy output from array / energy input from sun x 100%. It is often given as a power efficiency, equal to: power output from array / power input from sun x 100%.

Power is typically given in units of watts (W), and energy is typical in units of watt-hours (Wh).

To ensure the consistency and quality of photovoltaic systems and increase consumer confidence in system performance, groups such as the Institute of Electrical and Electronics Engineers and the American Society for Testing and Materials are working on standards and performance criteria for PV systems.

2.7 Two approaches for using PV’s: stand-alone and grid-interface:

2.7.1 Stand-alone system:

Needs batteries to store power for the situations when the sun is not brightly shining. Does not use electrical utility power.

The stand-alone system is known as a “separate system” by the electric utility. However, a “separate system” in the utility’s terminology can be present in a house that also has utility power as long as they are entirely separated.

2.7.2 Grid-interface system:

Uses power from the central utility when required and supplies surplus home-generated power back to the utility.Called as a “parallel” system by the utility.

The following information presents a partial overview of the guidelines often needed to interface with the grid:

i. Technical data and information must be supplied to the power company. This includes physical layout drawings, equipment specifications and characteristics, coordination data (this pertains to the parts that will achieve the link to the utility system), test data on the equipment, synchronizing methods, operating and instruction manuals, and maintenance schedule and records.
ii. Interconnection equipment is installed and maintained by the customer.
iii. Maintenance records must be provided to power company if requested. Protective equipment must be maintained by the customer every 2 years or as required by power company.
iv. The customer must provide their own protective devices for their system.
v. Extra costs incurred by the power company in the interface arrangement must be borne by the customer.
vi. The PV system can operate only after written approval is received from the power company.
vii. The customer and the power company must have agreed upon safety procedures.

The interface between the home produced power can be metered in a manner that when power is produced by the PV’s and sent into the grid the meter will run backwards. When power is brought in from the grid the meter will run in the regular direction. This is called “net metering”. Either approach (stand-alone or grid interface) can be done partially; with PV’s being used in conjunction with a generator in a stand-alone system, or with the central grid power serving as a primary power source in a grid-interface system.

2.8 Steps in designing a PV system:

2.8.1 Calculate the Electrical Load:

Examine the uses of energy in a home in three categories (thermal or heat energy, electrical energy, and refrigeration), conservation opportunities can then be isolated in each category that can affect overall electrical consumption.

i. *Thermal energy requirement for heating living spaces, water, and cooking.*

Best effectuated by non-electrical fuels such as solar, gas, wood, and others. Electric space heating, water heating, and cooking require an huge amount of electricity. It is impractical to utilize photovoltaics to produce electricity for these purposes. Solar energy can be utilized in other forms such as passive and active solar space heating and solar water heating more efficiently. Gas can also be utilized for the thermal loads more economically and efficiently than electricity.

ii. *Electrical loads (lighting, appliance and equipment operation)*

Should be done with the most conserving items that can effectuate the task. Highly energy efficient lighting products are readily present and the energy efficiency of appliances can be easily compared for the best choices available. Best utlity for PVs is in this category.

iii. *Refrigeration for air conditioning and food preservation.*

Consumes proportionally large amounts of electrical energy making PV power very dearly for these functions. Gas powered air conditioning is present as an substitue.

For food preservation, there are gas refrigerators and two manufacturers of very high efficiency electrical refrigerators and freezers.

2.9 PV Subsystems – Inverters, Controllers, and Wiring:

i. Inverters

Conventional appliances and equipment and utility-supplied power utilize alternating current (AC) power and PV systems produce direct current (DC) power. Inverters are needed to convert the power from the PV's from DC to AC. In the past, produced inverters are reliable and efficient. They are also a high cost for the project starting at over $1,000 for a size that will accommodate a residence.

For practical reasons, including electrical code compliance and financing, it is best to have a conventional (AC) electrical distribution system in the home. This will allow the utilization of appliances, equipment, and lighting that is commonly present.

ii. Charge controllers

Regulate the voltage entering batteries to prevent overcharging the batteries. Present in several capacities and must be sorted to match the system.

Prevents losses of power back through the panels at night.

iii. Wiring

Some direct current (DC) equipment may be wanted to function in a home. DC appliances and equipment, although initially more dearly than their AC counterparts, will use low power to operate. In some cases, such as pumps, the DC motors are much more efficient. When DC wiring is going to be used in a house, a heavy wire is required. Generally, #10 wire is best for direct current applications but larger wire may be necessary if the wire runs are quite long. Electrical code requirements will apply to PV installations in regards to having fused disconnects, load centers, and proper grounding. Inverted power (AC) is wired normally as per code.

2.10 Mounting PV panels:

PV arrays must be kept to receive the most sunlight. The 45 degree slope will assist to offset the shorter day of winter by bringing the panels nearer to perpendicular to the lower winter sun.

There are various techniques to attach the panels – attached with adjustable tilt angles, manual tracking, passive tracking, and active trackers. All of these mounting approaches can be kept on the ground or on a roof except for some active trackers which are pole attached and thus more suitable for a ground mount.

Fixed mounts are the least expensive and lowest energy generating mounting systems. A metal frame is best suited for outdoor conditions. PV panels will considerably outlast the best wood racks.

The fixed mount with changeable tilt angles and manual tracking mounts will necessitate manually changing the angle of the PV panels either several times a day (manual tracking) and/or seasonal adjustments to place the panels as nearer to perpendicular as feasible to the sun (tilt angle adjustments).

Trackers are usable if the site is appropriate. There needs to be no obstacles in the east and west that will block the sun since the trackers will orient the PV panels to face the sun from early morning to late afternoon. Passive trackers are typically freon activated to track the sun from east to west only andthere is no automatic tilt angle change. Active trackers can draw a very small amount of power from the PV panels (as low as one watt) and mechanically track from east to west and adjust to the proper tilt angle. The passive trackers will increase the panels output from 40-50%. Active trackers will increase panal output by as much as 60%. Howsoever, it is very important to realize that the largest profits for the trackers occurs during the longest days of summer. There are not large profits in the winter.

Fig 2.3 PV Mounting System

2.11 Maintenance:

Solar PV requires little maintenance – you'll just need to keep the panels relatively clean and make sure greeneries don't begin to overshadow them. Panels that are tilted at 15° or more have the additional advantage of being cleaned by rainfall to ascertain optimal performance. Debris is more likely to pile up if you have ground mounted panels.

If dust, debris, snow or bird droppings are a problem they should be cleaned with warm water (and perhaps some washing-up liquid or something similar – your installer can advise) and a brush or a high pressure hose (or telescopic cleaning pole) if the panels are hard to reach. Always be careful if you are working above the ground or close to the top of a ladder. Alternatively, there are a number of specialist window cleaning companies who will clean solar PV panels for you at a cost (of around £30 based on our research in March 2012) depending on the size of your array and location. Many of these companies use a water fed pole system which does away with the need for a ladder.

Once fitted, your installer should leave written details of any maintenance checks that you should carry out from time to time to ensure everything is working properly. This should include details of the main inverter fault signals and key trouble-shooting guidance. Ideally your installer should show this to you at the point of handover. Watching closely to your system and the amount of electricity it's producing (alongside the weather conditions) will acquaint you with what to expect and alert you to when something might be wrong.

The panels should last 25 years or more, but the inverter is more likely to need replacing some time during this period. Consult with your installer for accurate maintenance necessities before you perpetrate to installing a solar PV system.

Chapter 3

TRANSFORMERLESS (TL) AND MULTILEVEL INVERTER APPEAL

3.1 Attractive features of multilevel inverters are as follows:

i. They can generate output voltages with extremely low distortion and lower dv/dt.
ii. They draw input current with very less distortion.
iii. They generate smaller common mode (CM) voltage, thus reducing the stress in motor bearings. In addition, using sophisticated modulation methods, common mode voltages can be eliminated.
iv. They can operate with a lower switching frequency.

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the outputs of which generate voltages with stepped waveforms. The commutation of switches permit the addition of capacitor voltages, which reach high level at the output, while the power semiconductors must withstand only reduced voltages. A two level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor, while the three level inverter generates three voltages and so on.

Considering m is the number of steps of the phase voltage with respect to the negative terminal of the inverter, then the number of step in the voltage between two phases of the load k is

$$K=2m+1$$

And the number of steps p in the phase voltage of a three phase load in wye connection is

$$P=2k-1$$

The term multilevel starts with the three level inverter. By increasing the number of levels in the inverter, the output voltages have more steps generated in a staircase waveform, which has a reduced harmonic distortion. However a high number of leels increses the control complexity and introduces voltage imbalance problems.

The functions of using multilevel power inverters are two-fold.

Firstly, the series connection of power converter modules reduces the voltage stress of each converter module (or increases the voltage capability of the overall converter structure), making the multilevel inverters suitable for high voltage applications.

Secondly, the resolutions of the ac voltage waveforms (i.e, quality of generated voltage) increases with the number of voltage levels available in the multilevel inverters. As a result of the improved resolution in the voltage harmonic content filtering efforts can be reduced.

3.2 Advantages of MOSFETs:

Thyristors and Bipolar Junction Transistors (BJT) were the only power swtches until the MOSFETs wre introduced in the late 1970s. The BJT is a current-controlled device; whereas the MOSFET is a voltage-controlled device. In the 1980s, the IGBT was introduced, which is also a voltage controlled device. The MOSFET is a positive-temperature-coefficient device whereas IGBT may or may not be a positive-temperature-coefficient device.

The MOSFET is a majority carrier device making it ideal for high frequency applications. Inverters, which change DC to AC electricity, can be operated at ultrasonic frequencies to avoid audible noise. The MOSFET also has high avalanche capability compared to the IGBT. Operating frequency is important in choosing a MOSFET. The IGBT has lower clamping capability compared to the equivalent MOSFET. DC bus voltage at the inverter input, power rating , power topolg and frequency of the operation must be considered when choosing between IGBT and MOSFET. An IGBT is generally used for 200V and above applications; whereas the MOSFET can be used in applications from 20V to 1000V. Newer MOSFETs have lower conduction loss and switching loss and are replacing IGBTs in medium voltage applications up to 600V. generally, IGBTs are used for high-current and low-frequency switching; whereas MOSFETs are used for low-current and high-frequency switching.

3.9 **MOSFET requirements for inverter applications**:

i. The specific on resistance (Rsp) should be low to reduce conduction loss. The device to device Rdson variation should be less, which serves two purposes – a)DC component at the inverter output is less and this Rdson can be used for current sensing to control abnormal conditions (mostly in low voltage inverters) ; and b)The low Rsp reduces the die size for the same which results in low cost.

ii. The Unclamped Inductive switching (UIS) should be acceptable when die size is reduced. The MOSFET cell structure should be designed with good UIS and should not be compromised too much. Generally, modern trench MOSFETs have good UIS for the same die size as compared to planar MOSFETs. The die reduces thermal resistance (Rrjc). In this case, lower Figure of Merit (FOM) can be expressed as

Rsp x Rthjc/ UIS

iii. Good Safe Operating Area (SOA) and lower transconductance.

iv. Marginally low gate to drain capacitance Cgd, (Miller charge), but low Cgd/Cgs ratio is needed. The moderately high Cgd helps reduce EMI.Very low Cgd increases dv/dt and hence EMI. The low Cgd/Cgs ratio reduces the chance of shoot-through. These inverters do not operate at high frequency so some increase in gate ESR can be allowed. Since these inverters operate at medium frequency some higher Cgd and Cgs may be allowed.

v. lower Coss to reduce switching loss, even though the operating frequency is relatively low in this application. Some increase in Coss may be applicable.

vi. Sudden changes in Coss and Cgd during switching can cause gate oscillations with high overshoot, which can damage gate over time. In this case. High source-to-drain dv/d can become a problem.

vii. High gate threshold voltage (Vth) for better noise immunity and better paralleling of MOSFETs Vth should be more than 3V.

viii. Body diode recovery : softer and faster body diode with low reverse-recovery charge (Qrr) and low reverse recover time (Trr) is needed. At the same time, softness factor S (Tb/Ta) should be greater than 1. His reduces diode recovery, dv/dt, and shoot-through likelihood in the inverter. Snappy body diodes can cause shoot-through and high voltage spike problems.

ix. In some cases, high (Idm) pulsed drain current capability is needed to provide high (Isc) short-circuit current, and high motor starting current.

x. Controlled turn-on and turn-off, dv/dt and di/dt of the MOSFET to control EMI.

xi. xReduced common-source inductance by using more wire bonds on the die.

3.4 Transformerless Inverters for solar photo voltaic:

What is a transformerless (TL) inverter?

The differences between standard or conventional inverters and transformerless inverters are:

i. Conventional inverters are built with an internal transformer that synchronizes the DC voltage with the AC output.

ii. Transformerless (TL) inverters use a computerized multi-step process and electronic components to convert DC to high frequency AC, back to DC, and ultimately to standard-frequency AC.

3.4.1 Transformerless (TL) Inverter Appeal:

Transformerless inverters are light, compact, and relatively inexpensive. Since transformerless inverters use electronic switching rather than mechanical switching the amount of heat and humidity produced by standard inverters is greatly reduced.
TL inverters maintain the unique ability to utilize two power point trackers that allow installations to be treated as separate Solar PV Systems. In other words with TL inverters, Solar PV Panels can be installed in two different directions (i.e. north and west) on the same rooftop and generate DC output at separate peak hours with optimal effects. Traditional inverters work through only one power point, which means panels that are performing at lower frequencies will lower DC output for the entire system.

3.4.2 Possible Benefits of using a Transformerless Inverter:

i. Usually much lighter in weight than inverters with transformers.

ii. Have higher efficiency ratings

iii. Capable of dual MPPT inputs, depending on manufacturer
iv. Lower cost and size
v. Embodied energy.

3.4.3 Transformerless (TL) Inverter Considerations:

Transformerless inverters do not have electrical isolation between DC and AC circuits. This may raise some grounding and / or lightning protection concerns. In order for transformerless inverters to comply with NEC specifications specially designed and more expensive PV Wire must be used.

Transformerless inverters have been developed for use with Grid-Tie Solar PV Systems, so Off-Grid systems users will not necessarily achieve the same benefit yet.

3.5 Inverter Efficiency:

Inverter efficiency is determined by the percentage measurement of energy convergence (i.e. the closer to 100% of DC to AC convergence for the longest amount of time the more refined inverter efficiency). When calculating efficiency it is important to include peak and off-peak performance percentages in addition to how often your inverter is operating at rated capacity.

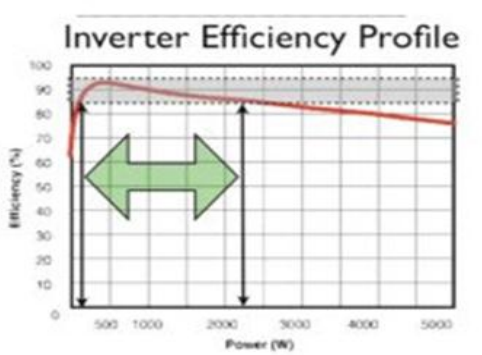


Fig 3.1 Inverter Efficiency Profile

In the above chart (Fig. 1) red represents standard rate of inverter efficiency, the green arrow indicates Solar PV panel power output (DC), and the gray area represents the operational window for inverter efficiency (85-95%).

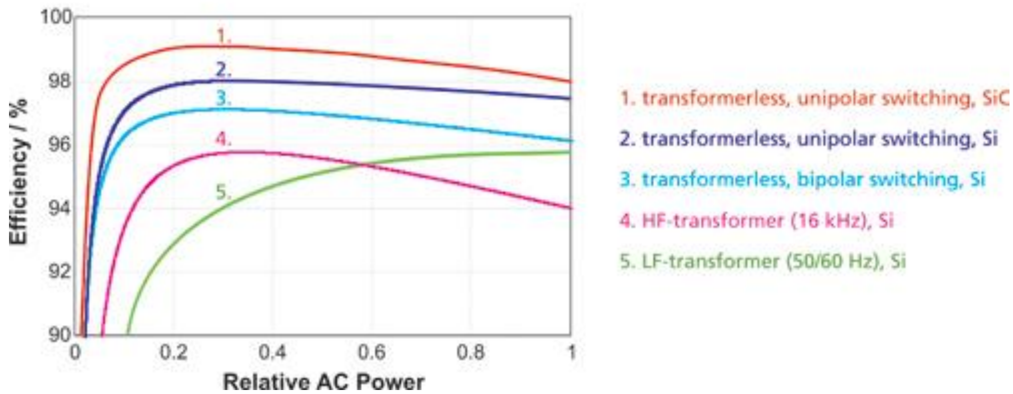


Fig 3.2 Comparision of Transformer vs Transformerless Inverter

Studies show that even a small percentage increase in inverter efficiency means the power supply increase can be quite significant if factored throughout the life span of the inverter.

3.6 Installation Considerations for TL Inverters:

i. The positive and negative PV source circuits must BOTH be switched and over-current protected with TL Inverters.
ii. The PV array equipment must still be grounded, but not the PV source.
iii. The modules and the source circuits must use wire rated PV WIRE or PV CABLE.
iv. The negative conductor of the PV array is not grounded, and therefore shall no longer be colored white when terminating at the inverter or disconnect. Refer to NEC 690.35 for some relavent TL inverter information
v. PV source circuits shall be labeled with the following warning at each junction box, combiner box, disconnect, and device where the ungrounded circuits may be exposed during service:

3.7 Safety:

Unlike their conventional counterparts, transformerless inverters lack electrical isolation between DC and AC circuits. This may raise safety concerns. However, safety mechanisms such as isolation resistance tests and residual current measurement can lower the risk of shock.

In Australia, the installation of photovoltaic systems is regulated under AS 5033 and must comply with safety standards. It is important to note that TL inverters have been common in Europe for the last decade or two, even though they are relatively new to Australia. As technology evolves, it is imperative that the standards committee monitors concerns to provide for the public safety.

Transformerless inverters may also create marginally stronger electromagnetic fields than transformer-based inverters. Nevertheless, EMF strength lies well below recommended limits and may be further minimized with advancing technology.

As always, care should be taken around all electricity-generating systems and on rooftops.

3.8 Control and Grid Synchronization:

Nowadays, fossil fuel is the main energy supplier of the worldwide economy, but the recognition of it as being a major cause of environmental problems makes the mankind to look for alternative resources in power generation. Moreover, the day-by-day increasing demand for energy can create problems for the power distributors, like grid instability and even outages. The necessity of producing more energy combined with the interest in clean technologies yields in an increased development of power distribution systems using renewable energy.

Among the renewable energy sources, hydropower and wind energy have the largest utilization nowadays. In countries with hydropower potential, small hydro turbines are used at the distribution level to sustain the utility network in dispersed or remote locations. The wind power potential in many countries around the world has led to a large interest and fast development of wind turbine (WT) technology in the last decade. A total amount of nearly 35-GW wind power has been installed in Europe by the end of 2004. Another renewable energy technology that gains acceptance as a way of maintaining and improving living standards without harming the environment is the photovoltaic (PV) technology. The number of PV installations has an exponential growth, mainly due to the governments and utility companies that support programs that focus on grid-connected PV systems .

The control tasks can be divided into two major parts.

1) Input-side controller, with the main property to extract the maximum power from the input source. Naturally, protection of the input-side converter is also considered in this controller.

2) Grid-side controller, which can have the following tasks:

i. active power generated to the grid should be controlled;
ii. reactive power transfer between the DPGS and the grid should be taken care of;
iii. dc-link voltage needs to be controlled;
iv. high quality of the injected power should be ensured;
v. grid synchronization

Chapter 4

Simulation Results and Discussion

a) Results for PV Array

The I-V characteristics of PV array are plotted for different values of temperature and solar irradiation in the fig.1 & fig.2. Standard design approach shows that an increased number of cells can provide a nominal level of usable charging currents for normal range of solar insolations. In figure 8 the zero current indicates the condition of open circuit, so the value of voltage at that point gives the value of open circuit voltage of the PV array. Similarly a zero voltage indicates a short circuit condition; the current at this point is used to determine the optimum value of current drawn for maximum power. The value of maximum current increases with increase in temperature.

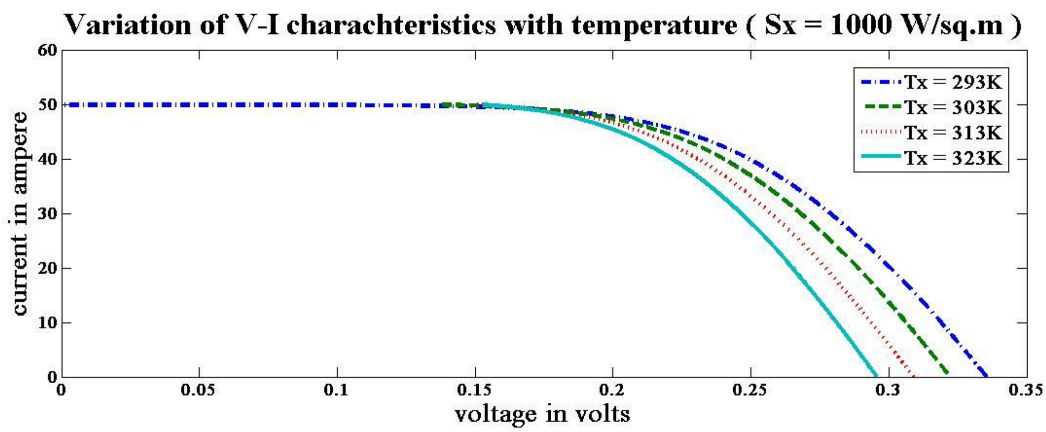


Fig. 1: Variation of I-V characteristics of PV cell with Temperature.

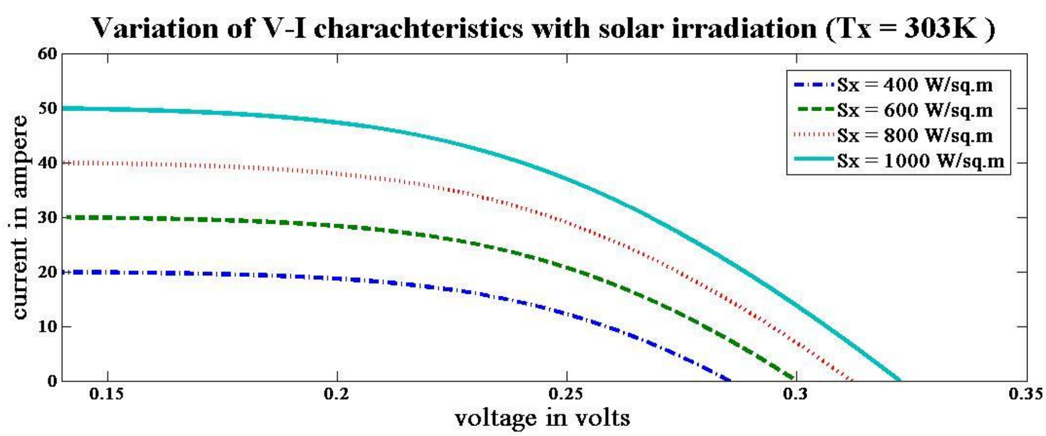


Fig. 2: Variation of I-V characteristics of PV cell with Solar Radiation.

Fig. 3 and 4 depicts the relationship between PV array and output power of PV module for different values of temperatures and solar irradiation. From this curve it was ascertained that the maximum power decreases for increase in temperature.

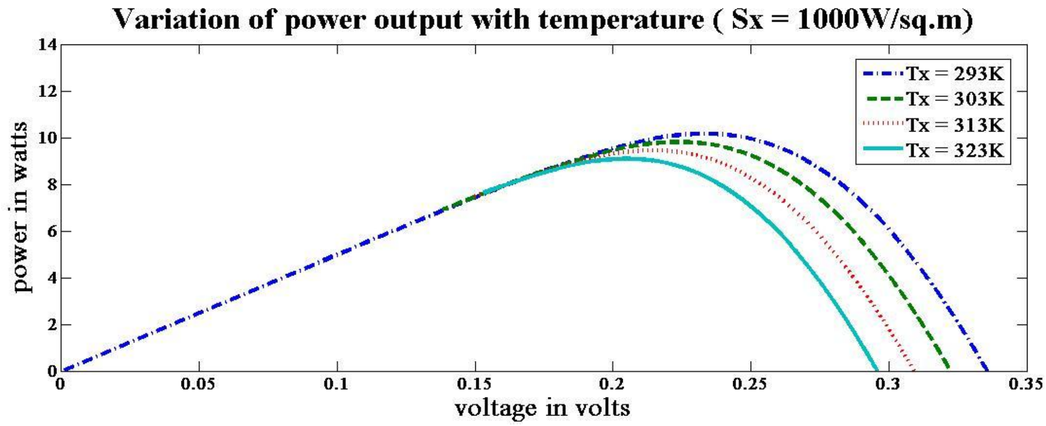


Fig. 3: Variation of Power output with Voltage at Different Temperature

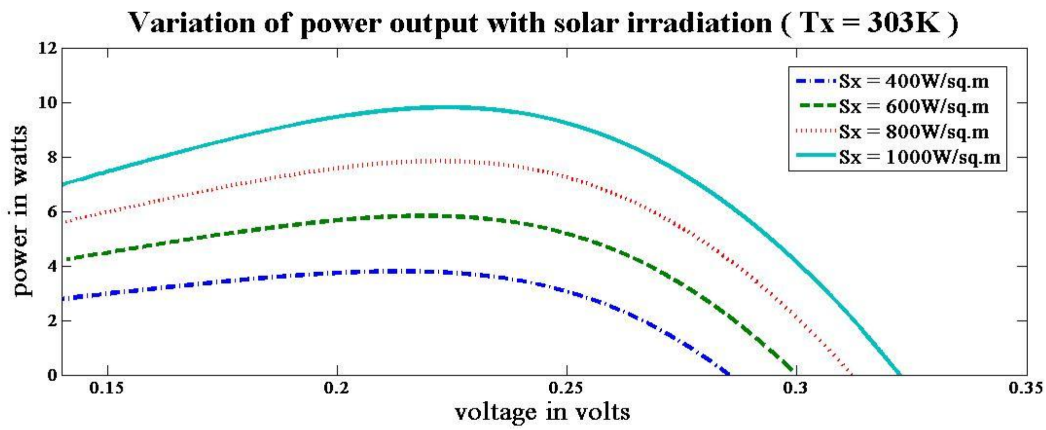
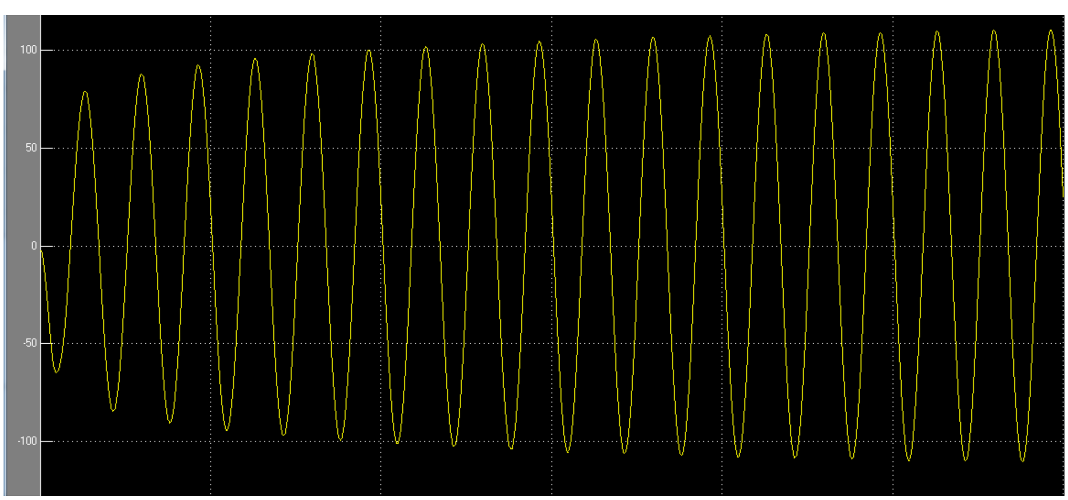
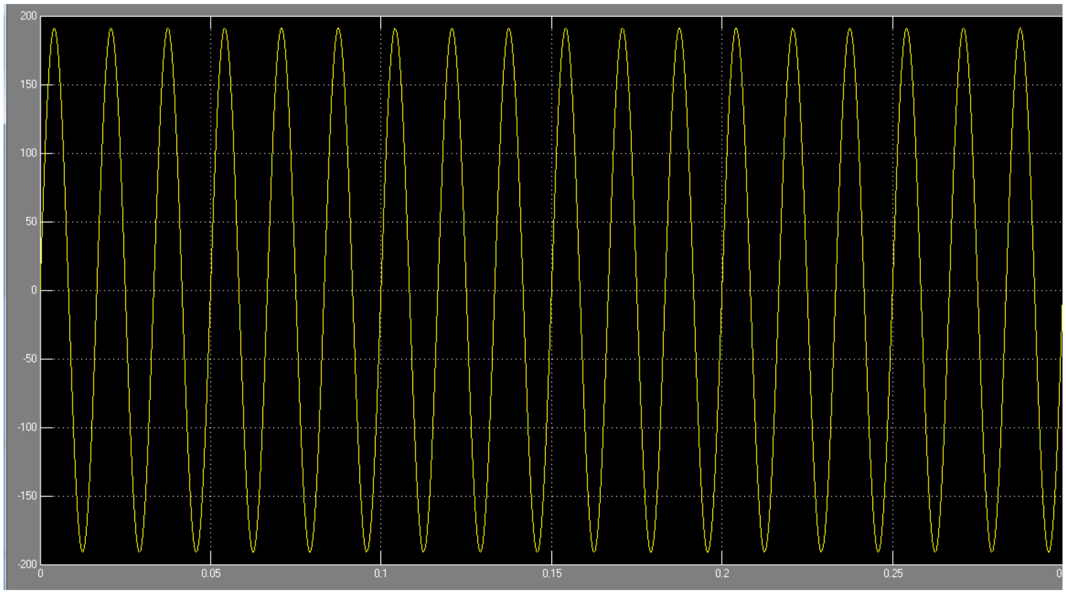


Fig. 4: Variation of Power output with Voltage at Different Solar Radiation.

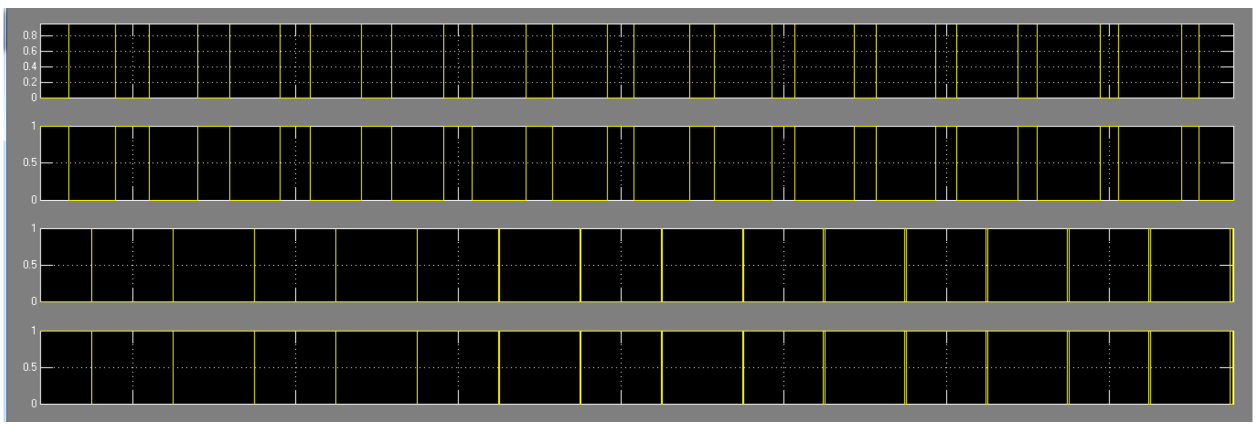
b) Results for phase current, voltage and gate signals



Phase Current



Phase voltage



Gate Signals

Chapter 5

CONCLUSION

This work introduces a simulink model for transformerless single-phase grid-connected photovoltaic system with a cascaded inverter and its different aspects have been discussed in this paper. Advantageous transformerless concepts along with attractive features of multilevel inverters and control and grid synchronization were studied in this report. The gating signals for the eight inverter switches are generated by using an optimised cyclic switching sequence which ensures minimum switching frequency, low DC bus capacitor ripple and equal stress on each switch.

Chapter 6

References

1) R. Lawrence and S. Middlekauff, "The new guy on the block," IEEE Ind. Appl. Mag., vol. 11, no. 1, pp. 54–59, Jan./Feb. 2005.

2) IEA-PVPS, Cumulative Installed PV Power, Oct. 2005. [Online]. Available: http://www.iea-pvps.org

3) M. Shahidehpour and F. Schwartz, "Don't let the sun go down on PV," IEEE Power Energy Mag., vol. 2, no. 3, pp. 40–48, May/Jun. 2004.

4) Welter P. Power up, prices down, grid connected inverter market survey (Leistung rauf, Preise runter, MarkituÈbersicht netzgekoppelter Wechselrichter, in German). PHOTON-das Solarstrom Magizin (German Solar Electricity Magazine) 1999.

5) Welter P. PV modules market survey (Es lebe die Vielfalt, Die Auswahl an Modultypen wird groÈûer, in German). PHOTON 1998

6) http://www.eere.energy.gov/basics/renewable_energy/pv_cells.html

7) http://www.solarenergy.net/Articles/how-photovoltaic-cells-work.aspx

8) Types of PV systems. University of Florida. Key Factors in selecting solar components. List of Eligible SB1 Guidelines Compliant Photovoltaic Modules
https://en.wikipedia.org/wiki/Photovoltaic_system