Studies on Variation of Different Parameters of a Small Scale Grid Connected SPV System with Solar Irradiance

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

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IN
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Submitted by

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EXAM Roll No - M4ENR19012

UNDER
SUPERVISION OF

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I hereby certify that the work which is being presented in the thesis entitled "STUDIES ON VARIATION OF DIFFERENT PARAMETER OF A SMALL SCALE GRID CONNECTED SPV SYSTEM WITH SOLAR IRRADIANCE" by "JAYASREE MONDAL" in partial fulfillment of requirements for the award of degree of M.Tech. in Energy Science & Technology submitted in the School of Energy Studies at JADAVPUR UNIVERSITY, KOLKATA, is an authentic record of my own work carried out during a period from 2018 to 2019under the supervision of Dr. Ratan Mandal. The matter presented in this thesis has not been submitted by me in any other University / Institute for the award of M.Tech. Degree.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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NOMENCLATURE

A	Ampere
AC	Alternating Current
CO	Carbon Monoxide
DC	Direct Current
DG	Distributed Generation Plant
IEO	International Energy Outlook
NOx	Oxide of Nitrogen
kWp	Kilowatt Peak
RES	Renewable Energy Sources
PF	Power Factor
PV	Photovoltaic
Rs	Series Resistance
Rp	Shunt (Parallel) Resistance
SPV	Solar Photovoltaic
THD	Total Harmonic Distortion
V	Volt
VA	Volt- Ampere
W	Watt
VOCs	Volatile Organic Compounds

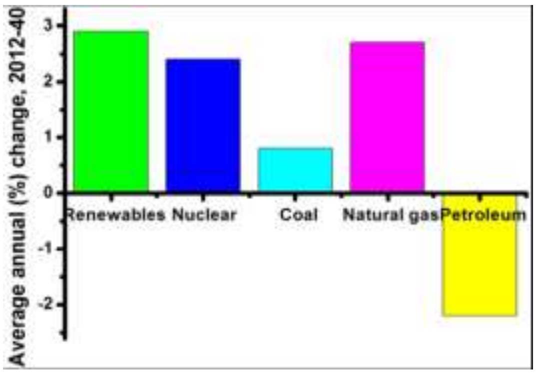
CONTENTS

Chapter 1: INTRODUCTION

1.1. INTRODUCTION

The power generation sectors are mostly reliant on non-replenish ablefossil fuels which contribute to environmental contamination. Thecoal reserves are diminishing at a distressing rate. Considering thepresent day scenario, the focus is reallocating towards integration ofsmall and medium scale power plants based on renewable energysources (RES) into the power distribution system **[1]**.These plants arecalled as distributed generation (DG) plants.

As per international energy outlook (IEO), 2016 report **[2]**renewableenergy consumption will increase by an average of 2.9% per yearfrom 2012 to 2040 as shown in Figure 1.1 It is expected that the net power generation from the renewable will be equal to the power generationfrom coal by 2040 and almost half of this renewable power generationwill come from wind and solar. Rapid development has led to lower costof renewable power generation. Solar photovoltaic (PV) is expected towitness an average cost cutting of 40–70% by 2040 and on-shore wind by 10-20%. From Figure 1.2, it is observed that solar is the fastest growingform of renewable energy, with net increase in solar power generationby an average of 8.3% per year. It is followed by wind and geothermal power.



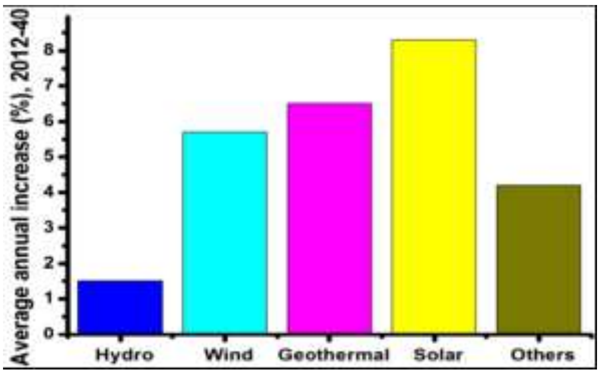


Figure 1.1 Average annual change in electricity generation by different energy sources

Figure 1.2 Average annual change in net renewable electricity energy sources generation by

1.2. ENERGY

Energy is one of the major inputs for the economic development of any country. In the case ofthe developing countries, the energy sector assumes a critical importance in view of the everincreasingenergy needs requiring huge investments to meet them.

Energy can be classified into several types based on the following criteria:

• Primary and Secondary energy

• Commercial and Non commercial energy

• Renewable and Non-Renewable energy

1.2.1. Primary and Secondary Energy

Primary energy sources are those that are either found orstored in nature. Common primaryenergy sources are coal,oil, natural gas, and biomass(such as wood). Other primaryenergy sources availableinclude nuclear energy fromradioactive substances, thermalenergy stored in earth's interior,and potential energy due toearth's gravity. The major primaryand secondary energysources are shown in Figure 1.3.

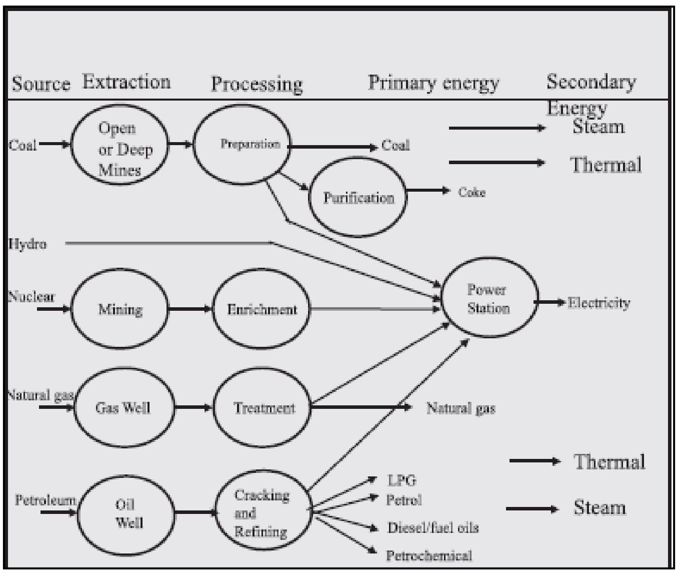


Figure 1.3 Major Primary and Secondary Sources

Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oilor gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non-energyuses, for example coal or natural gas can be used as a feedstock in fertiliser plants.

1.2.2. Commercial Energy and Non Commercial Energy

Commercial Energy

The energy sources that are available in the market for a definite price are known as commercialenergy. By far the most important forms of commercial energy are electricity, coal andrefined petroleum products. Commercial energy forms the basis of industrial, agricultural,transport and commercial development in the modern world. In the industrialized countries,commercialized fuels are predominant source not only for economic production, but also formany household tasks of general population.

Examples: Electricity, lignite, coal, oil, natural gas etc.

Non-Commercial Energy

The energy sources that are not available in the commercial market for a price are classified asnon-commercial energy. Non-commercial energy sources include fuels such as firewood, cattledung and agricultural wastes, which are traditionally gathered, and not bought at a price usedespecially in rural households. These are also called traditional fuels. Non-commercial energyis often ignored in energy accounting.

Example: Firewood, agro waste in rural areas; solar energy for water heating, electricitygeneration, for drying grain, fish and fruits; animal power for transport, threshing, lifting waterfor irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

1.2.3. Renewable and Non-renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examplesof renewable resources include wind power, solar power, geothermal energy, tidal power andhydroelectric power (See Figure 1.4). The most important feature of renewable energy is that itcan be harnessed without the release of harmful pollutants.

Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which arelikely to deplete with time.

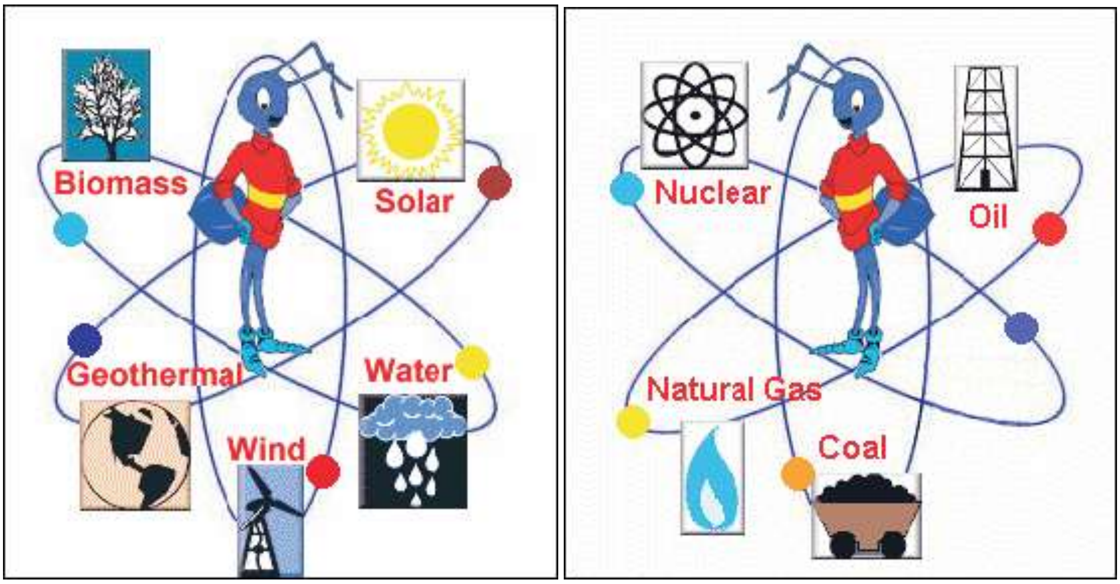


Figure 1.4 Renewable and Non-Renewable Energy

1.3. ENERGY AND ENVIRONMENT

The usage of energy resources in industryleads to environmental damages by pollutingthe atmosphere. Few of examples of air pollution are sulphur dioxide (SO_2), nitrous oxide(NO_X) and carbon monoxide (CO) emissionsfrom boilers and furnaces, chloro-fluro carbons(CFC) emissions from refrigerants use,etc. In chemical and fertilizers industries,toxic gases are released. Cement plants andpower plants spew out particulate matter.Typical inputs, outputs, and emissions for atypical industrial process are shown in Figure1.5.

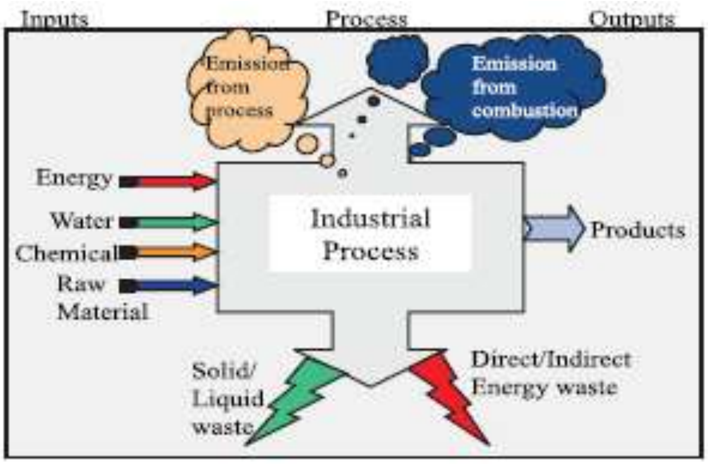


Figure 1.5 Inputs & Outputs of Process

1.3.1. Air Pollution

A variety of air pollutants have aknown or suspected harmful effects on human health and theenvironment. These air pollutants are basically the products of combustion from fossil fuel use.Air pollutants from these sources may not only create problems near to these sources but alsocan cause problems far away. Air pollutants can travel long distances, chemically react in theatmosphere to produce secondary pollutants such as acid rain or ozone.

1.3.2. Evolutionary Trends in Pollution Problems

In both developed and rapidly industrialising countries, the major historic air pollutionproblem has typically been high levels of smoke and SO_2 arising from the combustion of sulphur-containing fossil fuels such as coal for domestic and industrial purposes.

Smogs resulting from the combined effects of black smoke, sulphate / acid aerosol and foghave been seen in European cities until few decades ago and still occur in many cities in developingworld. In developed countries, this problem has significantly reduced over recent decadesas a result of changing fuel-use patterns; the increasing use of cleaner fuels such as natural gas,and the implementation of effective smoke and emission control policies.

In both developed and developing countries, the major threat to clean air is now posed by traffic emissions. Petrol- and diesel-engined motor vehicles emit a wide variety of pollutants,principally carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds(VOCs) and particulates, which have an increasing impact on urban air quality.

In addition, photochemical reactions resulting from the action of sunlight on NO_2 and VOCsfrom vehicles leads to the formation of ozone, a secondary long-range pollutant, which impactsin rural areas often far from the original emission site. Acid rain is another long-range pollutant influenced by vehicle NOx emissions.

Industrial and domestic pollutant sources, together with their impact on air quality, tend tobe steady-state or improving over time. However, traffic pollution problems are worseningworld-wide. The problem may be particularly severe in developing countries with dramaticallyincreasing vehicle population, infrastructural limitations, poor engine/emission control technologiesand limited provision for maintenance or vehicle regulation.

The principle pollutants produced by industrial, domestic and traffic sources are sulphur-dioxide, nitrogen oxides, particulate matter, carbon monoxide, ozone, hydrocarbons, benzene,1,3-butadiene, toxic organic micropollutants, lead and heavy metals.

1.3.3. Climatic Change

Human activities, particularly the combustion of fossil fuels, have made the blanket of greenhouse gases (water vapour, carbon dioxide, methane, ozone etc.) around the earth thicker. Theresulting increase in global temperature is altering the complex web of systems that allow lifeto thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant andanimal species.

1.3.4. Greenhouse Effect and the Carbon Cycle

Life on earth is made possible by energy from the sun, which arrives mainly inthe form of visible light. About 30 percent of the sunlight is scattered back into spaceby outer atmosphere andthe balance 70 percent reaches the earth's surface, whichreflects it in form of infrared radiation.The escape of slow moving infrared radiation is delayed by the green house gases. A thickerblanket of greenhouse gases traps more infrared radiation and increase the earth's temperature(Refer Figure 1.6).

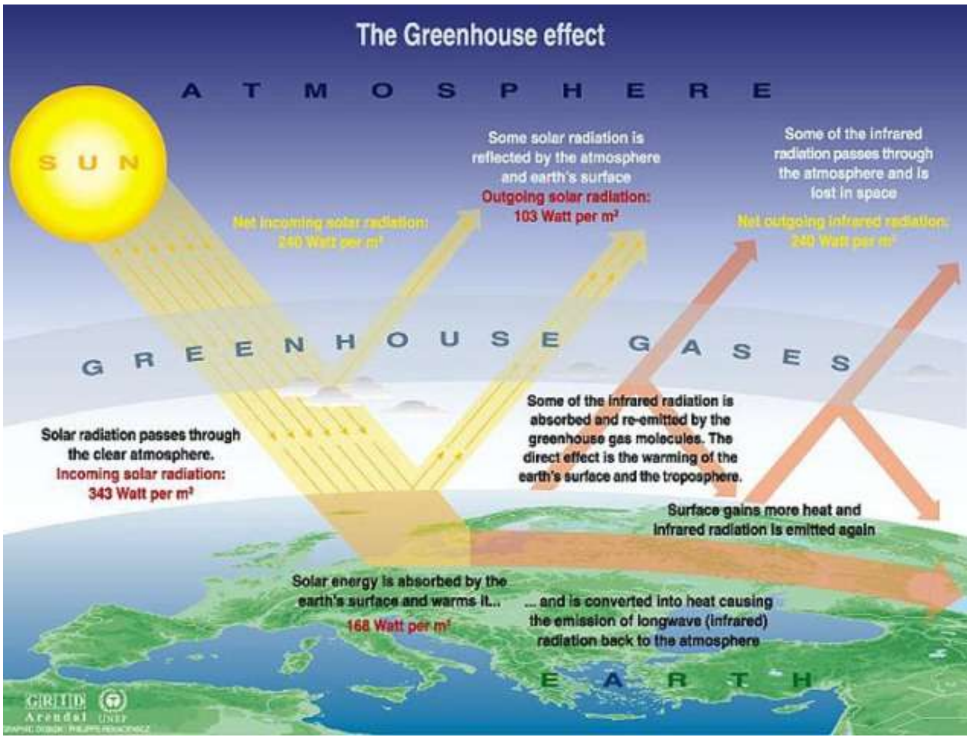


Figure 1.6 The Greenhouse Effect

1.4. SOLAR POWER

Solar energy in one form or another is the source of nearly all energy on the earth. Humans, like all other animals and plants, rely on the sun for warmth and food. However, people also harness the sun's energy in many other different ways. For example, fossil fuels, plant matter from a past geological age, is used for transportation and electricity generation and is essentially just stored solar energy from millions of yearsago.Photovoltaics (often abbreviated as PV) is a simple and elegant method of harnessing the sun's energy. PV devices (solar cells) are unique in that they directly convert the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long lasting.

Various types of non conventional energy sources are such as geothermal ocean tides, wind and sun. All non conventional energy sources have geographical limitations. But solar energy has lessgeographical limitation as compared to other non conventional energy sources because solar energy is available over the entire globe.

Although the bulk of photovoltaic devices today are used for purely practical and economic reasons, a potential benefit of photovoltaics is that PV is one of the most environmentally benign of any electricity generating source. The environmental impact of electricity generation, particularly the greenhouse effect, adds an important reason for examining photovoltaics.

A solar cell or photovoltaic (PV) cell is a device that converts solar energy intoelectricity by the photovoltaic effect. Photovoltaic is the field of technologyand research related to the application of solar cells as solar energy. Sometimes the term solar cell is reserved for devices intended specifically to capture energyfrom sunlight, while the term photovoltaic cell is used when the source isunspecified. Photovoltaic generation of power is caused by radiation thatseparates positive and negative charge carriers in an absorbing (Semiconductor) material. In thepresence of an electric field, these charges can produce a current for use in anexternal circuit. Such fields exist permanently at junctions or inhomogeneitiesin materials as ‘built-in’ electric fields and provide the required emf. for useful power production

1.5. SOLAR CELL

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction.

The basic steps in the operation of a solar cell are:

- the generation of light-generated carriers;
- the collection of the light-generated carries to generate a current;
- the generation of a large voltage across the solar cell; and
- The dissipation of power in the load and in parasitic resistances.

Solar panel systems are referred to as photovoltaic systems in the solar industry. Photovoltaic systems have several parts and each plays a distinct role.The entire system begins with the solar cells. These cells are where sunlight is actually used to produce electricity. Solar panels are a combination of multiple solar cells. These cells are arranged in such a way that the solar panels can capture and combine the electrical output of each solar cell and send it along a specified path.

The power which is generated fromsolar panel is varying with solar irradiance. This is DC(direct current) in nature. But our all load connections are AC (alternating current) in Nature. The DC power has to convert in AC power by means of any external electronic device. So there are so many parameters which are varying with solar irradiance and these parameters affect the quality of AC power. The parameters are output voltage of panel (V_{DC}), output current of panel (I_{DC}), Output power of panel, output voltage of inverter (V_O), output current of inverter (I_O),Real Power (W), Apparent power (S), Reactive power (Q), 5^{th} and 7^{th} harmonics etc.

1.6. OBJECTIVE OF THE PRESENT WORK

There have 1 kW grid connected solar photovoltaic plant on the roof top at School of Energy Studies Building. The variation of parameters can be observed with help of a power quality analyser and solarimeter.

To find out the variation of parameters with irradiance:

i) We have recorded V_{DC} (output voltage of panel), I_{DC} (output current of panel), W (output power of panel), presenceof 5^{th} and 7^{th}harmonics.and plotting their graphs with varying solar irradiance. By analyzing, we can have an idea of range up to which generation can be allowed so that the inverter can pick up the output.

ii)Recoding the data like V_o(output voltage of inverter),I_o(output current of inverter),S(apparent power),Q(reactive power VAr),W(real power),pf(power factor), presence of 5^{th} and 7^{th} harmonic, THD(total harmonic distortion) and plotting their graphs with the variation of irradiance.

Our aim and objective behind the work is to improve the quality of power supply of our roof top distributed type grid connected plant of installed capacity of 1KW PV plant at School of Energy Studies, Jadavpur university and to make it distortion less. We will analyse our recorded data to find out whether our supply to grid is distortion less or not. If there is distortion, we will try to find out the factors responsible for it and also tried to identify the range of solar radiation wit in that the system will feed quality power into the grid with improved power factor and reduced harmonics.

1.7. SCOPE OF THE PRESENT WORK

The present work has been presented in the form of thesis containing 6 chapters in which the first chapter includes the introduction part describing average annual change in electricity generation by different energy sources and electricity generation through renewable resources. The second chapter comprises the theories related to THD(total harmonic distortion) and studies of earlier journal papers based on PV system and plants along with gap of knowledge and conclusion. The system description, experimental procedure, information about metering and data recording device are included in the third chapter. Chapter four deal with the present technology and different types of PV plants and their accessories. The recorded data, their graphs, analysis and discussion with conclusion are included in fifth chapter. The sixth and the last chapter contains summary of the work, concluding remarks and avenue of future scope.

In the entire work we have emphasized on THD and Var because there is a lot of chances of it to run beyond range as we are working with the most vulnerable source, highly sensitive to a small natural variation and the variation of load in the grid in which it is connected.

1.8. CONCLUSION

In this chapter the former portion comprises annual change in electricity generation by different energy sources, average annual change in renewable electricity generation, primary and secondary energy sources, renewable and non renewable energy sources have been studied to find out the dependence of power requirement on non renewable resources and their impact on environment as well as depletion of exhaustive resources which has shouted the need of shifting the source of power generation towards pollution free nonrenewable resources and their merits and advantages over carbon and nucleus based power. The latter part deals with basic working principle and description of solar cellalong with the fabrication process. The forthcoming chapter includes the review of journal papers related to our work.

Chapter 2: REVIEW OF THE PREVIOUS WORK

2.1. INTRODUCTION

In the thirst of knowledge to accomplish our aim and objective we have gone through many books and journals to hunt the basic theories regarding THD and different kind of harmonic distortions. As our work is based on recording and metering which to be done with the help of a Power Quality Analyser (PQ 3100) which have substituted the requirement of Notch filter based Harmonic distortion analyser and its interfacing with the working system.

2.2. REVIEW OF EARLIER WORK

2.2.1. Harmonic Distortion [5]

The application of a sinusoidal input signal to an electronic device, such as an amplifier should result in generation of a sinusoidal output waveform. Generally, however, the output waveform is not an exact replica of the input waveform because of various types of distortions that may occur.

Distortion may be a result of the inherent non-linear characteristics of different components used in an electronic circuit. Non-linear behaviour of circuit elements introduces harmonics in the output waveform and the resultant distortion is often referred to as harmonic distortion (HD).

2.2.1.1. **Types of Distortion:**

Distortion is caused by many devices and components which form an electronic circuit. In this section the different types of distortion caused by amplifiers are considered. The various types of distortions which occur are:

i. **Frequency Distortion:** This type of distortion occurs because the amplification factor of the amplifier is different for frequencies.

ii. **Phase Distortion:** This distortion occurs an account of the energy storage elements in the system which cause the output signal to be displaced in the phase with the input signal. If signals of all frequencies are displaced by the same amount, the phase shift distortion would not be noticed. However, in actual practice, signals at different frequencies are shifted in phase by different angles and therefore the phase shift distortion becomes noticeable.

iii. **Amplitude Distortion:** Harmonic distortion occurs due to the fact the amplifier generates harmonics of the fundamental of the input signal. Harmonics always give rise to amplitude distortion, for example, when an amplifier is overdriven and clips the input signal.

iv. **Intermodulation Distortion:** This type of distortion occurs as a consequence of the interaction or heterodyning of two frequencies, giving an output which is sum or difference of the two original frequencies.

v. **Cross-over Distortion:** This type of distortion occurs in push-pull amplifiers on account of incorrect boas levels.

2.2.1.2. **Total Harmonic Distortion:**

A non-linear system produces harmonics of an input sine wave, the harmonics consisting of sine waves with frequencies which are multiples of the fundamental of the input signal. Total harmonic distortion (THD) is measured in terms of the harmonic content of the wave, as given by equation-

$$THD = \frac{[\sum(\text{Harmonic})^2]^{1/2}}{Fundamental}$$

A measure of distortion represented by a particular harmonic is simply the ratio of amplitude of harmonic to that of the fundamental Harmonic distortion (HD) is then represented by,

$$D_2 = \frac{E_2}{E_1}\ , \quad D_3 = \frac{E_3}{E_1},\ D_4 = \frac{E_4}{E_1}$$

When D_n(n=2,3,4…..) distortion of nth harmonic and E_n represents the amplitude of nth harmonic. E_1 is the amplitude of fundamental.

Total Harmonic distortion (THD) is defined as:

$$THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} = \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + \cdots}}{E_1}$$

Percentage harmonic distortion

$$=\sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} \times 100$$

$$=\frac{\sqrt{E_2^2+E_3^2+E_4^2+\cdots}}{E_1}\times 100$$

In a measurement system noise is read in addition to harmonics, and the total waveform, consisting of harmonic, noise and fundamental, is measured instead of the fundamental alone. Therefore the measured value of the total harmonic distortion (THD_M) is given by Equation –

$$THD_M = \frac{\{\Sigma[(Harmonics)^2+(Noise)^2]\}^{1/2}}{\{\Sigma[(Fundamental)^2+(Harmonics)^2+(Noise)^2]\}^{1/2}}$$

2.2.1.3. **IntermodulationDistortion:**

When a high frequency (f_1) signal and a low frequency (f_2) signal are mixed in a linear circuit contains the two frequencies only. When mixed in a non-linear circuit, for example an amplifier having distortion, modulation occurs. The output now contains the original frequencies (f_1 andf_2) and also the sum and differences frequencies (f_1+f_2) and(f_1-f_2) in addition to several harmonics and their sum and difference frequencies.

$$IMD = \frac{Amplitude of modulation\ (A_M)}{Amplitude of carrier (A_C)} \times 100$$

$$= \frac{Q-P}{P}\times 100$$

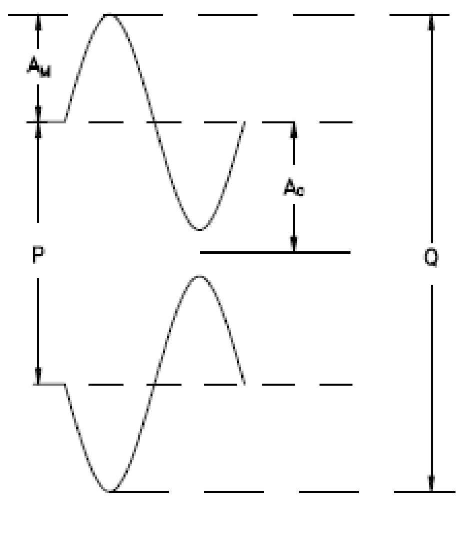


Figure 2.1 Waveform output from an intermodulation distortion meter

2.3. Review of Research Paper

Review of previous work were carried out by different researchers published in different journals. Various papers related to this present work have been studied to get an idea of previous work on this field.

Gianfranco et.al [6] provided a multi-faceted view on the characterization of the waveform distortion in grid-connected photovoltaic (PV)plants from experimental results. The focus is set on the characterization of the waveform distortion occurring under different operating conditions in field measurements and laboratory tests. The assessment is carried out by considering the system-based point of view, on the basis of the measurements gathered at the interface between the PV plant and the grid or the supply point in the laboratory. New methodological hints on the formulation of the experimental tests are provided. The results of the waveform distortion analysis for harmonic currents and voltages are compared to the requirements of present power quality standards, indicating that in practical cases the current distortion can be significantly higher than in normal test conditions. Furthermore, the key aspect concerning harmonic and inter-harmonic modeling of multiple grid-connected PV inverters is addressed. Experimental results on plant configurations with multiple PV inverters show that low-order harmonics sum up almost arithmetically, whereas the higher-order harmonics and the inter-harmonics sum up in an almost Euclidean way.

K. Padmavathi et al [7]observed that renewable energy is projected to meet a significant portion of the future energy needs of India. With solar energy, being abundantly available in most parts of the country, grid connected solar photovoltaic (SPV)power plants are assuming increasing importance. Energy fed into the grid by a solar power plant depends upon seasonal variation of the solar resource, losses due to temperature variation, system losses and losses due to condition of the grid. This paper presents performance analysis of a 3 MW grid connected SPV plant located in Karnataka State, India as per International Electro-technical Commission (IEC) Standard 61724, using monitored data. Normalized technical performance parameters of the plant are evaluated for the year 2011.Inverter failure losses and grid failure losses are estimated for two years of plant operation. Daily and seasonal variations in the SPV plant output are shown using monitored data at five-minute intervals. The SPV generation in relation to load duration curve of the substation is observed. A comparison of normalized performance parameters of the plant with similar parameters of other plants is given. Annual average energy generated by the plant was 1372 kWh peak Wp of the installed capacity. Performance of the plant is satisfactory in comparison with that reported from other countries.

Joop van Deelen et.al [8] showed that there is a gap in efficiency between record thin film cells and mass produced thin film solar panels. In this paper we quantify the effect of monolithic integration on power output for various configurations by modeling and present metallization as a way to improve efficiency of solar panels. Grid design and finger dimension optimization was performed monolithically integrated solar panels by modeling under standard conditions and with variation of boundary conditions such as transparent conductor used, conductivity of the metallic pattern and low light intensity. For each, the optimal cell and grid dimensions as well as the power output is presented. In contrast to previous studies that focus on 100 μm wide grid lines, our grid finger width was varied between over a wide range and a finger width of20μm was shown to give optimal results. We included mapping the power output for 20μm, 60μm and 100μm wide grid lines as function of cell length, finger spacing and TCO sheet resistance and show that also for wide fingers efficiency improvement of more than 15%is possible. This provides not only optimization of grid dimensions, but also the sensitivity of the power output with respect to the finger dimensions, TCO sheet resistance and the cell length. These results indicate that the application of a grid is a robust solution which allows for a considerable variation (>25%) in the parameter window around the optimum configuration with only small impact (<2%) on the power output.

L. Fialho et.al [9] presented a systemic modeling for a PV system integrated into an electric grid. The modeling includes models for a DC–DC boost converter and a DC–AC two-level inverter. Classical or fuzzy PI controllers with pulse width modulation by space vector modulation associated with sliding mode control is used for controlling the PV system and power factor control is introduced at the output of the system. Comprehensive performance simulation studies are carried out with the modeling of the DC–DC boost converter followed by a two-level power inverter in order to compare the performance with the experimental results obtained during in situ operation with three commercial inverters. Also, studies are carried out to assess the quality of the energy injected into the electric grid in terms of harmonic distortion. Finally, conclusions regarding the integration of the PV system into the electric grid are presented.

Kevin Ark Kumar et.al [10] discussed in their paper the details and results obtained from a study carried out on a roof top 20kWp solar photovoltaic(PV) power plant in a reputed manufacturing industry in India. Although there is plenty of sunshine, various financial supports and government policies, the growth of photovoltaic (PV) power plants in developing countries is still facing significant barriers due to unclear techno-economic aspects of the PV power plant. Therefore this paper highlights a few salient features of the installation, operational performance and economic calculations of a grid connected solar photovoltaic (PV) power plant. A few important aspects of solar power plant installation such as the feasibility of location in terms of geographical data, solar panel mounting design, interfacing aspects of PV system with grid are outlined. The results obtained from the study such as month wise energy generation, performance ratio, capacity factor, maintenance aspects, economic analysis etc. of the system are discussed in detail. The study enables researchers and engineers in this area to understand roof top solar PV power plant and its economic viability. It is expected that this study will encourage and provide guidance to industries in this region to set-up similar PV power plants.

Amal Marrekchi et.al [11] observed that nowadays, photovoltaic energy is becoming an increasingly important renewable energy in the world. A grid connected photovoltaic system consists of extracting the maximum power from the PV panel. This paper presented a PV-grid connected system and proposed a practical and efficient method for coupling a photovoltaic generator (PVG) on a single-phase electric grid throughout two conversion stages namely DC–DC boost converter and voltage source inverter (VSI). The DC–DC converter ensures that a maximum power extraction from the PVG and that the VSI matches the grid requirement for the energy produced. In fact, before discussing the injection of the produced power by the PVG into the electric grid, connection requirement have to be met. We presented then the coupling conditions to respect and the way to deal with them. The proposed method has been simulated revealing the ability of our system to highlight the coupling instance. The obtained results show the transient analysis of coupling and the efficiency of the proposed technique.

Ravi Nath Tripathi et.al [12] showed in their paper solar photovoltaic (SPV) system connected to the utility grid is designed and simulated. The utility grid and SPV system are coupled with current controlled voltage source converter (VSC) and LCL filter. The design of LCL filter, MPPT algorithm and power quality improvements are discussed and simulation results are shown for the performance analysis of grid-coupled PV system under different load condition. The system is controlled through power balance theory method. The principle behind the control implementation is to evacuate the solar power generated during the daytime and the reactive power demand for the load should be supplied by the PV. The grid coupled system consists of SPV system, dc–dc boost converter, maximum power point tracking (MPPT), voltage source converter (VSC), LCL filter, different loads and three phase utility grid. This system is capable of eliminating harmonic and load balancing by supplying unbalanced current from the PV as a compensator. The system is simulated with 10kWSPV array using indirect current control scheme.

Jinn-Chang Wua et.al [13] examined a PV power system with a flexible grid interface is studied in their paper. The flexible grid interface comprises two power conversion stages, a two-mode buck-boost converter (TMBBC) and a variable-level inverter (VLI). The operation of VLI is flexible according to the output DC voltage of the PV array, andit generates an AC voltage with three levels, five levels or seven levels and outputs a sinusoidal current to the grid. Partial power from the PV array is directly converted to AC power via only one power conversion such that the power efficiency for the PV power system is improved. Besides, the operating voltage range for the PV array can be extended because of the high boost gain of TMMBC. A hardware prototype is implemented to demonstrate the performance of the proposed flexible grid interface.

Anil K. Berwal et.al [14]observed that renewable energy is a viable alternative to meet growing energy demand of the country. Realizing this fact, Indian government has recently expressed an intention towards achieving 100 GW of solar capacity by 2022; out of which 40% is being expected through decentralized and roof top scale solar projects. One such Photovoltaic (PV) plant of 50kW capacity installed at the roof top of Saraswati library building of Deenbandhu Chhotu Ram University of Science & Technology has been analyzed for its technical and financial viability. We have also analyzed the mix of technicalities involved in this PV plant. This PV plant is generating more than5200 kWh/month of electricity and reducing 4070 kg/month of GHG emissions. Further, this plant is installed with govt. subsidy and found that the subsidy amount makes it lucrative by reducing pay back duration to 5.7years and increasing the IRR to 16.97%. But even without subsidy, the pay back duration comes out to be 10.3years and IRR equals to 8.22% to make it financially viable. Thus it is observe that if govt continued to provide subsidy up to 30% to such projects for next 2 to 3 years, then it will help to attract the domestic sector to get install more and more PV plant on their rooftop. Further attempt have been made to present a generic framework for providing SPV power system.

Sonali Goel et.al [15] observed that the energy demand across the globe has increased in many folds due to technological advancement, rapid growth in industries and increase in household energy demand. This led the engineers and planners to think and find the means to harvest the alternative energy sources other than the fossil fuel. Solar, wind, biomass, mini hydro are some of the resources used worldwide to generate energy as per the availability of resources. This paper presents a comparative performance of various stand alone solar photovoltaic(PV), grid connected PVand hybrid renewable energy system (HRES) studied across the globe. The standalone PV system is used to supply electricity to a small habitats/hamlets or to a single household. Hybrid energy system consists of two or more energy sources for generation of power for rural electrification in off grid locations and in grid connected PV systems, excess electricity produced is injected to the grid thereby generating additional income. The research works carried out by various researchers around the globe on renewable energy sources particularly for rural electrification is discussed in this paper. Besides this the utilization of renewable electricity for Plug-in-Electric Vehicles (PEV) studied across the globe were also discussed.

Photovoltaic systems belong to the green energy dynamics which is an ambitious program based on energy efficiency and sustainable development. In this study, the impact of the aging of a photovoltaic module is investigated on the electrical performance of a grid-connected system. A photovoltaic conversion chain with MPPT (Maximum Power Point Tracking) control and LC (Inductor-Capacitor) filter is modeled and dimensioned by Amina Azizia et.al [16] according to the grid constraints. A method of hybridation detection of the MPPT coupling long-time aging evolution and short-time determination is proposed. Aging laws for the electrical and optical degradations of the photovoltaic module are introduced for the long-time evolution. Results display the lowering of the maximal power point with a rate of 1%/year and a slight augmentation of the THD over time even though it remains inferior to the IEEE standard STD 19-1992 maximum value of 5% for a usage of 20 years. Moreover, an equivalent scheme for the additional electrical resistance engendered by the aging of the photovoltaic module regarding other resistances of the photovoltaic system is given. Finally, the elevation of this resistance by 12.8%in 20 years may have non-negligible consequences on the power production of a large-scale installation.

Solar Photovoltaic systems are widely accepted as alternate energy sources across the world. Grid Tied PV (GTPV) and Grid Interactive (GIPV) PV systems are the two configurations in which PV generation is integrated with Grid. Latter is more complex due to inclusion of battery as storage and connected load, along with Grid import/export. In this paper, performance of a 40kWp GIPV system, installed in India, is presented by K. Pritam Satsangi et.al [17]. The system under study comprises of PV, Grid, and Battery bank and connected load. Performance parameters like reference yield, array yield, final yield, performance ratio, and capacity factor are derived using standards IEC 61724. Also presented is Annual energy yield of the plant and Annual efficiencies of PV array, inverter and system. The effect of temperature on PV array and inverter performance is also evaluated. All these parameters are evaluated from real time annual data.

In present day scenario, the focus is reallocating towards integration of small and medium scale power plants based on renewable energy sources into the power distribution system. Solar is the fastest growing form of renewable energy and a single phase voltage source inverter is used to interface photovoltaic based plants with the distribution system. The grid integrated inverter has stringent control requirements. A current controller is employed to mitigate the harmonics in the current injected into the grid and regulate the power exchange between the plant and the grid. Aditi Chatterjee et.al [18] presented this paper of review of the current control strategies implemented for a single phase grid tied photovoltaic inverter. A comparative performance evaluation of the current control techniques is also presented through simulation and experimental results.

Since the penetration of photovoltaic (PV) systems in the Low Voltage (LV) distribution network is increasing the need to characterize and model the effect of these systems on power quality parameters is an up-to-date issue. Also, the reactive power capability of PV inverter should be defined and discussed. This research presents and investigates the experimental measurements of power quality parameters in-field on 8kWp PV system connected to the LV distribution network in Electronics Research Institute, Egypt. A. Elkholy et.al [19]researched to investigate unity power factor and constant reactive power functions as two different operation modes of PV inverter based on the measurements at PV inverter output and the grid point without local loads at off days of the governmental building in order to avoid load effects on the PV inverter parameters. Field measurement data were recorded using the power quality analyzer CA8335. Statistical analysis of each harmonic, power factor and total harmonic distortion are analyzed and presented under different loading conditions and two different functions of the PV inverter. The focus is set on the characterization of the relationship between current harmonics of PV inverter and voltage harmonics prevailing in LV system. It is found that the PV inverter presents high current total harmonic distortion levels at power levels below its rated value. This paper proposes mathematical models in order to characterize the current total harmonic distortion and the power factor at two different operation modes. The accuracy of the proposed empirical models was compared with previous research studies and presented the highest accurate results. The presented results are useful for the manufacturer of the tested PV inverter.

Photovoltaic power plants are obliged to maintain power quality standards when interconnected to the grid based on the grid codes (GCs). Variations in grid frequency can be one of the main sources of harmonic distortions in generated currents of a grid-connected photovoltaic power plant (GCPPP) as long as it is in corporate with frequency-dependant controllers such as resonant controllers in the current control loops. In fact, either the controller itself or the reference currents can contribute to the harmonic components of the generated currents. Current references in turn may become distorted due to outer voltage controller or inaccurate phase angle detection by phase-locked-loop (PLL) technique. Mitra Mirhosseini et.al [20] analysed a 3-phase GCPPP under grid frequency variations performed with the focus on associated frequency-dependant controllers i.e. current controller and filtered-sequence PLL (FSPLL). The resonant controllers are selected in this study which have the capability to attenuate generated odd-order harmonics but their performance under frequency variations need to be investigated for both ideal and non-ideal controller types. FSPLL is an effective PLL, however its performance is highly dependent to the grid frequency which requires more research regarding frequency sensitivity. Afterwards, FSPLL is developed further to detect the instantaneous grid frequency to enhance the GCPPP performance. Finally, the GCPPP is equipped with an active power controller to contribute to the frequency control of the power system. Presented results within MATLAB/Simulink environment verify the enhanced capability of the GCPPP with frequency detector/controller satisfying GCs.

2.4. CONCLUSION

After going through these series of journals and theories we have found a gap of knowledge about variation in functioning of these grid connected PV plant with the power factor and total harmonic distortions so encountered due to variance in solar irradiance. So, we have dedicated our work to study these variation of different parameters, harmonics and THD (total harmonic distortion) with sunshine. However, we have tried to get a clear idea about the harmonic distortion and THD and their impacts from many books. Now, we are well acquainted with the process to be acquired for recording and analysis of our system. But before starting the process of recording its necessary to go through the travelogue of silica to silicon solar cell and further its development to PV modules, it's working principle, I-V characteristics, losses, their interfacing and balancing and precaution to be taken for their proper functioning because it is worth noting to know their characteristics to diagnose the faulty records and their true cause, if any. All these will be covered in the forthcoming chapter.

Chapter 3: THEORIES ON SPV SYSTEM

3.1. INTRODUCTION

Instead of so many available option for solar cell material, silicon is the most dominating material in solar cell technology. In the contrary it has some advantages over them to owe its best position in the foresaid technology. Those characteristics of Si are as follows:

1. It is available in abundance and it's extraction is economically proved.
2. Non-toxic and reliable fabrication as compared to iv-vi group of compounds like: CdTe,SnS,GaAs etc.
3. Available indirect band gap with direct band gap increases its solar spectrum range of absorption of photons.
4. More stable, workable and durable cell can be obtained which is free from Dangling bonds.
5. Well acquaintance with the Si technology as it is being mastered over decades and decades after the rise of the concept of IC technology.

3.2. P-N JUNCTION

The basic requirement for photovoltaic energy conversion is an electronic asymmetry in the semi-conductor structure known as a junction. When n- and p-type semi-conductors are brought in contact, then electrons from the n-region near the junction would flow to the p-type semi-conductor, leaving behind a layer which is positively charged. Similarly holes will flow in the opposite direction leaving behind a negatively charged layer. A steady state is finally reached, resulting in a junction, which contains practically no mobile charges, hence the name depletion region.

The p-n junction (Figures 3.1 and 3.2) may be connected to a battery in two ways: (i) in forward bias (Figure 3.3a), the positive conventional circuit current passes from the p to the n material across a reduced-band potential difference V_B, (ii) in reverse bias (Figure 3.3b), the conventional positive current has an increased-band potential difference V_B to overcome. Thermally or otherwise generated electrons and holes recombine after a typical relaxation time τ having moved a typical diffusion length L through the lattice. In intrinsicmaterial the relaxation time can be long, τ B1s, but for commercial dopedmaterials relaxation times are much shorter, $\tau \sim 10^2$ to 10^8s.

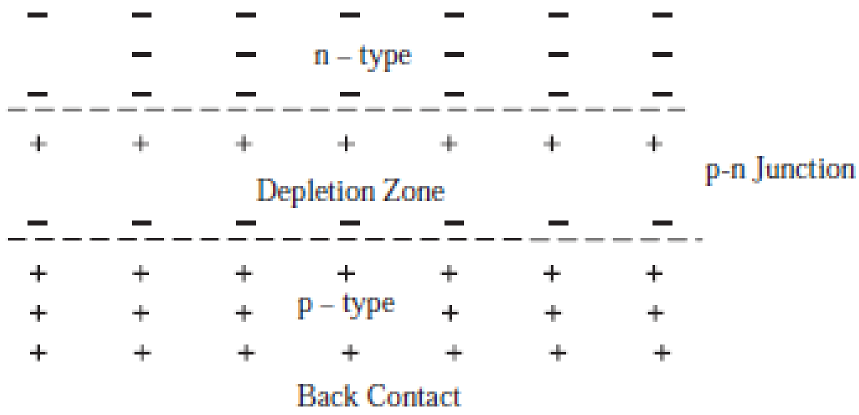


Figure 3.1 p n junction energy levels in a p n junction.

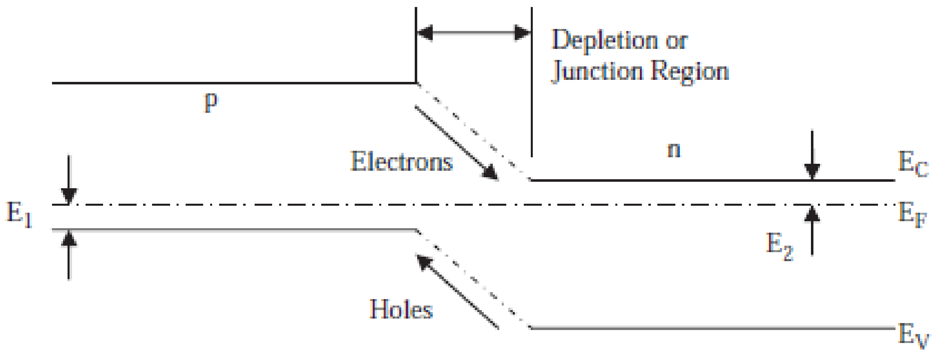


Figure 3.2 Energy levels in a p n junction

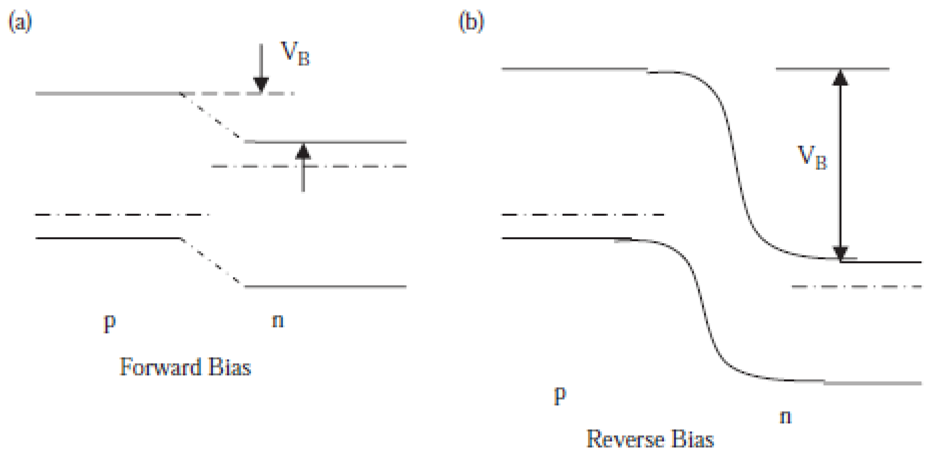


Figure 3.3 Energy levels in a p n junction with (a) forward bias and (b) reverse bias

3.2.1. Forward Bias

Forward-bias occurs when the p-type semi-conductor material is connected to the positive terminal of a battery and the n-type semi-conductor material is connected to the negative terminal. With a battery connected this way, the holes in the p-type region and the electrons in the n-type region are pushed towards the junction. This reduces the width of the depletion zone. The positive charge applied to the p-type material repels the holes, while the negative charge applied to the n-type material repels the electrons. As electrons and holes are pushed towards the junction, the distance between them decreases. This lowers the barrier in the potential. With increasing forward-bias voltage, the depletion zone eventually becomes thin enough that the zone's electric field can't counteract the charge carrier motion across the p-n junction, consequently reducing electrical resistance. The electrons which cross the p-n junction into the p-type material (or holes which cross into the n-type material) will diffuse in the near-neutral region. Therefore, the amount of minority diffusion in the near-neutral zones determines the amount of current that may flow through the diode.

3.2.2. Reverse Bias

Connecting the p-type region to the negative terminal of the battery and the n-type region to the positive terminal produces the reverse-bias effect. Because the p-type material is now connected to the negative terminal of the power supply, the 'holes' in the p-type material are pulled away from the junction, causing the width of the depletion zone to increase. Similarly, because the n-type region is connected to the positive terminal, the electrons will also be pulled away from the junction. Therefore the depletion region widens, and does so increasingly with increasing reverse-bias voltage. This increases the voltage barrier, causing a high resistance to the flow of charge carriers thus allowing minimal electric current to cross the p-n junction. The strength of the depletion zone electric field increases as the reverse-bias voltage increases. Once the electric field intensity increases beyond a critical level, the p-n junction depletion zone breaks down and current begins to flow, usually by either the Zener or the avalanche breakdown processes. Both of these breakdown processes are non-destructive and are reversible, so long as the amount of current flowing does not reach levels that cause the semi-conductor material to overheat and cause thermal damage.

Electrons and holes may be generated thermally or by light, and become carriers in the material (Figure 3.5). Minority carriers in the depletion region are pulled across electrostatically down their respective potential gradients. The minority carriers that cross the region become majority carriers in the adjacent layer. The passage of these carriers causes the generation current I_g which is mainly controlled by temperature in a given junction without illumination. In an isolated junction, there can be no overall imbalance of current across the depletion region. Thus, a reverse recombination current I_r of equal magnitude occurs from the bulk material, which restores the normal internal electric field. The band potential VB is slightly reduced by Ir. The recombination current I_r can be varied by external bias as explained earlier (Figure 3.4).

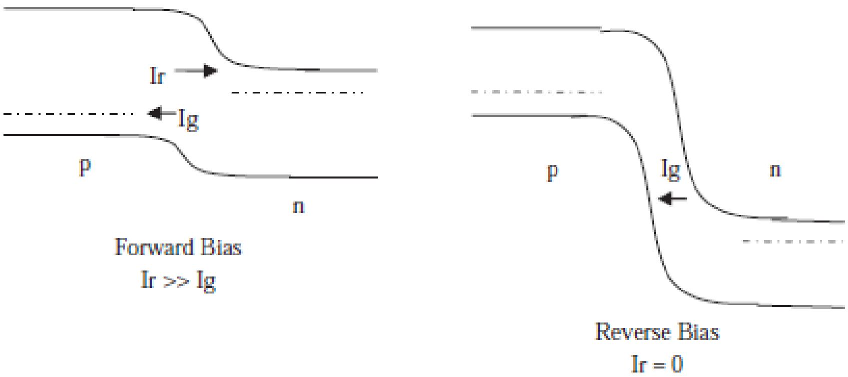


Figure 3.4 Generation and recombination currents with external bias

3.3. P-N JUNCTION CHARACTERISTICS

The p-n junction characteristics have been given in Figure 3.5

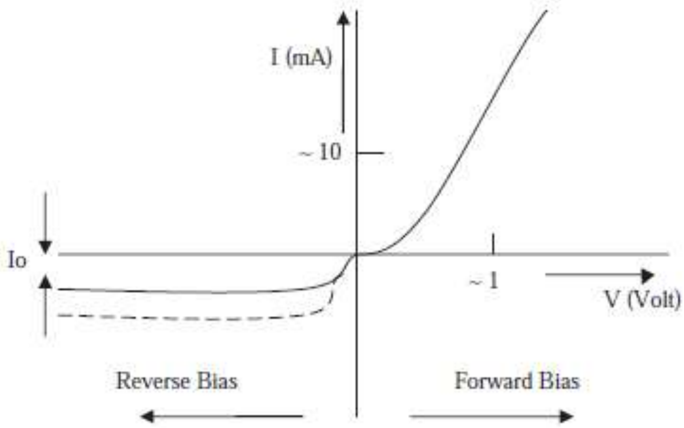


Figure 3.5 p-n junction dark characteristics

With no external bias (V=0).

$$I_r = I_g$$

With a forward bias of voltage V, the recombination current becomes an increased forward current.

$I_r = I_g \exp(eV/(kT))$

The total current (with no illumination) is

$I_D = I_r - I_g = I_g[\exp(eV/kT) - 1]$

The above equation is the Shockley equation and can be written as

$I_D = I_0[\exp(eV/kT) - 1]$

Where $I_0(=I_g)$ is the saturation current under reverse bias, before avalanche breakdown occurs. It is also known as leakage or diffusion current. For good solar cells I_0~10 ^{8}Am $^{-2}$. Its value increases with temperature (Figure 3.5, dotted curve)

3.4. PHOTOVOLTAIC EFFECT

When the solar cell (p-n junction) is illuminated, electron-holes pairs are generated and acted upon by the internal electric fields, resulting in a photo current(I_L). The generated photocurrent flows in a direction opposite to the forward dark current. Even in the absence of external applied voltage, this photocurrent continues to flow, and is measured as the short circuit current (I_{sc}). This current depends linearly on the light intensity, because absorption of more light results in additional electrons flowing in the internal electric field force. The overall cell current I is determined by subtracting the light induced current I_L from the diode dark current I_D.

$I=I_D-I_L$

Then; $I=I_0\exp(eV/kT) – 1]$

This phenomenon is called the photovoltaic effect.

3.5. TYPE OF SOLAR CELL

The photoelectric generation continues till the photons incident in the active surface of solar cell. But the efficiency depends on the quality of semiconductor used. The above said energy conservation is due to presence of barrier layer in the junction of two semiconducting layer.

The possible types of barrier layer are:-

i. P-n homo-junction
ii. P-n hetero-junction
iii. Tandem solar cell
iv. Metal semiconductor junction(MS)
v. Metal Insulator semiconductor junction(MIS)

P-n homo-junction comprises of two layer of same semiconductor one is made p-type another is n-type by doping.

P-n hetero-junction comprises of two different semiconductor layer such as III-V or II-VI compound semiconductors like GaAs-GaAlAs, CdS-$CuInSl_2$.

Tandem junction is used amorphous Si-Solar Cell with p-i-n configuration.

MS ad MIS structures are grown only in laboratory till now.

3.6. PHOTOVOLTAIC MATERIAL

Solar cells are made of various materials and with different structures in order to reduce the cost and achieve maximum efficiency. There are various types of solar cell material, single crystal, polycrystalline and amorphous silicon, compound thin-film material and other semi-conductor absorbing layers, which give highly efficient cells for specialized applications.

Crystalline silicon cells are most popular, though they are expensive. The amorphous silicon thin-film solar cells are less expensive. The amorphous silicon layer is used with both hydrogen and fluorine incorporated in the structure. These a-Si: F: H alloys have been produced by the glow discharge decomposition ofSiF_4 in the presence of hydrogen. The efficiency of an a-Si module is about 6–8%.

A variety of compound semi-conductors can also be used to manufacture thin-film solar cells. These compound materials are $CuInSe_2$, CdS, CdTe, Cu_2SandInP. The $CuInSe_2$ solar cell stability appears to be excellent. The combinations of different band gap materials in tandem configurations lead to photovoltaic generators of much higher efficiencies.

1.6.1. Silicon

Despite of numerous semiconductor material, Silicon (Si) has been selected as the most appropriate for solar cell due to the following reasons.

<u>Primary cause</u>

a) Silicon is the second most abundant material on the earth's crust in the form of silicon dioxide (SiO_2).
b) It is reliable and Non toxic.

Technical Cause

a) The photon absorption energy in case of Si isles than other direct band gap semiconductor lie CdTe, GaAs due to pressure of Indirect band gap thus wide absorption spectrum.
b) Higher degree of Chemical stability.
c) Si technology has been expertise from 40 decades in electronics and circuits.

3.7. SILICON SOLAR CELL TECHNOLOGY

3.7.1. Czchrlaski/Cz Techniques

The commercial form of Si is extracted from crystalline form of SiO_2 through carbon reduction process. The Si so obtained is metallurgical grade Si.

$SiO_2 + 2C \rightarrow$ MG-Si + C

It is further transformed into volatile compound tri chloro silane which is refine through fractional distillation.

$Si + 3HCl \rightarrow SiHCl_3 + H_2$

The single crystal is then sliced up to give standard Si cell shape of common use.Cz process is an ingot technology. One of the major disadvantage is 50% of Si is lost while slicing.

3.7.2. Process technology

a) Remove of saw damage

During slicing the ingot to get wafer uneven surfaces are formed. The sliced wafers are treated with 30% NaOH for 5 minutes to remove saw damages. Due to etching the surface layer of wafer have bulging perforated pattern.

b) Texturisation

Often high rate etching it is etched at slow rate with 2% NaOH to get pyramidal structure to get more light trapping capacity.

c) Junction formation

The most common way of junction formation is by spinning phosphoric acid H_3PO_4. The wafer is passed through a belt furnace and fired with dried H_3PO_4 so to dope P to form junction. Then it is coated with phospho-silicate glass.

d) Removal of impurities

During junction formation Borosilicate glass is formed which is to be removed before metal contact formation. So, the wafer is treated sequentially with 4% HF solution then with 1% NH_3 solution to avoid acidic rusting.

e) Back Contact formation

It is printed on the back of wafer using wire mesh screen and a paste of Ag, Al and borosilicate. The cell is first dried and fired with paste so that Ag forms ohmic contact with the Si. The bond so formed is called Eutectic bond.

f) Front Contact formation

The wafer is treated with 20% CH_3COOH to remove naturally form SiO_2 during treatment with HF and NH_3. Suitably using wire mesh screen and the same paste is printed on the front side. Again it is treated with %HF for 20s then for 30s to remove glass impurities.

g) Plasma edge isolation

It is achieved by coin stacking of cells an etching the stack with CF_4-oygen plasma.

h) Cell gradation

Form I-V characteristics recorded at standard test condition four parameters I_{SC}, V_{OC}, FF, η determined.

i) Module fabrication

A single cell or suitably interconnected matrix of solar cells when hermitically sealed with a transparent cover and durable back cover it is called Module.

3.7.3. Reason for module fabrication

PV device is always operated outdoor in an unpredictable and often adverse atmospheric condition. There arises of question of packaging it.

3.8. BASIC PARAMETERS OF SOLAR CELLS

There are certain parameters to be mentioned in the I-V characteristics of a solar cell.

3.8.1. Overall Current (I)

Overall current is determined by subtracting the light-induced current from the diode dark current and can be expressed as:

Overall current (I)=Diode dark current (I_D) – light–induced current (I_L)

$I = I_0 \exp(eV/kT) - 1] - I_L$

Where, I_0 is the saturation current, which is also known as the leakage or diffusion current ($I_0 \approx 10\ ^8 Am\ ^2$ for good solar cells); e is the charge on an electron and hole and k is Boltzmann’s constant.

Both I_L and I_0 depend on the structure of solar cells.

3.8.2. 3.8.2 Short Circuit Current (*I*sc)

Short circuit current is the light-generated current or photo current, IL. It is the current in the circuit when the load is zero in the circuit. It can be achieved by connecting the positive and negative terminals by copper wire.

3.8.3. Open Circuit Voltage (Voc)

Open circuit voltage is obtained by setting I=0 in the expression for overall current i.e. I=0 when $V=V_{oc}$.

$$\text{Voc} = \frac{kT}{e} \ln\left(\frac{I_L}{I_0} + 1\right)$$

The open circuit voltage is the voltage for maximum load in the circuit.

3.8.4. I-V Characteristics

The current equation for a solar cell is given by, $I = I_0[\left[\exp \frac{e((V-IR_S)}{kT} - 1\right]$ andshown in Figure 3.6. For a good solar cell, the series resistance R_s should be very small and the shunt (parallel) resistance R_p should be very large. For commercial solar cells R_p is much greater than the forward resistance of a diode so that it can be neglected and only R_s is of interest. The following are a few of the characteristics parameters that have been discussed.

The optimum load resistance R_L at (P_{max}) is equal to ¼$R_{p(max)}$ is connected, if the PV generator is able to deliver maximum power.

$P_{max} = V_{P\,max}\, I_{P\,max}$ and, $R_{P\,max} = \frac{V_{Pmax}}{I_{Pmax}}$

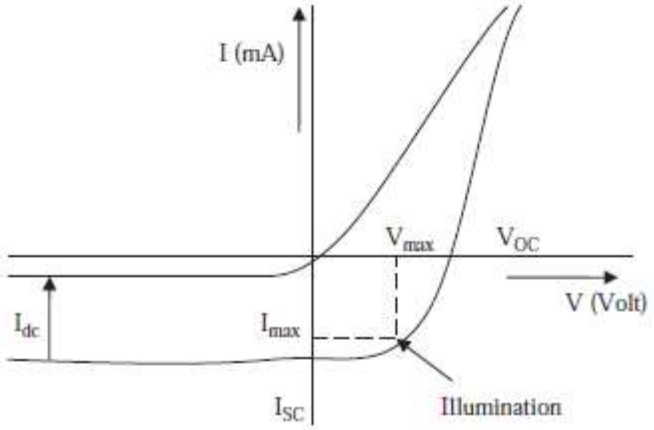


Figure 3.6 I V characteristics of a solar cell.

The efficiency is defined as $\eta = P/\phi$

where P = V x I is the power delivered by the PV generator.

$\phi = I_T x\ A$ is the solar radiation falling on the PV generator.

I_T is the solar intensity and A is the surface area irradiated.

3.8.5. Fill Factor (FF)

The fill factor, also known as the curve factor (Figure 3.7), is a measure ofsharpness of the knee in an I-V curve. It indicates how well a junction was madein the cell and how low the series resistance has been made. It can be lowered bythe presence of series resistance and tends to be higher whenever the opencircuit voltage is high. The maximum value of the fill factor is one, which is notpossible. Its maximum value in Si is 0.88.

$$FF = \frac{P_{max}}{V_{oc} x I_{sc}} = \frac{I_{max} x V_{max}}{V_{oc} x I_{sc}}$$

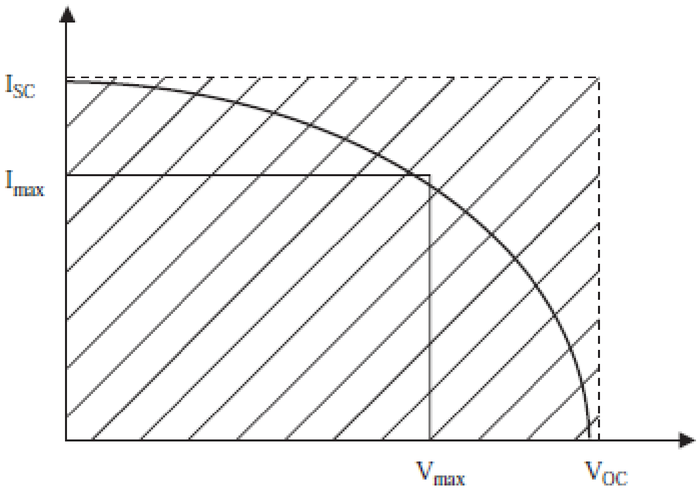


Figure 3.7 Characteristic curve for determining the fill factor.

3.8.6. Maximum Power (Pmax)

No power is generated under short or open circuit. The power output is defined as

$P_{out}=V_{out}xI_{out}$

The maximum power P_{max} provided by the device is achieved at a point on thecharacteristics, where the product IV is maximum. Thus

$P_{max}=I_{max}xV_{max}$

The maximum possible output can also be given as

$P_{max} =V_{oc}xI_{sc}$ x FF

where FF is the fill factor given by eqn (3.17).

3.8.7. Solar Cell Efficiency (η_{ec})

The solar cell power conversion efficiency can be given as

$$\eta_{ec} = \frac{P_{max}}{P_{in}} = \frac{I_{max}xV_{max}}{\text{IncidentsolarradiationxAreaofsolarcell}}$$

$$= \frac{V_{oc}xI_{sc}xFF}{I(t)xA_c}$$

where I_{max} and V_{max} are the current and voltage for maximum power, correspondingto solar intensity (I(t)).

3.9. PV MODULE JOURNEY

a) Stringing

Tested and shorted solar cells are interconnected by solder flux to obtain strings of solar cells.

b) Cleaning

To remove solder flux and often extraneous matter they are treated with organic solvent.

c) Lay up

These cleaned strings are layed down on a white glass sheet upside down on a table top so the inner surfaces faces upward.

Solar cell is placed on EVA layer upon toughened glass. Then it is covered with a scrim glass further covered with EVA layer then finally placed with Tedlar/ Tedlar-olyster-tedelar/tefzel.

d) Lamination

The laid down assembly is put into the lamination and heatedat 100 ^{0}C. So the EVA layer will laminate the solar cell from both front and back side.

e) Fixation of junction box

A junction box is fixed at the back of panel having two laminated +ve and –ve.

f) Testing

At last they are tested in microprocessor controller tester which measures relevant electro-optical parameters like V_{oc}, I_{sc}, V_m, I_m P_m

g) Commercialisation test

It comprises of test of PV module against same fixed standards.

Table 3.1 Summary of PV module Test Levels

Test No	Title	Test Level
B1	Visual Inspection	No defined defects visible at illumination level not less than 1000 lux.
B2	Performance at STC	Cell Operating Temperature: $25^0 \pm 2^0$ C
B3	Insulation	1000Vdc + twice the open circuit voltage of the system at STC for 1 minute . Insulation resistance not less than 50 MΩ at 500 Vdc
B4	Measurement of Temperature Coefficient	Temperature coefficients of short-circuit current and open-circuit voltage.
B5	Measurement of NOCT	Total solar irradiance: 800 W/m^2. Ambient Temperature: 20^0 C. Wind speed: 1m/s
B6	Performance at NOCT	Cell operating Temperature: NOCT Irradiance: 800 W/m^2 with IEC 904-3 reference solar spectral Irradiance distribution
B7	Performance at Low	Cell operating Temperature: $25^0\pm 2^0$ C Irradiance: 200 W/m^2 with IEC 904-3 reference solar spectral Irradiance distribution
B8	Outdoor Exposure	60 kWh/m^2 total solar irradiance
B9	Hot Spot Endurance	Five 1 hour exposures to 1000 W/m^2 irradiance in worst-case hot-spot condition.
B10	UV Exposure	15 kWh/m^{2}UVirradiance.
B11	Thermal Cycling	50 and 200 cycles from -40^0 C to $+85^0$ C
B12	Humidity Freeze	10 cycles from $+85^0$ C, 85% RH to -40^0 C
B13	Damp Heat	1000 hours at $+85^0$ C , 85% Rh.
B14	Robustness of Termination	As in IEC 68-2-21.
B15	Twist	Deformation angle: 1.2.
B16	Mechanical Load	2 cycles of 2400 Pa uniform load, applied for 1 hour to font and back surfaces in turn.
B17	Hail Resistance	25 mm diameter ice ball at 23.0 m/s, directed at 1 impact locations.

3.10. LOSSES IN MODULE

The losses in a modules are due to the following factors: -

a) Interconnections
b) Front transparent cover
c) Potting medium
d) Solar Cell mismatch

a) Losses due to interconnection

Copper strips in the PV module of a constant resistance responsible for I^2R loss. It can be reduced by using alloy contacts having low contact resistance.

b) Losses due to front transparent cover

Due to transparent cover the full light incident on module may not be exposed to module. Some of it may be reflected. IT can be minimized by using high transmission and tempered glass. Ex- Tedlar, Tefzal

c) Potting medium

In the PV module, the coating so used in between solar cell and transparent cover in the front and back is called potting medium. It also continue to loss which can be minimized by using good quality potting medium, like- Ethyle Vinyl Acetate

d) Loss due to solar mismatch

In a module if two solar cell IV characteristic mismatches then it leads to the shifting of maximum power point hence, efficiency decreases. So, they should be nearly identical

PV array

Identical modules of commonly same PV modules are arranged in parallel and series combination.

Parallel arrangement – for higher current capacity

Series arrangement – for higher voltage

3.11. CONCLUSION

After going through these journals and theories we have got some idea for cross checking the our data acquiring system as well as can choke out the critical events encountered by the system in the entire working day. Since our recording meter is mainly for 3-phase AC system we have to be familiar with the theories related to phasor diagram, circle diagram and relation of power factor with apparent, real, reactive power.

However as far as system design is concerned we have to go through the types of PV system and their interfacing, BOS, accessories for metering and protection of the system. All these will be covered in the forthcoming chapter.

Chapter 4: PRESENT TECHNOLOGY AND SYSTEM CONFIGURATION

4.1. INTRODUCTION

Solar cell or PV module cannot be operated in isolation for a fruitful PV system requires many devices, component, controller and regulator for its installation. Such other apparatus so required are called Balance of System(BOS).

4.2. BALANCE OF SYSTEM (BOS) [21]

4.2.1. Types of BOS

Mechanical, Electrical, Electronic

Mechanical BOS

It generally comprises of storage racks, battery boxes, poles and stays for carrying electrical wires.

Electrical BOS

Lightning arrestor, wiring, cabling fuses, monitors, meters, circuit breaker, switch gears

Electronic BOS

Its nature depends on the capacity of PV system, more is the capacity more complex is the electronic BOS.

It consists of maximum power tracker (MPT), battery change controller unit, power control unit (PCU) inverter.

4.2.2. Essential requirement of BOS

a) Capability of operate outdoors
b) Reliability
c) Protection against misuse
d) Qualified component

4.3. TYPES OF PHOTOVOLTAIC SYSTEM

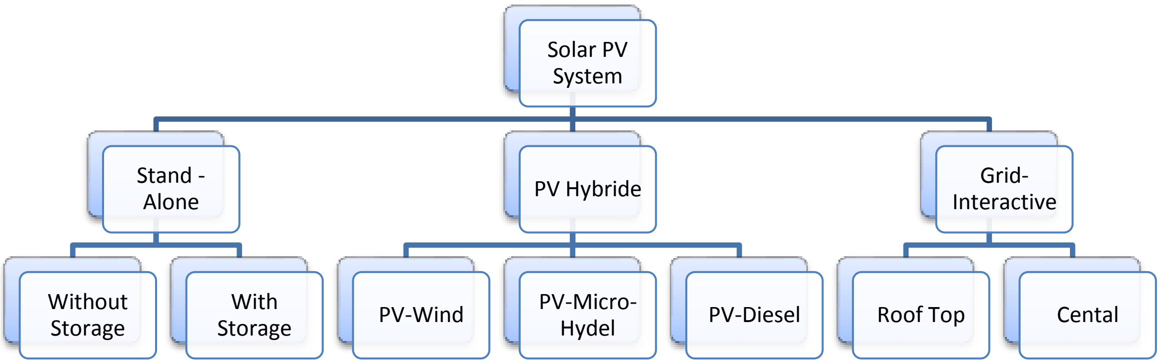


Figure 4.1 Different types of photovoltaic system

4.3.1. Stand alone (off grid) system

The electrical energy so generated is used to charge the battery. The stored energy is then converted into useful AC form.

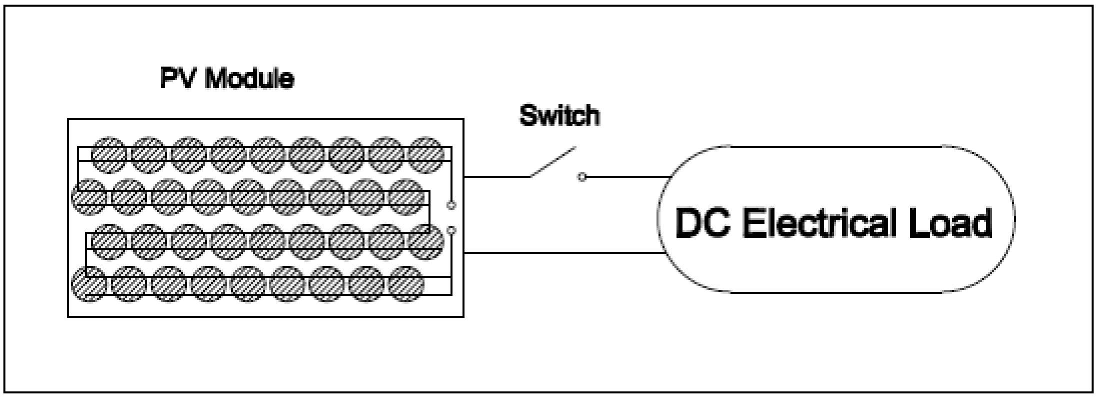


Figure 4.2 Block diagram of the simplest possible PV system

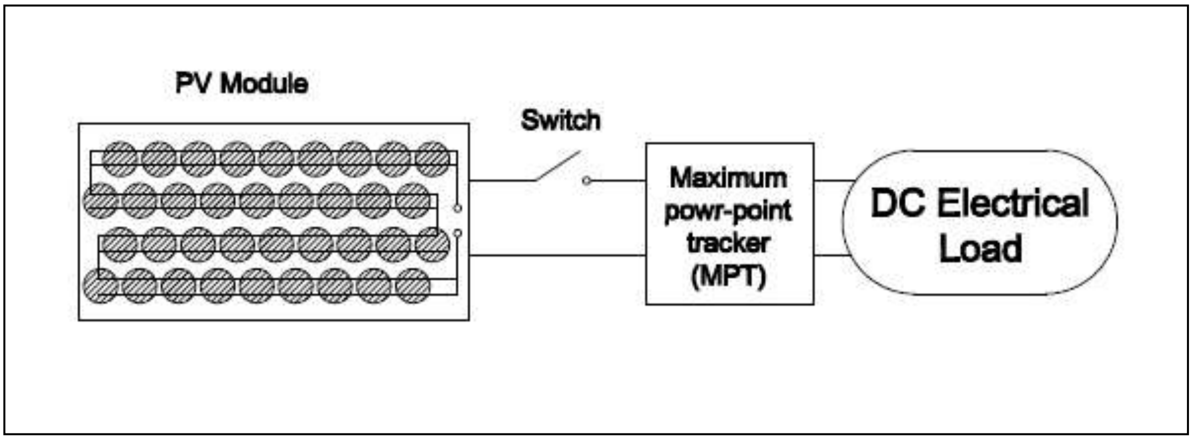


Figure 4.3 Directly-connected system with MPT for a dc load

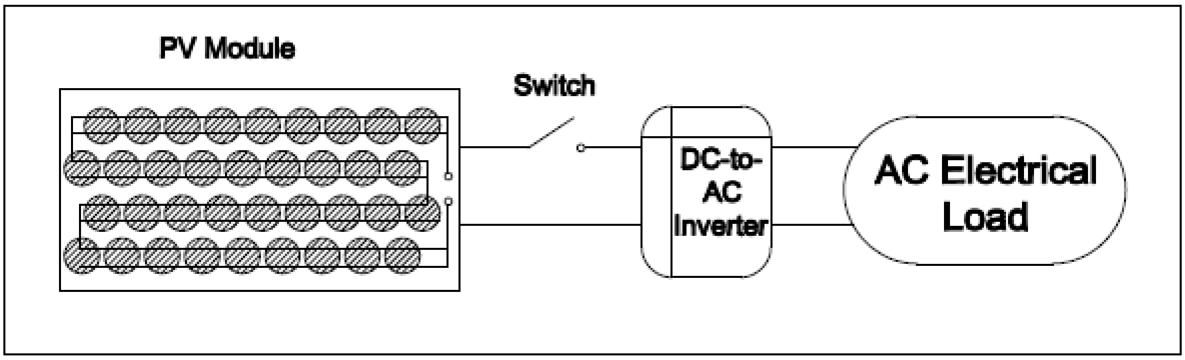


Figure 4.4 Simplified directly connected system to drive ac load

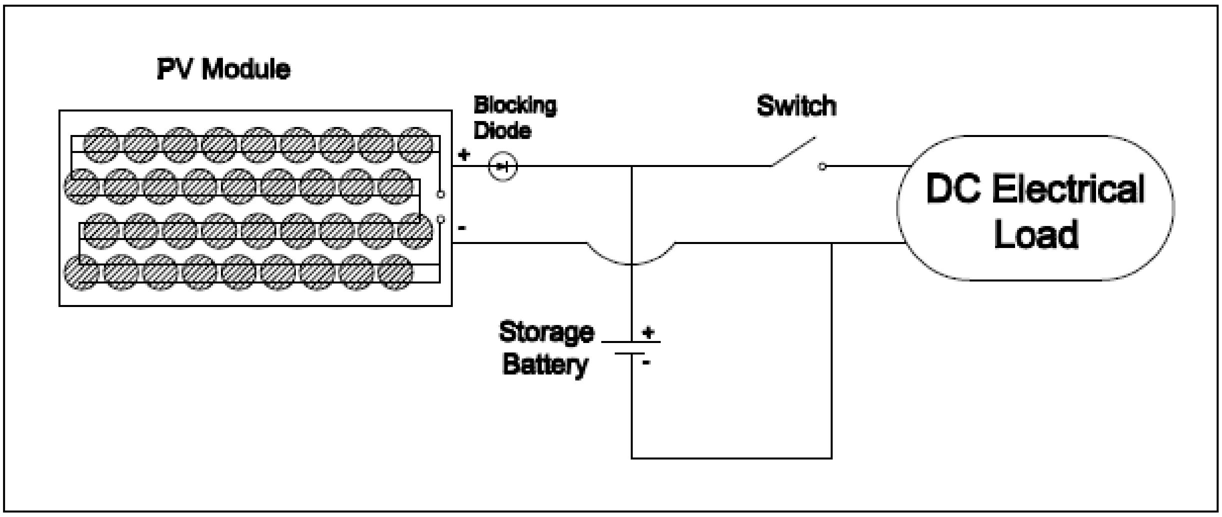


Figure 4.5 Schematics of a stand-alone system using battery

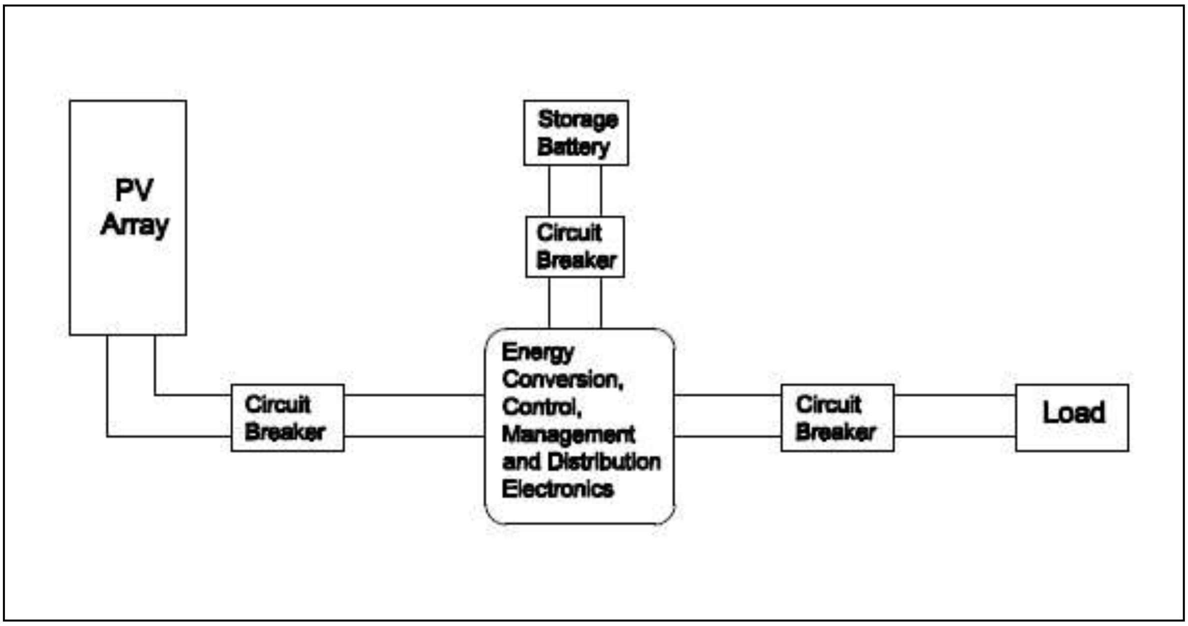


Figure 4.6 Schematics of a generalized stand-alone PV system

4.3.2. PV-Hybrid System

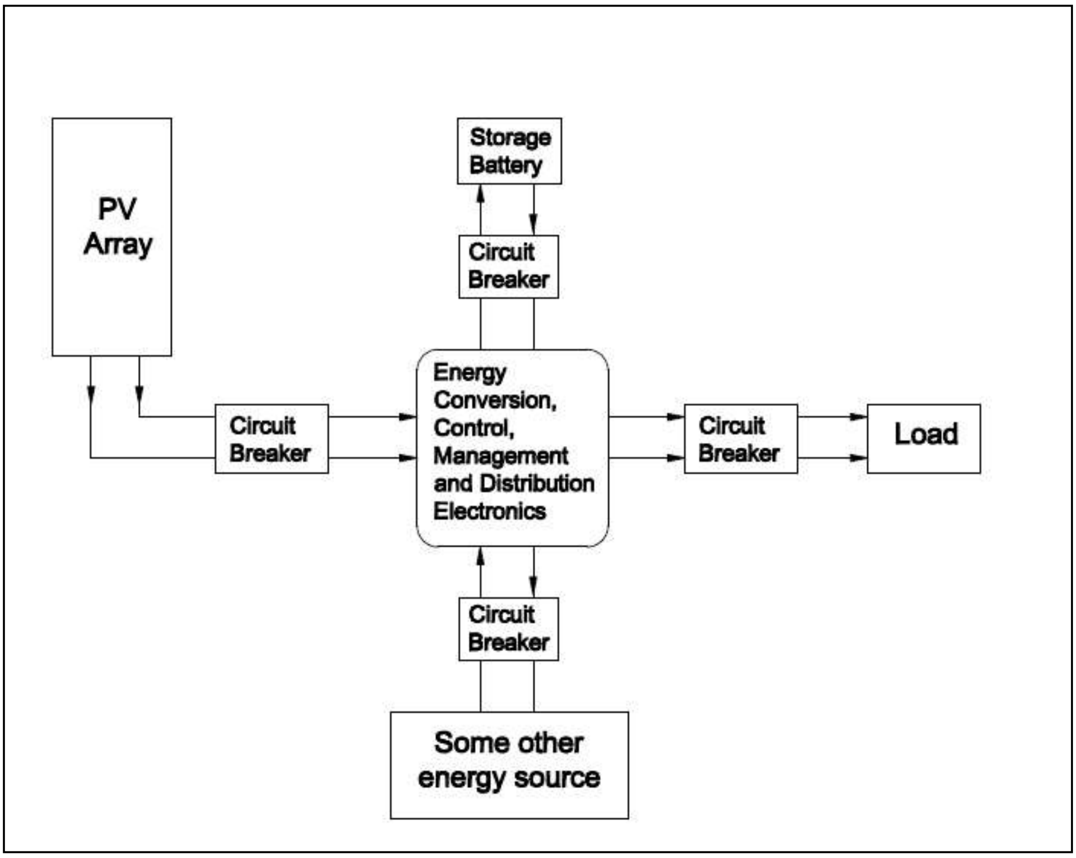


Figure 4.7 Schematics of a typical PV-hybrid system

4.3.3. Grid Interactive System

Grid connected SPV system (centralized)

This type of power plants delivers electricity directly into the grid through an inverter which converts and synchronises it with grid.

Grid connected distributed system

The power plant is used to supply extra power to the grid after supplying the electricity network directly into it.

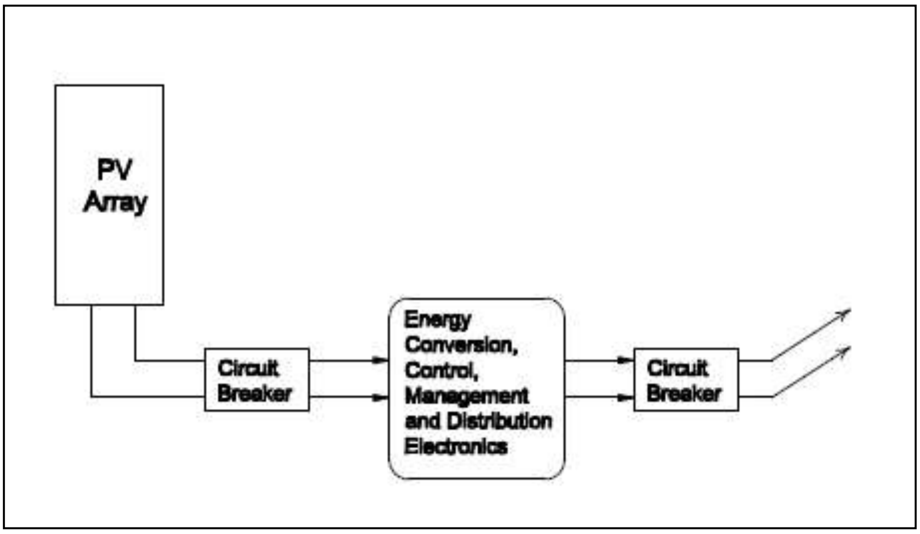


Figure 4.8 Schematics of a grid-connected PV system

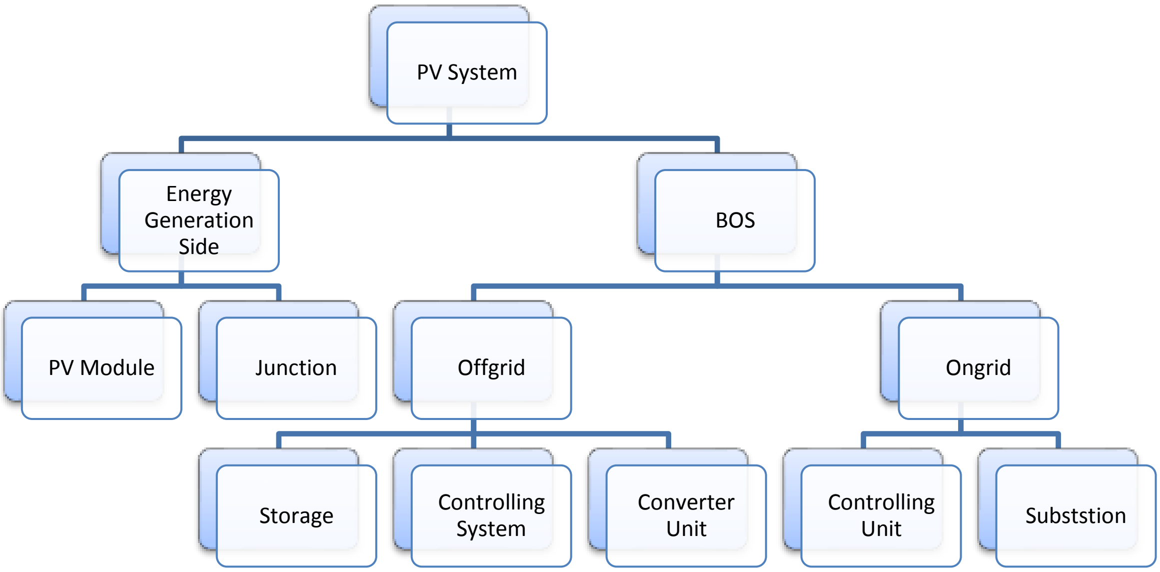


Figure 4.9 PV System Arrangements

4.4. Inverter

The DC power from the stored in battery is to be transformed to AC power to run the appliances and there comes the requirement of the device so called inverter .It is used to convert dc power to ac power.This conversion can be achieved either by transistors or SCR's. For low and medium power output, transistors inverter are suitable but for high power output SCR's based Driven inverter are more common type and the only inverter used for conversion into multiphase ac output .

4.4.1. Classification of Inverter :

Inverter circuits may be divided into two classes on the basis of their output waveform;

1) Amplifier type sine wave inverters

These are suitable for low power output applications because of low conversion efficiency.

2) Saturated switch type inverters

They have high efficiency because power transistors or SCR's are used to operate like switches to convert variable DC power to square wave AC power. These are suitable for high power application.

These inverters are further categorized into two types:

a) Voltage driven inverters
b) Current driven inverters.

a) Voltage-driven inverter :

In the voltage driven inverter,the circuit connects a DC voltage source though semi-conductor switches, directly to the primary of the transformer.

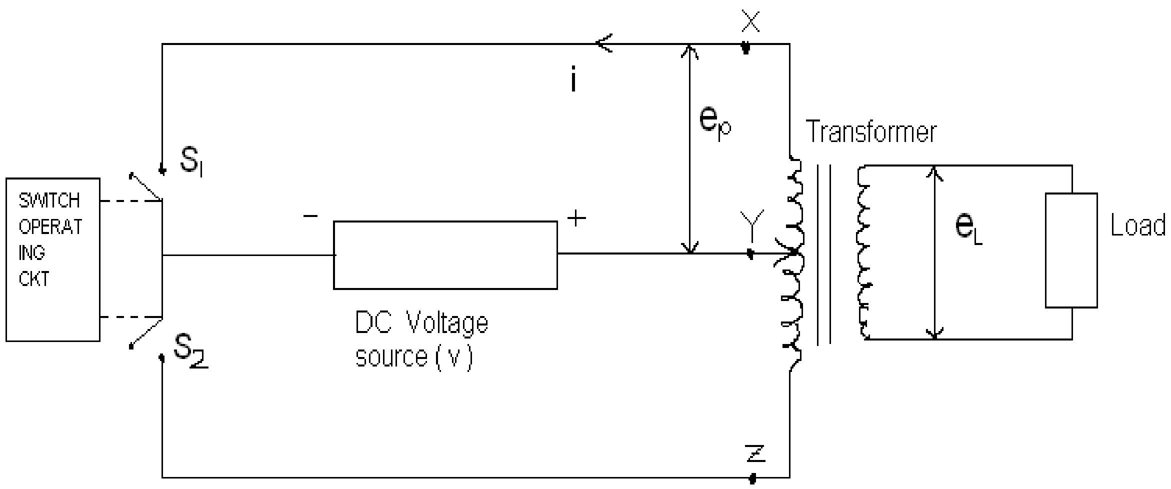


Figure 4.10 Basic Scheme of Voltage Driven Inverter

b) Current driven inverter:

In a current driven inverter, the current is held at constant value and fixed in phase with the switching time and irrespective of the voltage wave which is based on the load so connected.

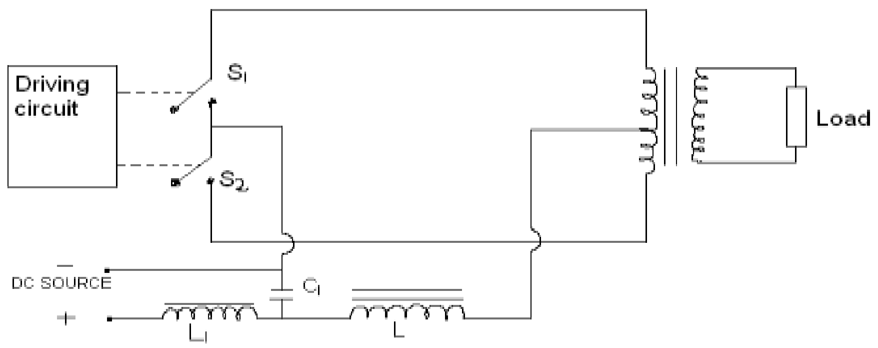


Figure 4.11 Basic Scheme of Current Driven Inverter

L = choke coil having high inductance (X_L=**ω**L offers high reactance to DC), It will maintain the constant current flow the circuit (L=di/dt). For sine wave output an LC tank circuit is connected at the output of the current driven inverter.

4.4.2. Transformerless Inverter

Input voltage range (450 – 600 V DC)

Output voltage range (300 – 350 V AC), 3 phase

It has substituted 415 V AC inverter in modern technology.

In these inverter IGBT(insulated gate bipolar transistor) is used instead of transformer which has reduced the sizeandmaintenancetroubleas well as the bulkiness and protect it from thermal run away.The 300-350V AC in the substation is stepped up with transformer t to 110 KV AC power for feeding into the grid for transmission.

Filter circuit or modulators are used for synchronization and blending the power to the grid by modulating the waveform nearly sinusoidal after sensing the voltage, frequency and phase sequence in both sides.

4.5. CONCLUSION

We have gone through the devices used in our system that is a roof top PV grid connected distributed type PV system with maximum installed capacity of 1KW without storage. The next chapter will deal with the equipments and meters used in the experimental set up especially PQ 3100 and their specifications, recording the data and their analysis after putting them in graph and other statistical form.

Chapter 5: SYSTEM DESCRIPTION & EXPERIMENTAL PROCEDURE

5.1. SYSTEM DESCRIPTION

Our system is grid integrated distributive type of installed capacity 1kW roof top (Figure 5.1) at School of Energy studies, Jadavpur University. It consists of four modules each with V_{mp} = 36.18V and P_m = 250W connected in series produces power at voltage around 120V.

Figure 5.1 Solar Panel

The control board (Figure 5.2) which is connected the solar panel to grid through an inverter is available in the laboratory to measure DC and AC power separately.

Thesingle line diagram of 1kW on grid solar power arrangement is shown in Figure 5.3.

Figure 5.2. Control Board Connection

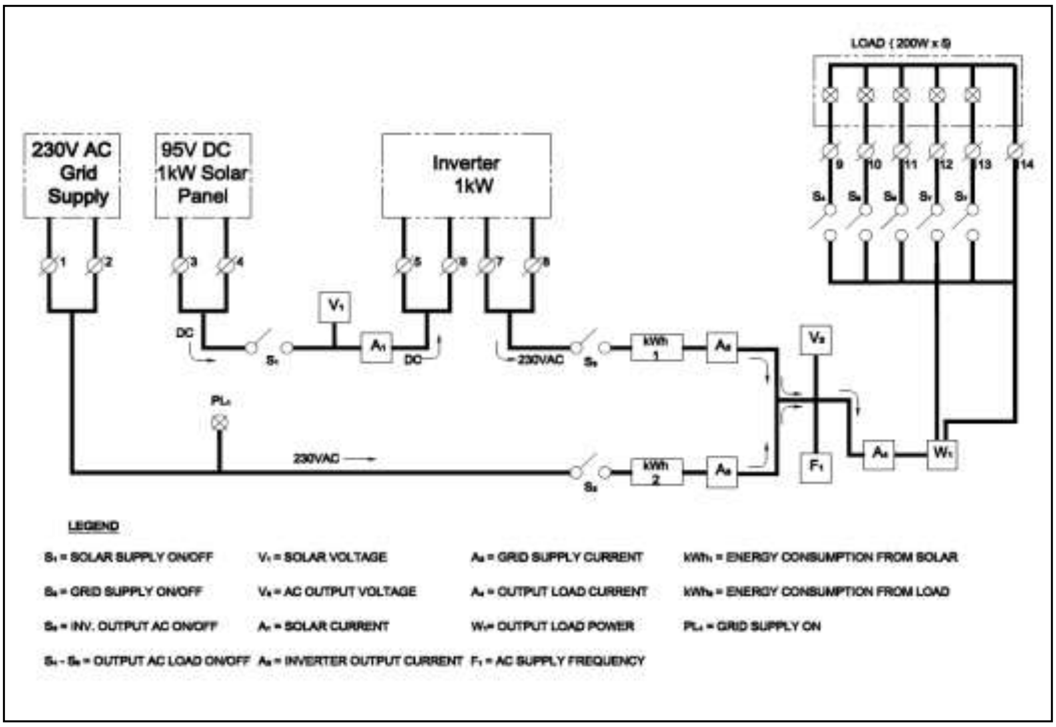


Figure 5.3 Single Line Diagram of 1kW on Grid Solar Power Arrangement

Table 5.1.Specification of Solar Panel

Module Type	SS250P
Nos. of Panel	4
Rated Peak Power(P_{max})	250W
Rated Voltage (V_{mp})	36.18V
Rated Current (I_{mp})	6.92 A
Open Circuit Voltage (V_{oc})	44.46 V
Short Circuit Current (I_{sc})	7.28 A
Fire rating class-C, Application class-A, Fuse rating – 15A	
Power specification measured at standard Test Conditions. Insolation of 1000W/m^2, AM 1.5, 25^0 C Cell temperature. With Power Tolerance±3%	

The two terminals of thepanel is connected to the switch board through two port single throw MCB to Moving Iron Voltmeter and Ammeter and the same leads were connected at the input side of inverter.

Table 5.2. Specification of On-Grid Single Phase Solar Inverter

PV input ratings:	
Maximum rated PV input voltage:	450V
Maximum PV short circuit current:	14.0A
PV input operating voltage range:	60-450V
Maximum operating PV input current:	12.0A
A.C. Output Ratings:	
Nominal Voltage:	230V~
Maximum Continuous Current:	5.7A
Nominal Frequency:	50Hz
Maximum Continuous Power	1100W
Protective Class I	
Ingress Protection:	IP65

The output of the inverter is again brought back to the switch board through MCB to a separate MI voltmeter and ammeter to measure the AC voltage and current.

The inverter converts the solar DC power into AC of 220 V and 50 Hz to synchronise with grid.

The switch board also has terminals connected to grid through a MCB and energy meter. The two sources of power are connected in parallel to the local loads present in the board.(The local load here implies 4 bulbs each of 200W)

Consumption

Case1 :- If power through PV system < power required by local loads

— Then the extra power is required by load is extracted from the grid.

Case 2 : If power through PV system > power required by local loads

— Supplies power will be fed to the grid

Case 3 : If there is no local loads

— The entire power produced by the PV system is fed to the grid.

Our aim is to find out the variation in parameters like I(current DC and AC), V,P(output voltage AC and DC), presence of 3^{rd}, 5^{th} and 7^{th} harmonic and THD(total harmonic distortion) etc. with variation in sunshine.

Apparatus used: Power Quality Analyser (PQ3100) (HIOKI made) and Solarimeter

Figure 5.4 Power Quality Analyser (PQ3100) (HIOKI made)

The device PQ3100 is capable to detect the malfunctioning of :

Single Phase 2 wire system	(1P2WDC)	1 voltage chord, 2 current sensors
Single phase 3 wire with 1main	(1P3W1M0	1 voltage chord 3 current sensors
3 phase 3 wire with 2 main	(3P3W2M)	2 voltage chords, 3current sensors
3 phase 3 wire with 3 Main	(3P3W3M)	3 voltage chords, 3 current sensors
3 phase 4 wire	(3P4W)	3 voltage chords, 3 current sensors

It gives a complete statistical data of the system comprising of voltage, current, harmonics (3rd, 5^{th}, 7^{th}), power, VAr, Apparent power, THD provided with a recording facility and for which time interval is set manually here.

Declared Input Voltage – 50 to 800V

Frequency – 50/60 Hz

Current capacityof clamp on ammeter depends upon the sensor chosen for the measurement.

AC flexible current sensor	CT7044 CT7045 CT7046	5000A, 500A, 50A
AC leakage current sensor	CT7116	5A, 500mA, 50mA
AC current sensor	CT7126	50A, 5A, 500mA
	CT7131	100A, 50A, 5A
	CT7136	500A, 50A, 5A
AC/DC auto-zero current sensor	CT7736	100A,10A
	CT7736	500A, 50A
	CT7742	2000A, 1000A, 500A
Clamp on sensor	9669	1000A, 100A

Our current range lies between 0-5A

So, we have used :-

AC Current sensor – CT7131 (5A, 50A, 100A)

AC/DC auto zero current sensor – CT7731 (100A, 10A)

For voltage measurement we have used alligator clips provided with the instrument PQ 3100(HIOKI).

We have to go for a comparative analysis of a DC/AC (2-wire) system. So, we require 2 voltage chords and one current sensor at a time. First

5.2. EXPERIMENTAL PROCEDURE

Preparing for the measurement:

i. Machine is off
ii. Connecting voltage chord

a. For DC measurement: DC neutral is connected with the machine neutral port with alligator clip.DC positive terminal with respective port1 of the instrument.
b. Similarly, for ac measurement connection has been done.

iii.Connecting current sensor

Clamp on ammeters of two different types CT 7731(DC) and CT 7131(AC) is used.

The direction of current shown on clamp on ammeter is matched carefully with original flow of current.

iv. Switch on the machine now.

Figure 5.5 Connection for DC Measurement

v. Machine is shown

Figure 5.6 Setup (HIOKI PQ3100)

On pressing SET UP button a screen will be shown as above where we can set the current range further:

Click on SCREEN > MEASUREMENT SETTING 1>MEASUREMENT SETTING 2> RECORDING SETTING> EVENT SETTING> SYSTEM SETTIN SETTING> INTERFACE SETTING can be done as per requirement of the work.

Figure 5.7a Wiring (HIOKI PQ3100)

On pressing WIRING button the display will show the connection so done. We have to check the connection of current sensor and voltage chords and confirm whether they are connected properly or not. The second display of wiring will show voltage, current, power sum. We have to match the readings with our analog meters on switch board.

Figure 5.7b Wiring (HIOKI PQ3100)

On pressing MONITOR button, we can see waveform by clicking on SCREEN>WAVEFORM>POWER (shows power curve)>VOLTAGE (voltage curve)>CURRENT (current curve)> VECTOR DIAGRAM (shows voltage and current as in circle diagram)>HARMONIC (shows waveform of different harmonics).

vi. Setting recording time – 1min
vii. Setting current range – 0 to 5A
viii. Start recording and the recorded statistical data so recorded in SD is developed in the DC and AC with the help of software installed from CD given by the manufacturer.

WE have repeated the same procedure for ac measurement.

5.3. CONCLUSION

During the preparatory work one should have clear knowledge of ac-3ϕ connection otherwise the device showing the connection diagram can't be diagonise correctly. One should also be well acquainted with circle diagram because while taking reading with DC, the variable DC will be shown as AC with changing PF (power factor). The power quality analyser is well suited for measurement of one system either AC or DC at a time so we were unable to find out the inverter efficiency as well as overall efficiency. However, Our first priority is to have a sharp vision on the presence of harmonics and their impact and to measure THD (total harmonic distortion) of our system. The data recorded by the instrument is presented in table form. They plotted in graph with varying solar radiation then they are analysed and discussed and presented in the next chapter.

Chapter 6: RESULTS AND DISCUSSIONS

6.1. MEASUREMENT, DATA ACQUISITION AND DISCUSSION

Solar radiation is measured by solarimeter at same angle and direction with solar panel at the time interval ~10min manually. Various parameters of DC power generated from 1 kW solar panel are measured by power quality analyser (PQ 3100, HIOKI) at the time interval 1min automatically from control board connection. The measured data are tabulated in Table 6.1.

Table 6.1 DC MEASUREMENT

Time	Radiation (W/m2)	Power, P(kW)	Voltage, V(Volt)	V (H5)	V (H7)	Current, I(Amp)	I (H5)	I (H7)	P_t	%Power Regulation
12.03	877.3	803	125.38	0.03	0.01	6.42	0.004	0.004	822.87	2.41
12.10	930	854	126.19	0.03	0.01	6.78	0.004	0.004	861.71	0.89
12.20	958	848	120.52	0.03	0.01	7.06	0.004	0.004	882.35	3.89
12.30	950	874	120.87	0.03	0.01	7.24	0.004	0.004	876.45	0.28
12.40	285	412	123.71	0.01	0.01	3.36	0.004	0.004	386.35	-6.64
12.50	244	345	119.81	0.01	0.01	2.89	0.004	0.004	356.13	3.12
1.00	378	530	126.48	0.01	0.01	4.21	0.004	0.004	454.89	-16.51
1.10	897	842	121.89	0.03	0.01	6.91	0.004	0.004	837.39	-0.55
1.20	850	811	123.50	0.03	0.01	6.57	0.004	0.004	802.75	-1.03
1.30	810	774	120.83	0.03	0.01	6.41	0.004	0.004	773.27	-0.09
1.40	820	816	128.22	0.02	0.01	6.38	0.004	0.004	780.64	-4.53
1.50	232	340	116.80	0.01	0.01	2.93	0.004	0.004	347.28	2.10
2.12	710	705	123.93	0.02	0.01	5.70	0.004	0.004	699.57	-0.78
2.22	681	687	124.98	0.02	0.01	5.50	0.004	0.004	678.20	-1.30
2.29	668	673	123.20	0.02	0.01	5.47	0.004	0.004	668.62	-0.66
2.40	594	626	124.25	0.02	0.01	5.05	0.004	0.004	614.08	-1.94
2.52	277	380	133.39	0.01	0.01	2.90	0.004	0.004	380.45	0.12
3.02	500	545	128.80	0.02	0.01	4.24	0.004	0.004	544.80	-0.04
3.10	460	500	127.91	0.01	0.01	3.92	0.004	0.004	515.32	2.97
3.20	412	481	127.12	0.01	0.01	3.79	0.004	0.004	479.94	-0.22
3.35	166	264	129.94	0.01	0.00	2.04	0.004	0.004	298.64	11.60
3.38	330	404	132.16	0.01	0.01	3.07	0.004	0.004	419.51	3.70

Variation of parameters of DC power with change in solar irradiance are shown in Figure 6.1, 6.2, 6.3 and 6.4.

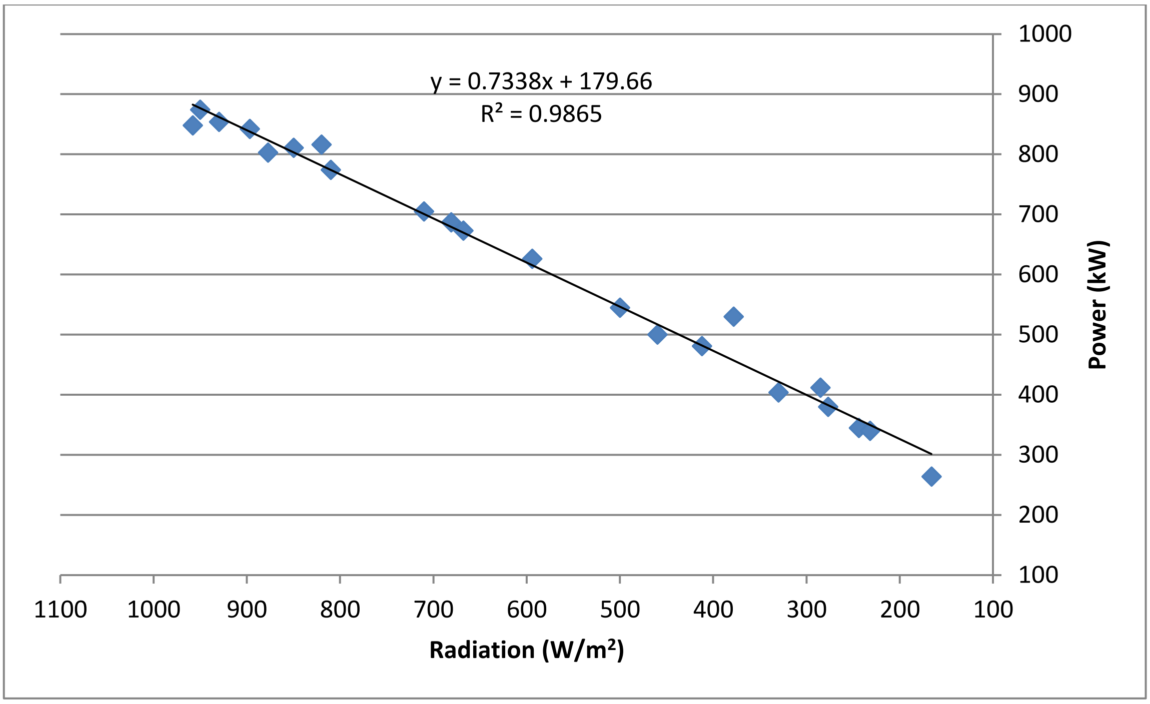


Figure 6.1 Power Vs Radiation

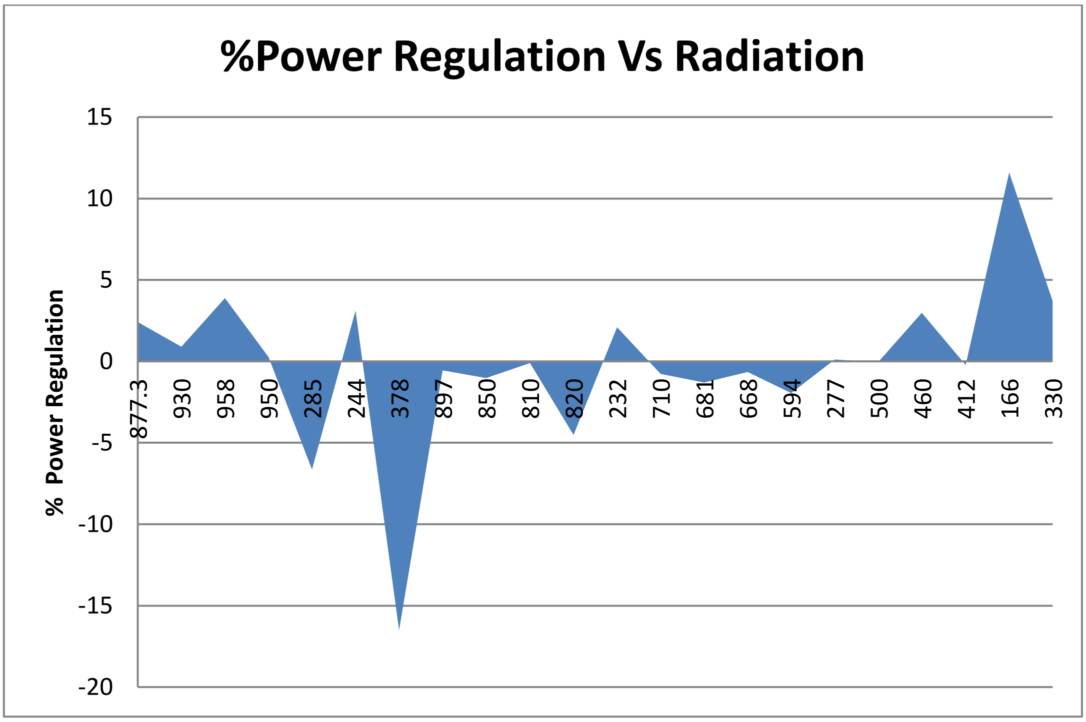


Figure 6.2 %of Power Regulation Vs Radiation

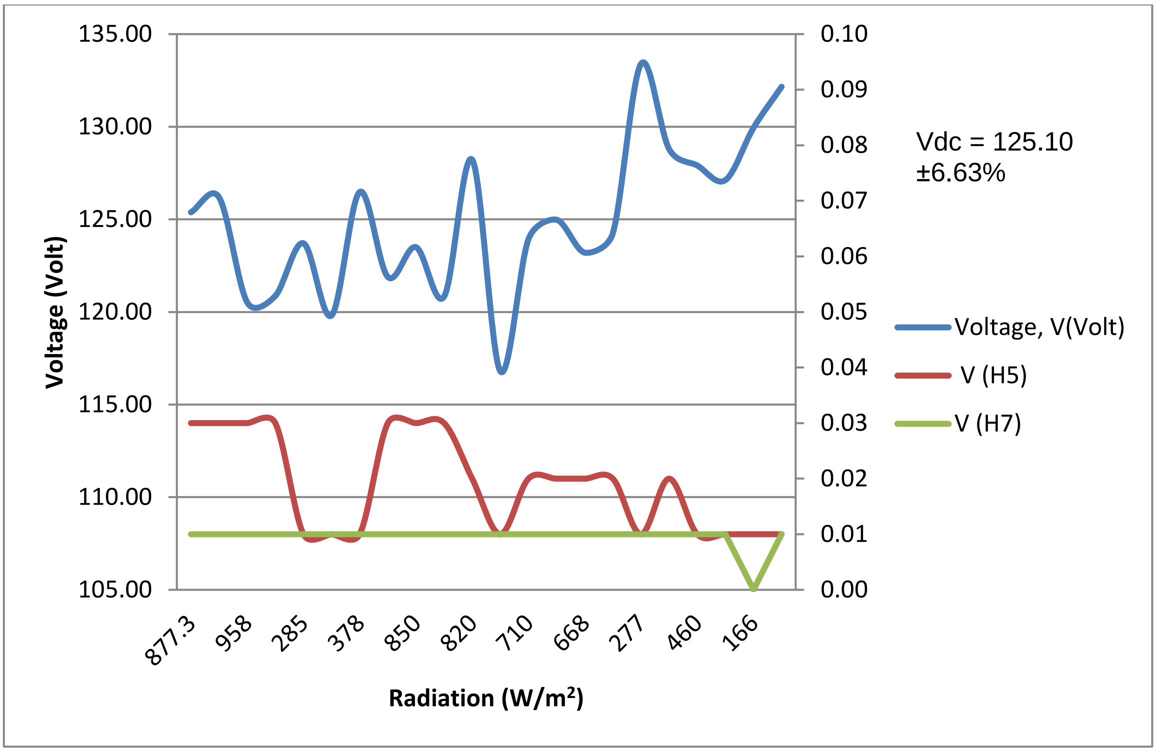


Figure 6.3 Voltage Vs Radiation

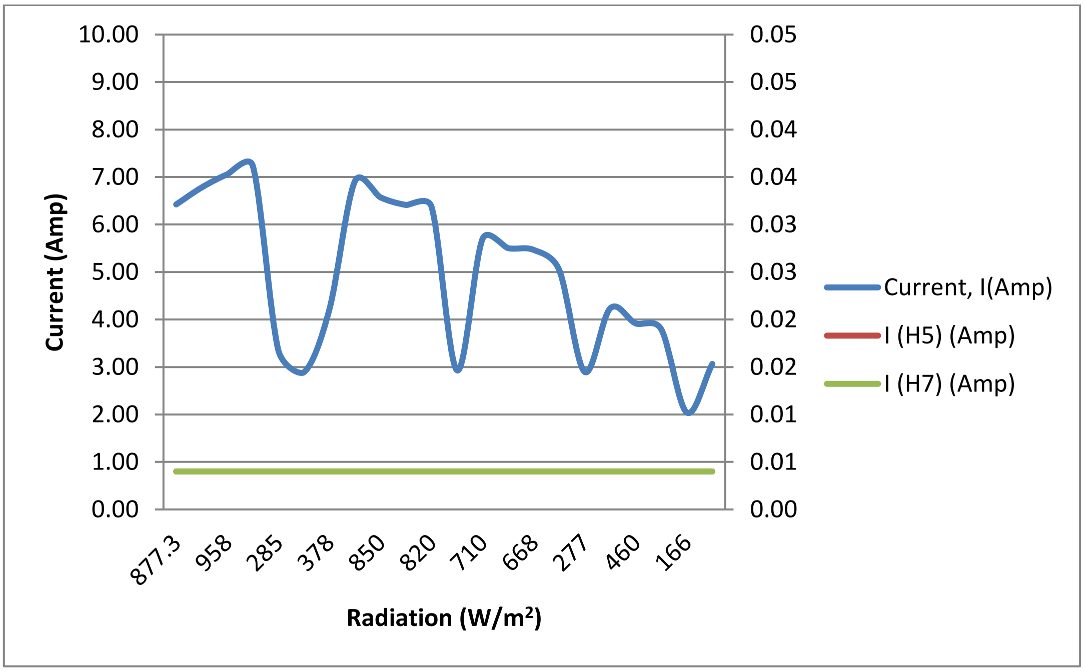


Figure 6.4 Current Vs Radiation

DISCUSSION ON DC MEASUREMENTS

After DC measurement, we have seen that:

i. DC power varies proportionally with solar irradiance.
ii. DC power regulation is from -15% to +10%.
iii. DC voltage varying with irradiance from 125V to 132V.
iv. 5^{th}voltage harmonic shows variation up to 0.01V to 0.03V
v. 7^{th} voltage harmonic shows variation up to 0.01 V
vi. Output current varies from 2A to 7.5A with harmonics less than 0.01A.

The voltage and current shows minor variation within specified range of inverter input. The voltage and current harmonics so encountered due to variation in sunshine. These were shown no disturbance in the input side of inverter.

Again solar radiation is measured by solarimeter at same angle and direction with solar panel at the time interval ~10min manually. Various parameters of AC power converted through inverter are measured by power quality analyser (PQ 3100, HIOKI) at the time interval 1min automatically from control board connection. The measured data are tabulated in Table 6.2.

Table 6.2 AC MEASUREMENT

Time	Radiation (W/m2)	Power, P (kW)	Voltage, V (Volt)	V(H 5)	V(H 7)	Current ,I (Amp)	I(H 5)	I(H 7)	PF=cosφ	App. Power, S (VA)	Reactive Power , Q (Var)	Voltage _ THD
12.00	800	658	231.6	0.90	1.28	3.01	0.03	0.03	0.94	697.7	232.0	0.78
12.10	836	675	231.5	0.88	1.26	3.08	0.03	0.03	0.95	713.6	231.5	0.76
12.20	810	668	233.5	1.31	1.23	3.03	0.03	0.03	0.94	707.9	234.2	0.85
12.30	835	668	233.2	1.02	1.17	3.04	0.03	0.03	0.94	707.7	233.7	0.76
12.40	790	656	231.6	0.87	1.10	3.01	0.03	0.03	0.94	696.6	234.4	0.71
12.50	820	652	231.8	0.92	1.28	2.99	0.03	0.03	0.94	692.7	234.0	0.76
1.00	810	651	233.8	1.12	1.52	2.96	0.03	0.03	0.94	692.5	236.1	0.89
1.10	785	647	231.4	1.01	1.52	2.97	0.03	0.03	0.94	687.7	233.1	0.88
1.21	752	632	231.8	0.95	1.67	2.91	0.03	0.03	0.94	673.5	232.7	0.92
1.29	755	624	231.1	0.81	1.58	2.88	0.03	0.03	0.94	665.8	232.2	0.85
1.40	745	613	231.8	0.64	1.56	2.83	0.04	0.03	0.93	655.8	233.1	0.84
1.50	700	584	231.3	0.49	1.51	2.72	0.04	0.03	0.93	628.8	233.2	0.79
2.08	650	549	229.8	0.87	1.59	2.59	0.04	0.03	0.92	594.9	229.0	0.92
2.20	650	531	228.1	0.67	1.58	2.53	0.04	0.03	0.92	577.7	227.5	0.88
2.30	615	507	227.4	0.73	1.68	2.44	0.03	0.03	0.91	555.1	226.1	0.93
2.40	560	480	226.8	0.56	1.79	2.34	0.04	0.02	0.90	530.4	225.8	0.95
2.50	525	447	225.9	0.64	1.83	2.22	0.04	0.02	0.89	500.1	224.2	0.99
3.00	480	423	225.9	0.70	1.73	2.12	0.04	0.02	0.88	478.7	224.2	0.98
3.12	470	389	225.7	0.60	1.66	1.99	0.04	0.02	0.87	448.8	223.8	0.94
3.20	440	365	225.2	0.60	1.67	1.90	0.04	0.02	0.85	427.2	221.9	0.95
3.30	380	332	225.2	0.69	1.69	1.77	0.05	0.01	0.83	399.4	222.0	0.97
3.40	350	297	227.3	0.82	1.60	1.64	0.05	0.02	0.80	371.3	222.8	0.96
3.50	305	252	227.2	0.70	1.69	1.48	0.06	0.02	0.75	335.9	222.1	0.96
4.00	280	215	227.3	0.78	1.90	1.36	0.06	0.03	0.70	308.0	220.6	1.02

Variation of parameters of DC power with change in solar irradiance are shown in Figure 6.5, 6.6, 6.7, 6.8 and 6.9.

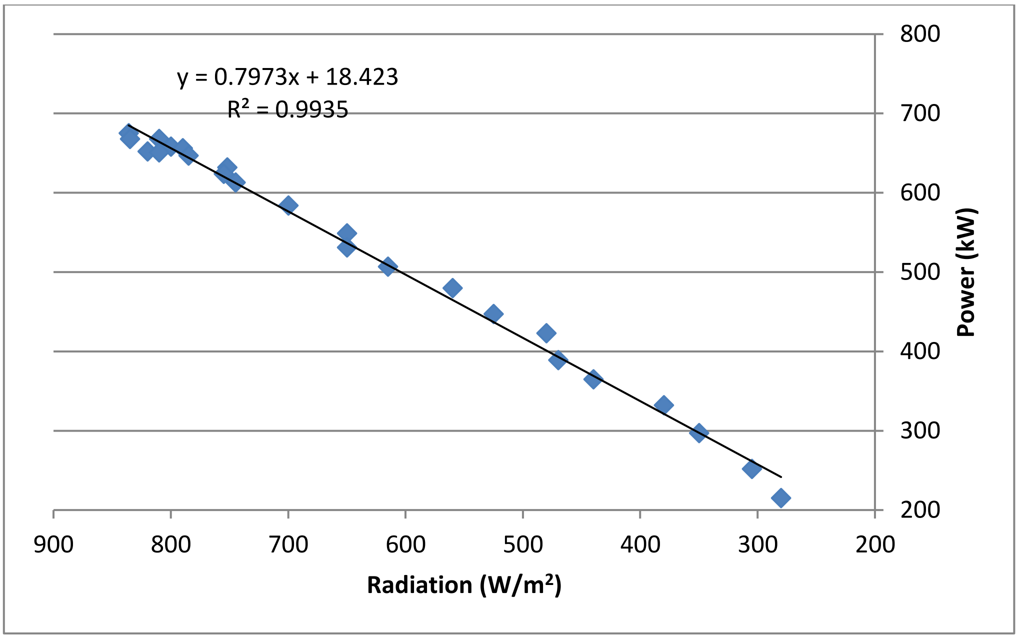


Figure 6.5 Power Vs Radiation

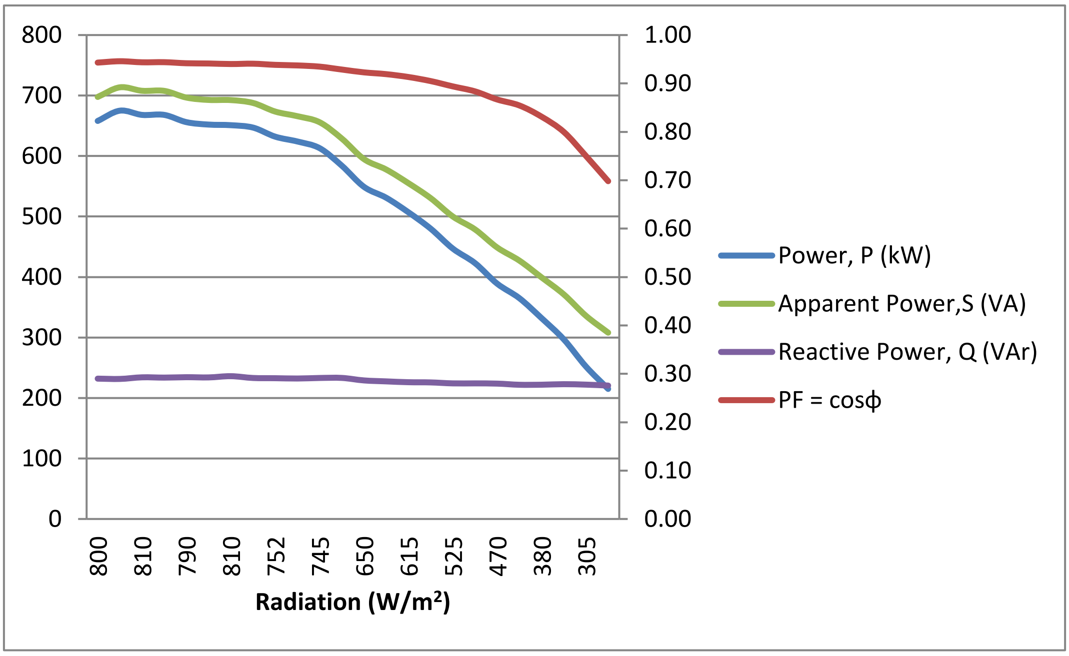


Figure 6.6 Different Power Vs Radiation

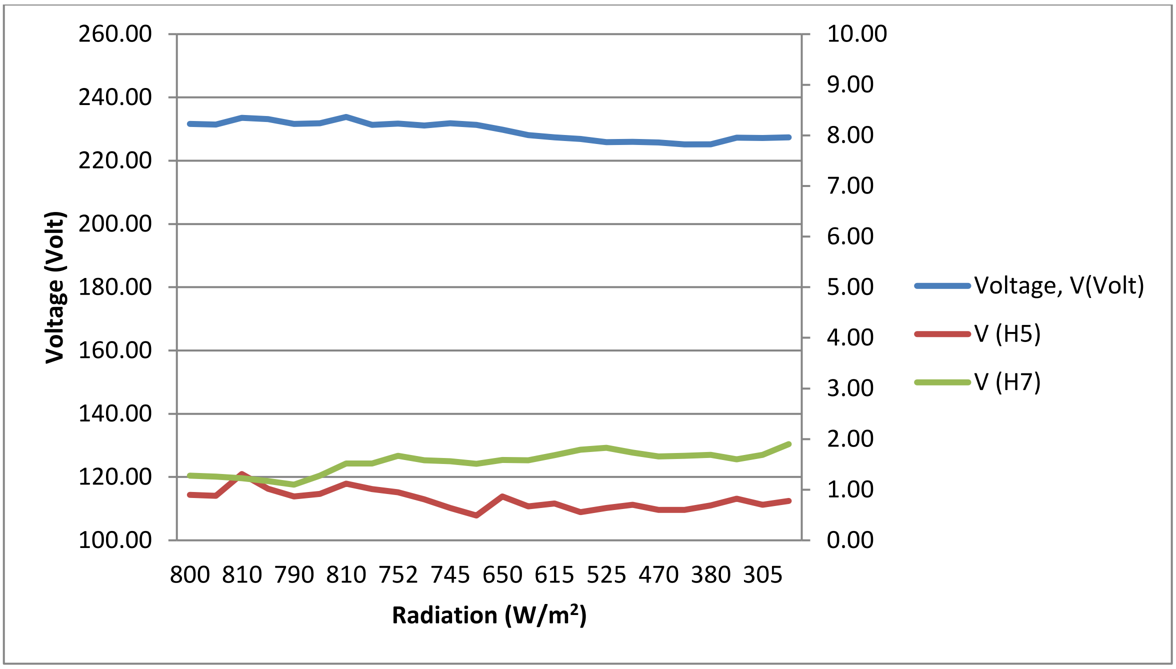


Figure 6.7 Voltage Vs Radiation

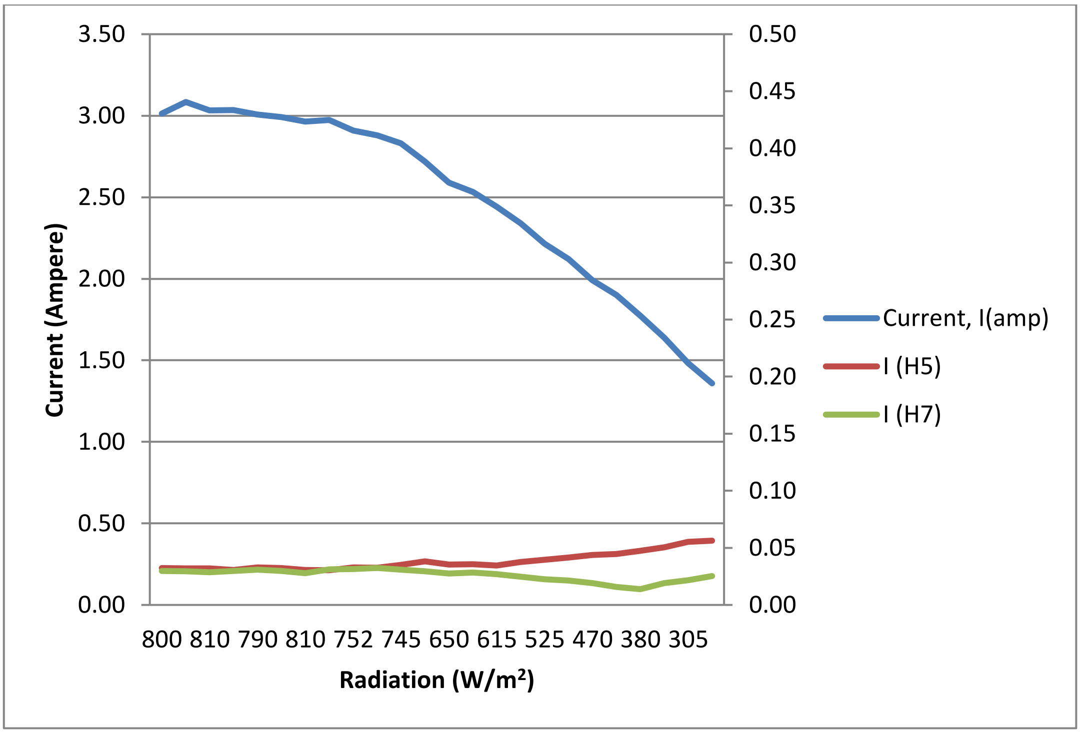


Figure 6.8. Current Vs Radiation

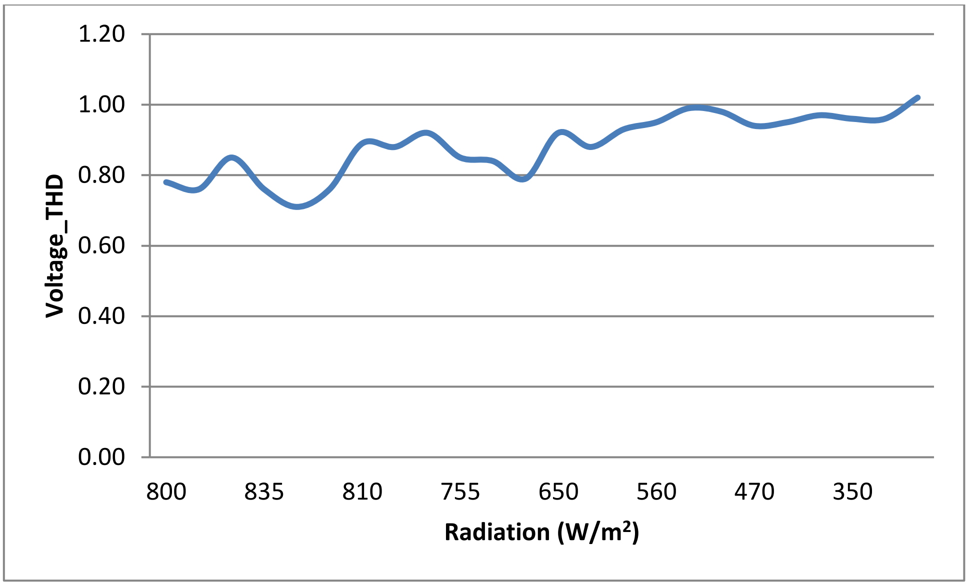


Figure 6.9. Voltage_THD Vs Radiation

DISCUSSION ON AC MEASUREMENT

i. AC real power shows non- linear variation with sunshine. It falls from 650W to 200W with the fall in sunshine.

ii.S(apparent power), Q(volt-ampere reactive) shows non-linear variation, falling with the fall in sunshine.

iii. Output voltage remains around 230V with harmonics within 1V.

iv. Output current falls from 3A to 1.2A with the fall in sunshine with harmonics varying within the range 0.06A.

vii. Power factor is varying from 0.94 to 0.9 when solar radiation is varying from 850 to 550 W/m^2. Then it gradually decreases upto 0.8 with gradual decrease in solar radiation up to 350 W/m^2. After that it sharply deceases with decrease in solar radiation.

viii. THD varying within 0.71V to 1.08V. THD is maximum at low radiation and low power generation.

6.2. CONCLUSION

Most loads in modern electrical distribution systems are inductive. Examples includemotors, transformers, gaseous tubelighting ballasts, and induction furnaces. Inductive loads needa magnetic field to operate.

Inductive loads require two kinds of current:

- Working power (kW) to perform the actual work of creating heat, light, motion, machine output, and so on.
- Reactive power (kVAr) to sustain the magnetic field

Working power consumes watts and can be read on a wattmeter.It is measured in kilowatts (kW). Reactive power doesn’t performuseful “work”, but circulates between the generator and the load.It places a heavier drain on the power source, as well as on thepower source’s distribution system. Reactive power is measured in kilovolt-amperes-reactive (kVAr).

Working power and reactive power together make up apparent power. Apparent power is measured in kilovolt-amperes (kVA). Power factor is the ratio of working power to apparent power. It measures how effectively electrical power is being used. A high power factor signals efficient utilization of electrical power, while a low power factor indicates poor utilization of electrical power.

It is desirable that power should not be less than 0.8. From measurement data and graphs it is clear that to maintain the PF and to minimize THD , power should not feed into grid when power generation is below 300W or radiation is below 350W/m^2.

Otherwise all the parameters of the said PV plant are varying within the specified range of inverter. The inverter is provided with filter that is why the harmonic seen in the input side of it has been reduced and our supply is found unaffected. However, the next chapter deals with the variation in parameters and their effects alongwith the merits of result so obtained is described more elaborately with sharp conclusion and future scope of the work.

Chapter 7: CONCLUSION

7.1. SUMMARY OF THE WORK

We have plotted the recorded data with variation of irradiance in continuous graph then studied them. We have got that harmonic with DC voltage and current were quite noticeable with the variation in the intensity of sunshine but there were no problems observed in the input side of the inverter. On the contrary, wehave got fresh AC output with harmonics within negligible range and frequency 50Hz. This may be due to presence of filter within the inverter which filters out the harmonics. The variation in power factor was reported from 0.7 to 0.94 which shows reactive volt ampere) is within the range suitable for the grid. Synchronizing unit of the inverter that Q(upholds the frequency of our output well within power frequency.

7.2. CONCLUDING REMARKS

At low power generation (below 300 W), it is advisable to feed power through a reactive compensation device to maintain desirable power factor and additional filtering arrangement may be provided for reducing THD.

Otherwise the analysis leads us to a conclusion that our system performing is satisfactorily with the grid without any major effects on the grid supply. The power factor can further be rectified by using some capacitor bank to boost and blend our output power so we can use maximum of our yield. The variation of parameters may not be only due to sunshine but also due to panel temperature which can be controlled to put a limit in the range of variation of these parameters with the available domain of sunshine in our sight. Since our recording device cannot work with two system (AC and DC) simultaneously hence we were unable to find out the overall efficiency. Due to lack of time and unavailability of devices efficiency calculation cannot be incorporated by some other means

7.3. AVENUE OF FUTURE SCOPE

This work will be helpful for our junior researchers in future to work with this PV system. The work can be carried further for calculation of panel efficiency, inverter efficiency and overall efficiency. The impact of harmonics can be studied further in more details by simulation of inverter by calculating Z-parameters, Y-admittance parameters and h-parameters of inverter to observe the distortion of power supply due to variation in grid load. These studies will be important to increase the plant capacity, hybridization of the plant with other minor renewable or non-renewable plants, functioning can be made more reliable. As we know harmonic problem is one of major problem usually the power plants face which leads to distortion of supply and malfunctioning of various appliances and their degradation. So, studies should be carried out in each and every phase of changes in PV system because it is the most appropriate renewable power to sustain most of our power requirements and relinquish the carbon burden on our environment due to power generation. Also the same kind of study may be carried out on the MW level SPV power system for better understanding and feeding of reliable quality of power in to the grid.

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