DESIGN OF 1 MW GRID-TIED SOLAR POWER PLANT IN RAJASTHAN

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Dehradun
April, 2013

DESIGN OF 1 MW GRID-TIED SOLAR POWER PLANT IN RAJASTHAN

A thesis submitted in partial fulfillment of the requirements for the Degree of
Master of Technology
(Energy Systems)

By
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This is to certify that the work contained in this thesis titled **"DESIGN OF 1 MW GRID-TIED SOLAR POWER PLANT IN RAJASTHAN"** has been carried out by **Ms. Arpita De** under our supervision and has not been submitted elsewhere for a degree to the best of our knowledge.

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This is to certify that **Ms. Arpita De**, student of **University of Petroleum and Energy Studies, Dehradun** pursuing **M-Tech (Energy Systems)**, has successfully completed dissertation project at Gensol Consultants Pvt. Ltd., Ahmedabad during February-April, 2013.

The dissertation project report entitled **"DESIGN OF 1 MW GRID-TIED SOLAR POWER PLANT IN RAJASTHAN"** submitted by the student to the undersigned is an authentic record of her original work, which she has carried out under my supervision and guidance.

We wish her all the best in her future career.

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Abstract

India, with its combination of strong solar resource levels and its enabling policy framework, is inclined of becoming a hub for the solar market. The driver for implementation of Renewable Energy Certification (REC) mechanism in India is Renewable Purchase Obligation (RPO) mandated by State Electricity Regulatory Commission for power utilities. Electricity Act 2003 mandates SERC with the function of RE promotion within each state. Under EA 2003, the SERCs set targets for distribution companies to buy certain percentage of their total power requirement from renewable energy sources. This target is known as **Renewable Purchase Obligation (RPO).**

The National Action Plan of Climate Change (NAPCC) is a part of the Government of India's continuous efforts to minimize the gap between the country's electricity supply and demand scenarios. The GoI is also taking initiatives to improve the efficiency of the power sector. These reforms are crucial in meeting the energy requirements of a progressing economy. The NAPCC has incorporated strong regulatory measures to reach these targets. Further, the NAPCC has imposed increasing the share of renewable to 10% by 2015 and 15% by 2020.

In this project, Pre-feasibility Studies for Various Solar Power Plant were undertaken in the past to investigate solar power generation technologies, identify an appropriate solar technology, and establish the economic viability of a solar power facility. The prefeasibility studies were followed by a feasibility study that includes engineering studies, ongoing commercial evaluation, financial modeling and environmental and planning studies.

The main aim of this report is to demonstrate our readiness and to submit a detailed plan for setting up of a grid connected solar plant of capacity 1 MWp at Bikaner, in the state of Rajasthan. We have undertaken proposed land topographic surveys, analyzed the power evacuation options and sought metrological data of Bikaner for the detailed System design calculations.

Acknowledgement

With a deep sense of gratitude, I wish to express my thanks and regards to my project guide **Ms. Madhu Sharma,** Asst. Prof. and Course Coordinator – Energy Systems, COES, University of Petroleum & Energy Studies, Dehradun for her immense guidance in planning, executing and writing the work from time to time. Her experience, knowledge and encouragement were the guiding source and I am sure this will be with me all along.

This work would not have been possible without selfless support of **Mr. Anmol Singh Jaggi**, Director, Gensol Consultants Pvt. Ltd., Ahmedabad who accepted my project request and allowed me to work on the same from their Ahmadabad office and supervised my work from time to time. My special thanks to **Ms. Neha Pathak**, Associate Consultant, Gensol Consultants Pvt. Ltd, who was also my project mentor at Gensol Consultants Pvt. Ltd campus for her deep involvement and continuous guidance, also thank for her able supervision & invaluable technical suggestions without which it couldn't be possible to complete this project work.

I simply & sincerely thank my beloved parents an for their blessings and encouragement. I would also like to give my thanks to all the Gensol Consultants Pvt. Ltd. team members, without their support this would never been a successful project.

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Nomenclature

AB :	Air Breaker
ACB :	Air Circuit Breaker
AC :	Alternate Current
BOS :	Balance of System
DAS :	Data Acquisition System
DC :	Direct Current
DP :	Double Pole
DPR :	Detailed Project Report
HT :	High Tension
LT :	Low Tension
LV :	Low Voltage
MNRE :	Ministry of New and Renewable Energy
RREC :	Rajasthan Renewable Energy Corporation
kWh :	Kilo Watt Hour
MWh :	Mega Watt Hour
MCB :	Main Combiner Box
PLF :	Plant Load Factor
PV :	Photo Voltaic
PT :	Power Transformer
SEB :	State Electricity Board
VCB :	Vacuum Circuit Breaker
XLPE :	Cross Linked Polyethylene
MWp :	Megawatt Peak
MW :	Megawatt

1 Introduction

1.1 Background

India is vastly populated and has high solar Insolation, which provides an ideal combination for Solar Market in India. Power is the backbone of any development of the nation. At present the power requirement is being met by three main sources which are Thermal, Hydel and Nuclear. While Hydel and Nuclear have their limitations and boundations, Thermal Power is often confronted by the challenge associated with the availability of fuel. Currently Thermal Power stations which compose the major part of the power demand use coal as fuel. Conventional fuels such as oil, gas and coal cannot meet the increasing demand forever. In addition to the requirement of huge funds, the incorporation of more such projects using conventional means of power generation will also involve issues of growing environmental concern, with depletion of fossil fuels.

In collaboration with Government of India's plan to increase the percentage of solar energy in the total energy mix while recognizing the need to expand the scope of other renewable and non fossil options, Project Developers are developing solar based power projects.

India lies in one of sunny regions of the world. Mostly parts of India receive 4-7 kWh of solar insolation per square meter per day with **300-325 sunny days in a year**. India has abundant solar resources, as it **receives about 3000 hours of sunshine every year**, equivalent to over 5,000 trillion kWh. The effective utilization of Solar Power will lessen the load on the requirement of fossil fuel for Power generation.

Keeping in mind the good potential of Solar Power and also the innitiative given by the Central & State Government in utilizing the abundant Solar Power in the State of Rajasthan for Power generation, Man Solar Company to set up 1 MW Solar PV based Power Plant in state.

This Report highlights the implementation of 1 MW Solar PV based Power generation project at Rajasthan state under Renewable Energy Credit (REC) mechanism.

The proposed site is located at **Sarah Kishnayat** Village, Tehsil – **Kolayat**, District - **Bikaner, Rajasthan.** The coordinates of the site is 27° 53' 47.36" N Latitude and 72° 56' 40.76"E Longitude

The present report is prepared with the intention to set up a Grid Connected SPV Power Project of 1 MWp capacity. The survey of the proposed land has been done, power evacuation options have been analyzed and based on metrological data of Rajasthan, the detailed system design has been worked out.
This project report covers technology selection, location, description & comparison of solar PV technologies, design criteria for SPV power plant including electrical equipments, plant facilities, and power evacuation requirements.

1.2 Corporate Social Responsibility

Rajasthan- land of royals is a shinning jewel set in the golden sands of a barren deserts landscape. The light that reflects off the golden sands engulfs a land renowned for its vibrant colors, people in bright clothes and beautiful jewelry, living in cities dotted and dominated by towering forts and palace that rise from the sands like mirage. The hard life of the desert dwellers made them seek means of making life more pleasant by developing their artistic talents.

Till date the desert regions of Rajasthan has been underdeveloped due to lack of necessary resources, especially water and electricity. People from this region either migrate to cities in hunt of a job or become cattle dwellers for most part of their life.

Tourism is one of the major sources of income for these people but that is also limited to few months only and available as an option only to few people. For those who live in small villages, this desert has been a menace till now. The inception of solar power projects in this region will change their lives completely. It has been estimated that in districts of Jodhpur and Jaisalmer itself, an investment of Rs. 4 billion will be made under various schemes of MNRE and Rajasthan government. As a result of this, the desert which has been seen as a menace is becoming a boon for the local people.

With the introduction of power projects, there will be a huge requirement for manpower and local support. This will not only ensure an income source for people but also improve their quality of living without compromising with the natural beauty of the deserts

1.3 Preface

The purpose of this report is to submit a detailed plan and process for setting up of a grid connected solar power plant of capacity 1MW at Bikaner, in the state of Rajasthan. The solar power project is proposed in Bikaner district of Rajasthan, because it is one of the best suited locations in terms of higher annual **Direct Normal Insolation (DNI),** favorable climatic conditions and land availability. The land has already been identified, the power evacuation options are being analyzed and meteorological solar radiation data collected, of Jodhpur for the Detailed System Design calculations.

1.4 Project Summary

This project report covers capacity selection, location, description & comparison of solar PV technologies, plant facilities, and power evacuation requirements, proposed site layout, manpower requirement and capital costs. The specific objectives of this report are to:

- Establish overall development plans and projections for the proposed 1MW Solar PV Project to be set up by Man Solar Company in Rajasthan.
- Identify the details (including the costs) of available photovoltaic technologies and technology tie up.

Technology:

The proposed plant will be based on poly crystalline technology. The technology is selected on the basis of energy production and financial cash flow.
Power Generation from the plant will be at 415 V & evacuation of power will be at 132/33 kV substation.

Cost and Generation:

The total project cost including photovoltaic panels, power conditioning units, mounting structures, civil works, power evacuation, site development, etc is estimated at Rs. 7.4 Crores. The project is proposed to be financed from a mix of debt and equity in the ratio 70:30. The debt part would contribute Rs.5.18 crores which would be financed by a major financial institution at a rate of interest of 30%. The repayment period is assumed to be 10 years. The equity part would contribute Rs. 2.22 crores. The plant is envisaged to sell 1693 MWh/year of electricity to the grid annually. The life of project is envisaged as 25 years.

Proposal for 1MW Project in Rajasthan
Numbers in Lakhs INR Unless Specified

Particulars	Total Cost
Plant, machinery and Transmission line Cost	629.00
Civil and General Works	88.80
Interest during constuction period	16.84
Preliminary and Preoperative Expenses	22.20
Total Cost	**740.00**
Total Cost including IDC	756.84

Table 1 - Cost Analysis

Project at a Glance:

1. Location

a. State: Rajasthan

b. District: Bikaner

c. Tehsil: Kolayat

d. Village: Sarah Kishnayat

e. Latitude: 28.0100°N

f. Longitude: 73.1900°E

g. Site elevation: 203 m

h. Land characteristics: Barren land

2. SPV Plant Details

a. Plant Capacity: 1 MWp

b. Total No. of Modules: 3580

c. No. of modules in series: 20

d. No. of modules in parallel combination: 179

e. Expected Plant Life: 25 Years

f. Plant Load Factor: 19.32%

3. Proposed Technology: Crystalline Silicon Technology

a. Technology: Si- Poly Crystalline

4. PV Module Specification

Technology: Poly Crystalline

a. Maximum Power Rating: 280 Wp

5. Mounting Details

a. Mounting Type: Tilt

b. Tilt angle of PV Module: 24°

6. Inverter/PCU

a. No. of units 2

b. Rated capacity 630 kWp and 315 KWp

7. Grid connection Details

a. 33/11 KV Kolayat

b. 132/33 KV Bikaner

c. Distance from 33/11 KV GSS 0 KM

d. Distance from 132/33 KV GSS 3 KM

8. Access to Site

a. Nearest National Highway NH 15

b. Nearest Railway Station Bikaner

c. Nearest State Highway: SH 20

d. Nearest Airport from Site: Jodhpur

e. Nearest Sea Port: Kandla

8. Annual Generation: 1693 MWh/Year

9. Construction Time: Six Months

10. Basic Details of the Site

a. Temperature:

Max Temperature: 48.5° C

Min Temperature: 28.5° C

d. Humidity: 45%

e. Mean Annual Rainfall: 360 mm

f. No. of Rainy days in a year: Max 30 Days

g. Mean Wind Speed: 3-3.5 m/s

1.5 Structure of Thesis

The thesis comprises of 6 chapters starting with the present one which throws light on background, and objectives. The chapter 2 deals with review of literature explaining the basic concepts on related issues of research and the previous works. Chapter 3 gives a description of the project, its phases, formulation and findings. Chapter 4 shows all the drawings and layouts of the plant and certain civil structures. Chapter 5 summarizes the results obtained by the complete analysis of the simulations done. Chapter 6 includes conclusions and references.

2 Literature Review

The area of work is chosen mainly because of the Developmental Scope prevailing in this area.

2.1 Renewable Energy in India – Power Scenario in India

Developing countries, in particular, see situations of limiting energy resources, especially the provision of electricity in rural and inaccessible areas, and there is an urgent need to confront this constraint to socio-economic development. India faces a significant gap between electricity demand and supply. Demand is increasing at a very rapid rate compared to the supply. According to the World Bank, roughly 40% of residents in India are deprived of power. The World Bank also states that 1/3rd of Indian business firms believe that fluctuating power is one of their primary problems for doing business.

To overcome this condition, a number of options are looked into. Power generation using solar energy is one such idea. India is bestowed with rich solar power. The average intensity available in India is 200 MW/km square.

Geographical area covered is 3.287 million km square, which equalizes to 657.4 million MW. In this, 87.5% of the land is for agricultural purposes, forest cover, etc., 6.7% for residencies, industries, etc., and 5.8% is either barren, snow bound, or inaccessible. Thus, only 12.5% of the lands cover available equivalent to 0.413 million km square can be used for solar energy power plants. Even if 10% of this area is available, the solar energy generated would be 8 million MW, which is equivalent to 5,909 m ton (million tons of oil equivalents) per year.

India has an enormous potential for renewable energy such as solar power, biomass and wind power.

2.1.1 Solar Energy

The launch of Jawaharlal Nehru National Solar Mission (JNNSM) has spread a lot of interest in the Indian solar energy area. To incorporate demand and attract investors in the sector, the government is giving various incentives. India has vast potential for solar PV and with the right policy support by the Government of India; India can become a global player in the solar power generation.

The daily average radiation is around 5 .0 kWh/m2 in north-eastern and hilly areas and about 7.0 kWh/m^2 in western areas and cold dessert areas with the sunshine hours varying between 2300 and 3200 per year. In most parts of India, clear sunny days are seen for 250 to 300 days a year. The annual radiation varies from 1600 to 2200 kWh/m2

2.1.2 Solar Irradiation Map in India

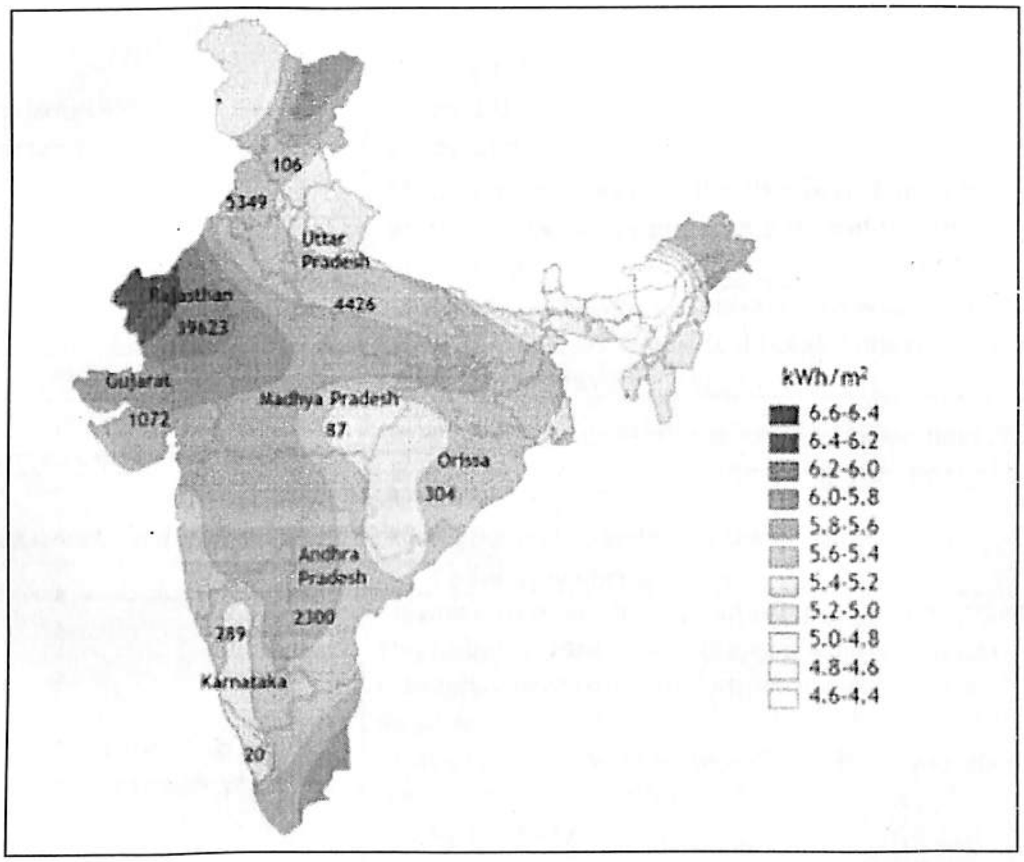

Figure 1 – Solar Irradiation

2.1.3 Solar PV in India – Industry Status and Trends

Since the past 100 years, industry has been run by fossil fuels. Electricity mainly comes from coal and sometimes natural gas, and our transportation media fuel is obtained from petrol and diesel. The exploited fossil fuels are vastly depleting. This indicates that in next 50-75 years, a large part of the energy generation will be done by alternative fuels.

2.1.4 Solar Photovoltaic in India – A Snapshot

Total available potential	India lies in a sunny tropical belt (High insolation) Total theoretical potential – annually over 5000 trillion kWh
Exploited potential (production/installed capacity)	Exploited potential (production/installed capacity) is very little; total installed capacity (grid and off grid) is approximately only 110 MW, and of that only about 17.82 MW (as of Dec 2010) is grid-connected (as of Jan 2011)
Future expected production/installed capacity	For solar CSP and PV together, National Solar Mission attempts to reach an installed capacity of • By 2013: 1-2 GW • By 2017: 4-10 GW • By 2020: 20 GW Moreover, large areas of the Thar Desert has been set aside for solar power projects, sufficient to generate 700 to 2100 GW
Specific government incentives	National Solar Mission and other Generation Based Incentives (GBI) are available through Ministry of New and Renewable Energy
Amount of investments happening in this now, expected in future	Government is expected to spend $19 billion until 2022.
Key bottlenecks and barriers	• Cost of solar PV • High population density (land scarcity) • Technology obsolescence
Cost of power generation - and trends in the same over years	Current cost of production (after bidding) -- Rs 12/kWh. This includes O&M, amortized/depreciated capital costs, loan repayment costs, and other expenses such as insurance. Costs of production expected of Solar PV power plants in the near future - Rs/kWh: • By 2012 --12 • By 2015 –9 • By 2020 –6

Table 2 – Solar Photovoltaic Potential

2.1.5 Jawaharlal Nehru National Solar Mission (JNNSM)

The National Solar Mission was made to promote the use of solar energy for power generation and popularizing the integration of renewable energy like biomass and wind with other Solar Energy methods. The Solar Energy can be obtained via two methods - solar thermal and solar photovoltaic.

NSM Phase	Utility Grid Power	Off Grid Solar	Solar Collector (sqmt)	REMARKS
2010-13	1000-2000	200	7 million	Focus on capturing the low-hanging options in solar thermal and on promoting off-grid systems to serve populations without the access to commercial energy and modest capacity addition in grid based systems
2013-17	4000-10000	1000	15 million	Capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country after taking into account the experience of the initial years
2017-22	20000	2000	20 million	To create favorable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.

Table 3 – JNNSM

Under the NSM a high level target and phased set of targets per technology has been set under three phases:

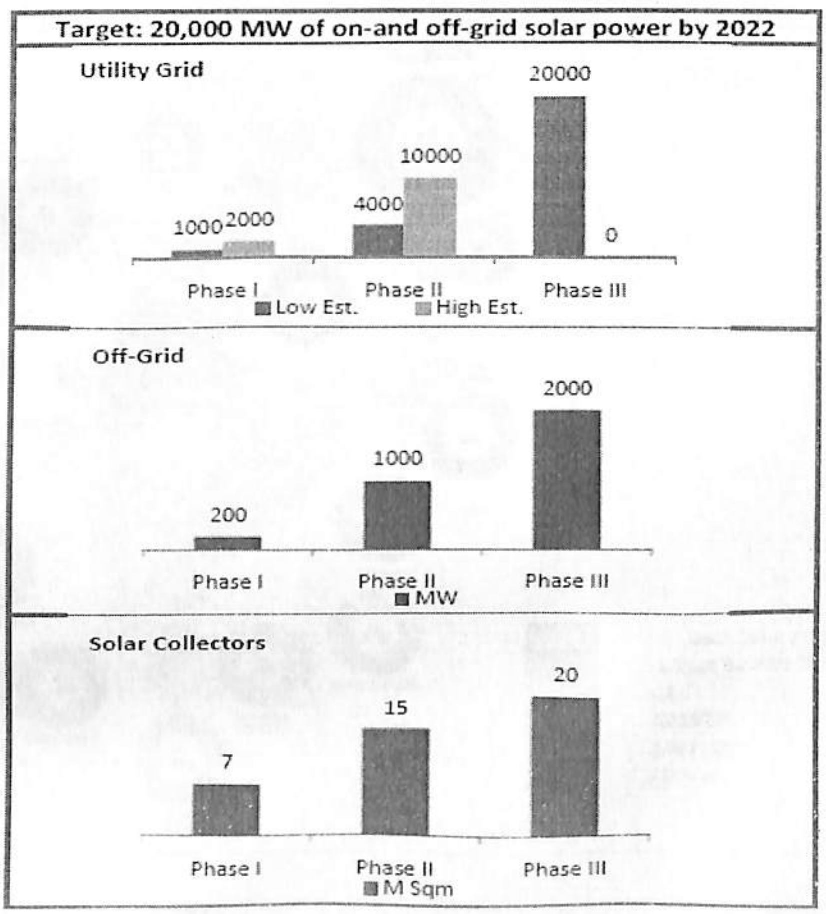

Figure 2 - JNNSM

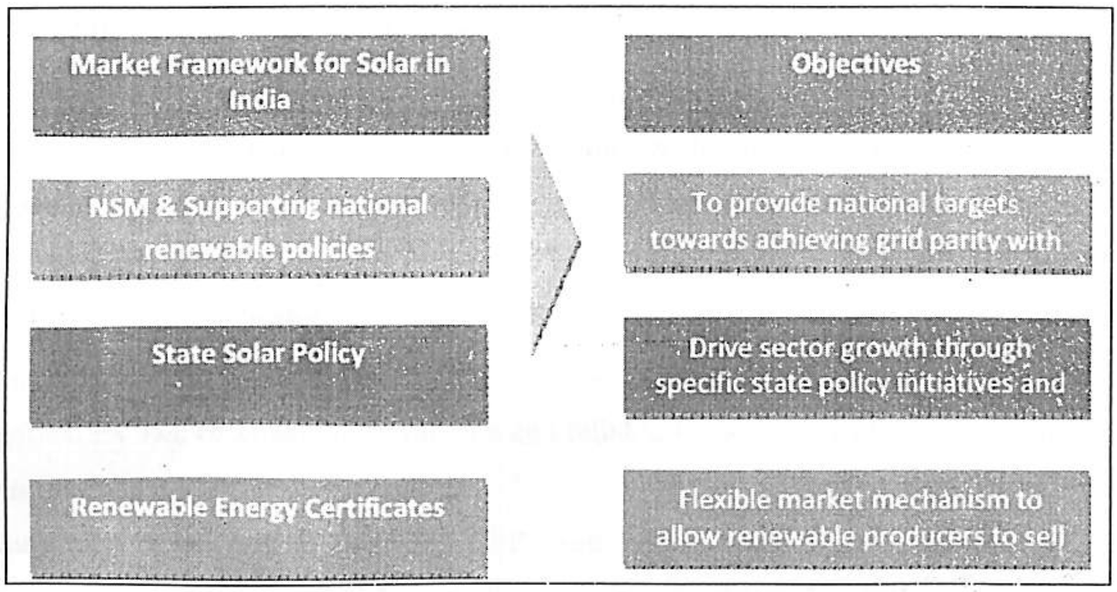

Figure 3 – Market Framework for Solar in India

2.1.6 Solar PV Projects in Progress in India

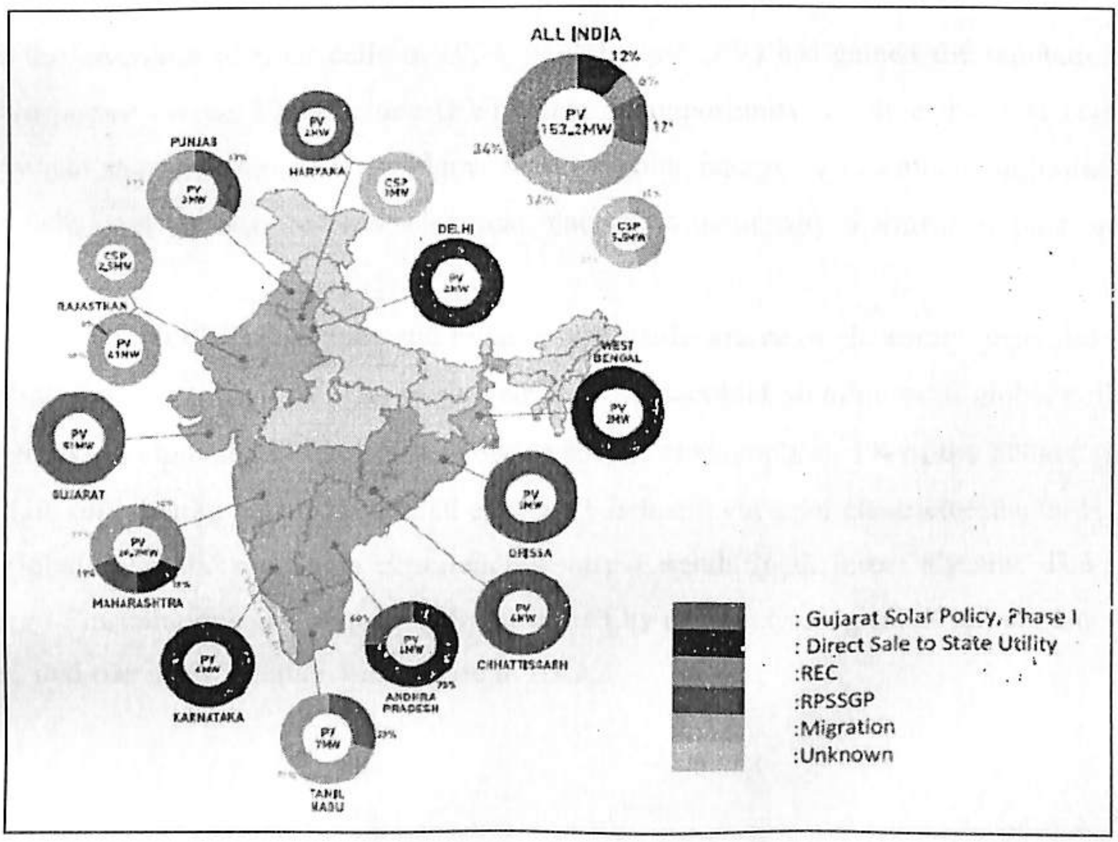

Figure 4 – Solar PV Projects Snapshot

2.2 Solar PV and PV Technology

The Solar energy is the most abundant energy resource on earth. The Solar Energy that hits the earth's surface in one hour is about the same as the amount consumed by all human activities in a year. Direct conversion of sunlight into electricity in PV cells is one of the three main solar active technologies, the two others being concentrated solar power (CSP) and solar thermal collectors for heating and cooling (SHC). Today, PV provides 0.1% of total global electricity generation. However, PV is expanding very rapidly due to dramatic cost reductions. PV is a commercially available and reliable technology with a significant potential for long-term is nearly all world regions.

Concentrating solar power systems (CSP) use concentrated solar radiation as a high temperature energy source to produce electrical power and drive chemical reactions.

CSP is typically applied in relatively large scale plants under very clear skies and bright sun.

2.3 Importance of PV

Since the invention of solar cells in 1954, photovoltaic (PV) has gained the reputation of a reliable power source. Photovoltaic (PV) offers an opportunity to solve the 21st century's energy and the environmental problems because solar energy is essentially unlimited and solar cells can convert it into electrical energy without any harmful impact on the environment.

Thus photovoltaic (PV) is a clean and reliable renewable source of electricity generation. The potential of photovoltaic (PV) can be judged from the fact that 30 minutes of global collected solar energy is equivalent to yearly worldwide energy consumption. 1% of the Sahara surface would be sufficient to supply the global electricity demand via solar electricity plants.

The global solar PV market is experiencing varied trends in different regions. The rising number of installations in Europe is being matched by new technological developments in the U.S.A. and rise in the manufacturing base in Asia.

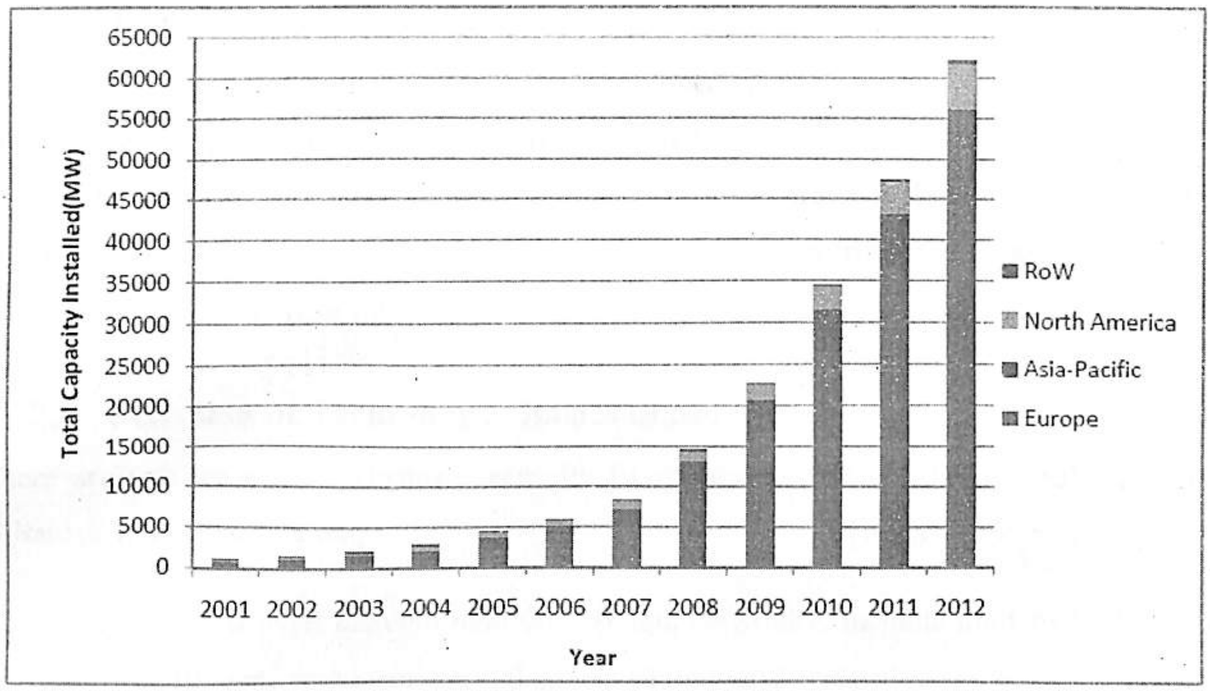

Figure 5 – Total Installation Graph

2.4 Deployment of PV Systems and Reductions in Co^2 Emissions

The deployment of PV will help to the reduce carbon intensity because of electricity generation. Taking into consideration the different average CO^2 emissions of electricity production mixes in different regions of the world, the 4500 TWh generated by PV in 2050 is expected to save 2.3 Gt of CO^2 emissions on an annual basis worldwide.

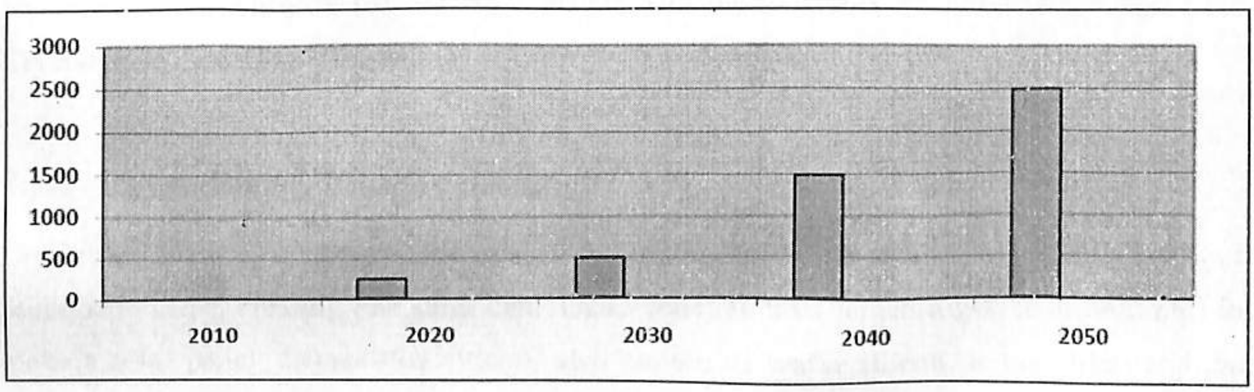

Figure 6 - CO^2 Emission Reduction Graph

2.5 Conclusion: Value of PV Energy in Economic Development

Installing PV technology in isolated or under-developed areas can be a cost-effective plan for clean electricity production. PV is attractive as a distributed energy source to provide basic power services, and can better the lives of people in many ways, including supplying clean electricity to light homes or schools; running medical refrigerators; powering small businesses; and pumping or purifying water.

2.6 Selection of Technology- Basics of Solar Power

There are two ways of producing electricity from solar source i.e. through solar photo-voltaic (PV) or solar thermal.

In Solar PV, cells convert incident light directly into electricity. Incident photons (light rays) strike on the PV cell (made of special grade silicon -a semiconductor) and "knock off" electron. These "free" electrons start flowing through a circuit forming an electrical current. Whereas solar thermal power plants concentrate the sunlight via mirrors onto a receiver where the radiation is absorbed and transferred into heat. The heat is used directly or through an intermediate fluid to generate steam, which is used in steam turbine to produce electricity.

2.7 General Overview of Technologies

In the world of Photovoltaic (PV) solar power, there are several types of semiconductor technologies currently in use for solar panels. But the 2 widely accepted technologies are Crystalline Silicon and Thin Films.

2.7.1 Crystalline Silicon Technology

Crystalline silicon panels are made by first putting a single slice of silicon through a series of processing steps, creating one solar cell. These cells are then joined together in multiples to make a solar panel. **Crystalline silicon, also known as wafer silicon,** is the oldest and the most widely used material in commercial solar panels. There are two main types of crystalline silicon solar

2.7.1.1 Mono-Crystalline Silicon

Mono-crystalline (also called single crystal) panels use solar cells that are cut from a piece of silicon grown from a single, uniform crystal. They are among the most efficient and expensive on the market. They require the highest purity silicon and have the most complicated manufacturing process.

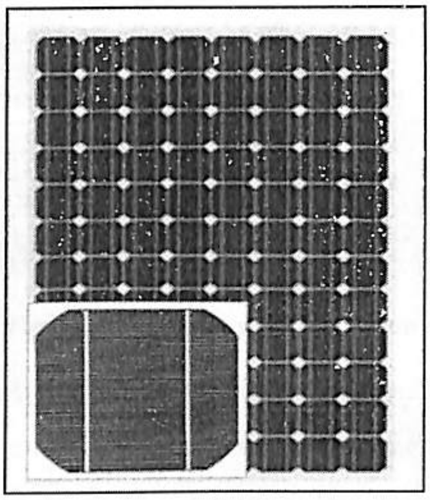

Figure 7- Mono Crystalline Silicon

Single-crystal silicon cells are the most common in the PV industry. The main technique for producing single crystal silicon is the Czochralski (CZ) method. High-purity poly-silicon is melted in a quartz crucible. A single-crystal silicon seed is dipped into this molten mass of poly-silicon. As the seed is pulled slowly from the melt, a single crystal ingot is formed. The ingots are then sawed into thin wafers about 200-300 micrometers thick (1 micrometer = 1/1,000,000 meter). The thin wafers are then polished, doped, coated, interconnected and assembled into modules and arrays.

2.7.1.2 Multi -Crystalline Silicon

Polycrystalline solar cells use wafers sliced from ingots cast using silicon melted in a crucible. These ingots are not formed from a single crystal, unlike mono-crystalline silicon which is slowly built up by revolving a seed crystal. The ingots can also be cast in a square shape, instead of the cylinders of polycrystalline silicon. Consisting of small grains of single-crystal silicon, multi-crystalline PV cells are less energy efficient than single crystalline silicon PV cells. The grain boundaries in multi-crystalline silicon hinder the flow of electrons and reduce the power output of the cell.

Figure 8 – Multi Crystalline Silicon

The energy conversion efficiency of multi-crystalline silicon ranges between 12 to 15%. A common approach to produce multi-crystalline silicon PV cells is to slice thin wafers from blocks of cast multi crystalline silicon. An emerging technology which has seen significant development in multi-crystalline arena is that of string **ribbon silicon technology** in which silicon is grown **directly as thin ribbons or sheets with the approach thickness for making PV cells**. Since no sawing is needed, the manufacturing cost is lower. The most commercially developed ribbon growth approach is **EFG (edge-defined film-fed growth).**

2.7.2 Thin Film Technology

Thin film solar panels are made by placing thin layers of semiconductor material onto various surfaces, usually on glass. The term thin film refers to the amount of semiconductor material used, which is thinner than the width of a human hair.

Thin film solar panels offer the lowest manufacturing costs, and are becoming more prevalent in the industry.

Due to the high shortage in silicon non crystalline or thin film technology had got a lot of boost in the recent past. These technologies also have much lower light to electricity conversion efficiencies than crystalline cells. The drawbacks of thin-film solar cells include an energy conversion efficiency of only around 8-12%, compared to efficiency in excess of

14% for solar cells based on silicon wafers.

Three Main Types of Thin Film are as following:

2.7.2.1 Amorphous Silicon

Amorphous silicon is non-crystalline form of silicon and was the first thin film material to yield a commercial product, first used in consumer items such as calculators. It is deposited in thin layers onto a variety of surfaces and offers lower costs than crystalline silicon, though it is less efficient at converting sunlight into electricity.

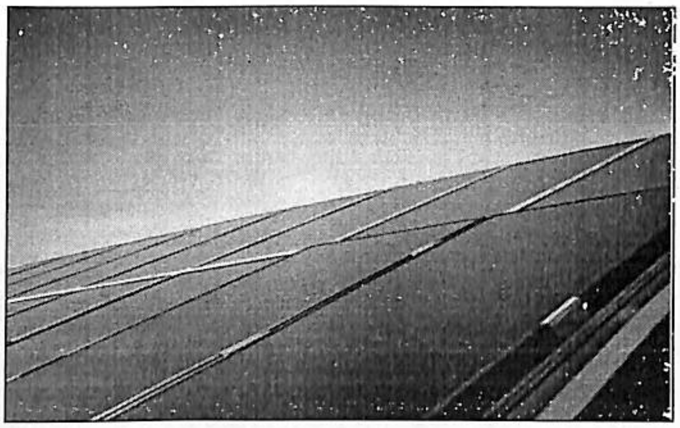

Figure 9 – Amorphous Silicon

2.7.2.2 Cadmium Telluride (CdTe)

CdTe is a semiconductor compound made from cadmium and tellurium. CdTe solar panels are made on glass. They are the most common type of thin film solar panel in the market and the most cost- effective to make. CdTe is not as efficient as crystalline silicon, but CdTe panels perform significantly **better in high temperatures due to a lower temperature coefficient.**

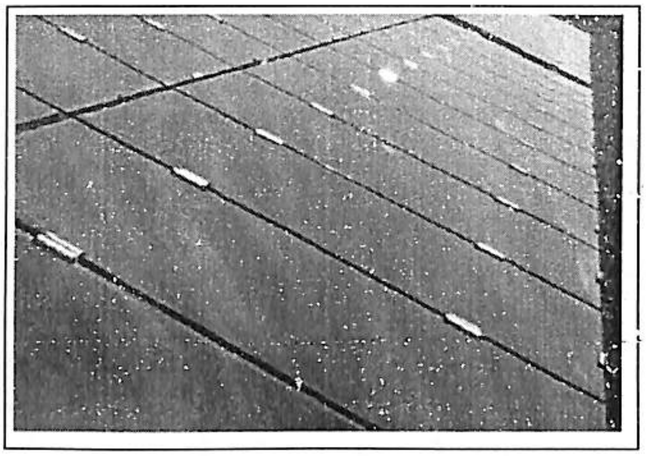

Figure 10 – Cadmium Telluride Panel

2.7.2.3 Copper, Indium, Gallium, Selenide (CIGS)

CIGS is a compound semiconductor that can be deposited onto many different materials. CIGS has only recently become available for small commercial applications.

Figure 11 – CIGS Panel

2.7.3 General Comparison

Parameter	Crystalline	Thin Film	Thin Film	CPV
Types of Materials	Polycrystalline	Amorphous Silicon, CdS, CdTe etc.	Micro Amorphous	Triple Junction GaAs Cell & lens , tracker
Handling	Better protection against breakage	Not Guaranteed	Guaranteed but not proven	Installation would be at site. Not Guaranteed
Power Efficiency	13-16%	6-8%	9-11 %	20-25%
Technology	Well Developed	Stable for Proven Performance	Under development	Under development
Module Weight	Light weight modules	Heavier modules	Heavy modules	Heaviest System
Area utilization	Higher power generated per	Less power per unit area	Less power per unit area	Highest power per unit area

	unit area due to high efficiency			
Temperature Effects	Temperature variations affect output	Least impact of Temperature variations	Lesser impact of Temperature variations	High variation
Irradiance	Used particularly for Normal radiations	Better performance with Diffuse radiations	Better performance with Direct and Diffuse radiations	Works only for Normal radiations
Module quantity	Lesser no required due to higher capacity	More modules required	Moderate number of modules required	Lowest nos. of modules required
Output per MW installed	High	Highest Output in Indian Conditions	Varies as per sunlight condition and various locations	Very High(due to tracking)
Transportation Cost	Lower Transportation cost	Higher cost	Lesser cost compared to amorphous	High cost
Mounting Structure	Fewer Mounting structure required per KW power	More Mounting structures required	More Mounting structures required	Sophisticated mounting required
Land Requirement	Lesser space required per MW	Largest space requirement	Larger space required per MW	Lowest space required
Inverter	High inverter flexibility	Limited inverter flexibility	Limited inverter flexibility	Limited inverter flexibility
Cost	High cost per Watt	Lower cost per Watt	Higher Cost per watt	Highest cost per Watt
Stabilization	Stable power output at initial stages	Stability achieved after 4-6 months	Stability achieved after 4-6 months	Unknown
Power Degradation	Less Degradation	Lower Degradation	Lower Degradation	High Degradation
Plant Maintenance	Less maintenance	Highest maintenance	Less maintenance	High maintenance

	required after installation so lower cost	required, so highest maintenance cost	required after installation so lower cost	required, so high maintenance cost
Cooling Requirement	Not required	Not required	Not required	Requires active or passive cooling which could increase cost
Cabling	Well known, and lower cabling losses	Well Understood but yet difficult due to higher number of arrays	Well Understood but yet difficult due to higher number of arrays	Complex and under development. Cabling losses expected to be high

Table 4 – PV Technology Comparison

2.8 Performance Ratio Calculation

The calculation of the performance ratio for a given solar power installation needs to take into account several key losses. These typically fall into three broad categories:

- Irradiation Losses
- PV Module Losses
- System Losses

2.8.1 Irradiation Losses

2.8.1.1 Shading

Given (i) the flat nature of the surrounding area and (ii) the fact that space is not at a premium and hence space between rows will be adequate to ensure no shadowing, we have assumed no losses as a result of shadow.

2.8.1.2 Dust

The deposit of dust on the surface of PV modules is difficult to evaluate by simulation as it depends on many factors. Since commencing operation of its first solar park in Vinon-sur-Verdon in early 2009, Solairedirect has studied the impact of dust deposits and has made some assessments of the impact on the overall performance ratio of the plant. It is suggested that regular cleaning of the modules forms part of the maintenance program, the frequency of which will be determined during the detailed design process when there is better access to more complete information.

2.8.1.3 Reflection

The reflection of light off a glass surface is a well-known phenomenon. The glass used is treated with an anti-reflection coating in order to decrease such losses.

2.8.2 PV Module Losses

2.8.2.1 Low Irradiation

Polycrystalline PV modules lose efficiency when the incoming irradiation is lower than Standard Conditions, where Standard Conditions are defined by a normal irradiation of 1000W/m2 where module temperature is 25^0C and light spectrum is AM1.5.

2.8.2.2 Light Induced Degradation

On exposure to sunlight during the first few months of operation, crystalline modules undergo an initial degradation due to the oxygen contamination in the silicon wafers during the manufacturing process.

2.8.2.3 Temperature

During operation the temperature of the modules increases above that specified in the Standard Conditions. This increase in temperature largely depends on the irradiation levels and to a lesser extent to the ambient temperature, which causes a decrease in module efficiency with the figures stated in the product data sheets for the modules.

2.8.2.4 Mismatch

Photovoltaic modules are categorized within specific power ranges. Their real power at Standard conditions can deviate from their nominal power at Standard conditions, but the power must stay within the range limits. Inside these ranges, the curve defining the cells powers is approximately a Gaussian curve, centered on the nominal power.

Usually power ranges are ±3% around the nominal power, which can lead to significant current and voltage differences for two modules labeled with the same nominal power. This is called mismatch.

2.8.3 Electrical System Losses

2.8.3.1 Thermal

The flow of current through wires generates heat, which is to be considered as a loss against total energy production.

2.8.3.2 Inverter

Inverters are one of the key areas of potential efficiency gain within a solar generation system. Typically inverters are characterized by their "European Efficiency", usually expressed as the efficiency at 50% (E50) of nominal power. In addition, inverters have the adaption circuits allowing them to control the PV modules in order to optimize couple power/current of the various strings. This is called the **Maximum Power Tracking Point.**

2.8.3.3 Transformer

Transformer losses are well understood and documented, primarily relating to the losses associated with thermal dissipation.

2.9 Solar Radiation Resource Assessment

2.9.1 Solar Radiation over Rajasthan

Rajasthan is bestowed with one of the best solar radiations in the world. For setting up solar energy power plants of capacity 100,000 MW, the land required is about 3600 square kilometers. Rajasthan has a desert area of more than 208100 square kilometers. Therefore, Rajasthan can become a solar power house in the decades to come. As

Government of Rajasthan is making efforts of harnessing the entire solar potential of State, the transmission and distribution utility have developed a very strong evacuation system comprising of 400 KV, 220 KV and 132 KV network for evacuation of power generated from the state.

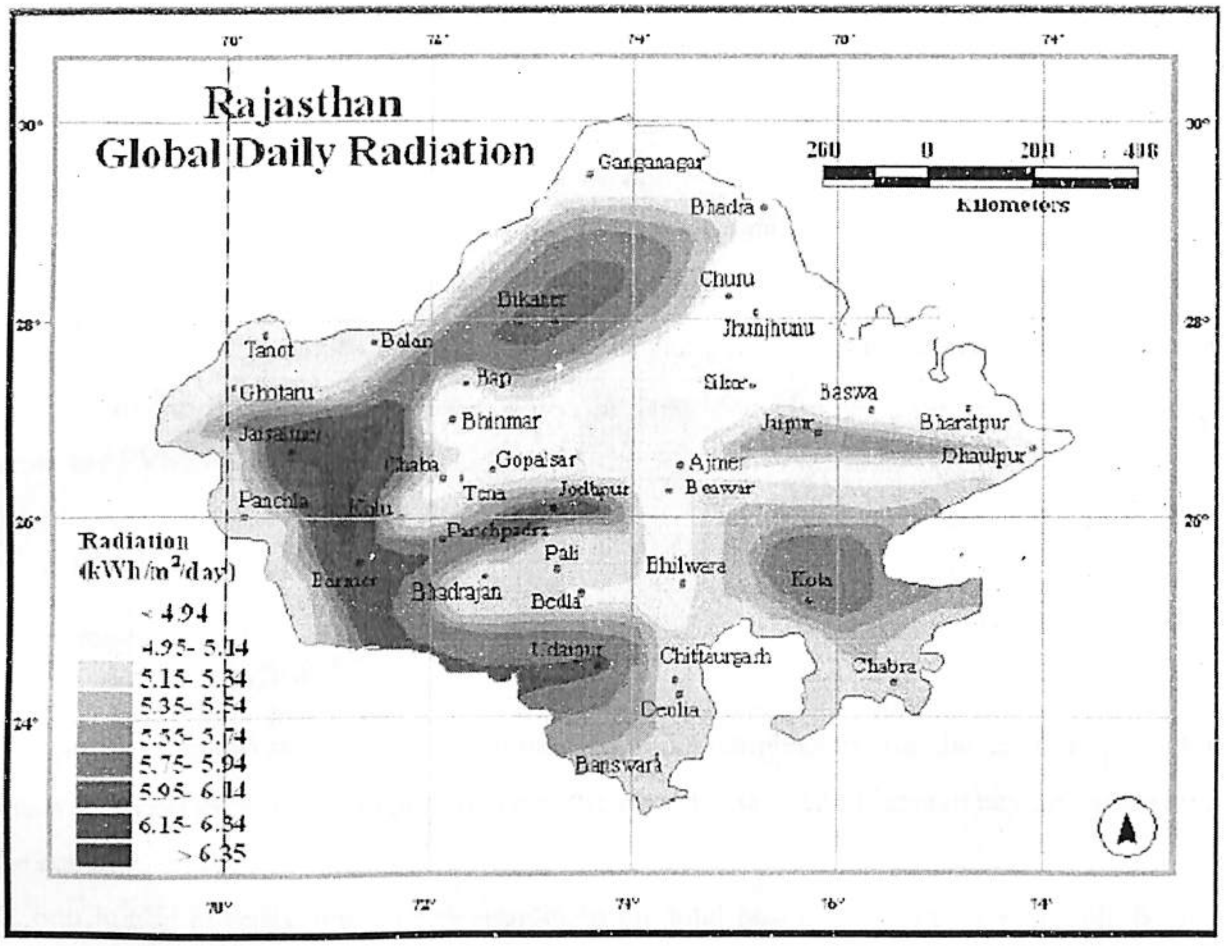

Figure 12 – Solar Irradiation Map

Along with the above, the average rainfall is least in the state, hence best suited for solar power generation. The global solar radiation map of Rajasthan is presented above; which is based on the measured data of Indian Metrological Department (IMD) and satellite data through NASA. The map clearly emphasize that the western and southern parts of the state receives good amount of annual average solar radiation.

2.9.2 Solar Radiation Resource Assessment

Resource assessment is the primary and an essential exercise towards project evaluation. In India, the Indian Meteorological Department (IMD) measures the solar radiation and other climatic parameters over various locations across the country. However, the measuring stations record only global and diffuse solar radiation on horizontal surfaces. The direct solar radiation is not measured at many locations of India; while it could be estimated through global and diffuse solar radiation on horizontal surface. The direct solar radiation is not measured by IMD in Jodhpur. The best way of carrying out the solar radiation resource assessment is to use TMY3 (Typical Meteorological Year weather data files) data files for selected location. Since the TMY data files for Indian locations are not available hence in the present study the METEONORM data and the NASA data has been analyzed and compared with the actual field data to get optimum and accurate results.

In the present study, solar radiation data on the horizontal as well as tilted plane has been taken from the Meteonorm database while the simulation for the proposed system is done using the PVSYST software.

2.10 REC Mechanism

2.10.1 An Overview

The policy framework of the Government of India emphasizes on the encouragement of renewable energy sources keeping in view the need for energy independency and security of the country.

- Contribution of renewable energy sources in the total portfolio of capacity as well as gross generation is still very low.
- Further, the National Action Plan on Climate Change (NAPCC) has recommended increasing the share of renewable to 10% by 2015 and 15% by 2020.

The main source for implementation of REC mechanism in India is Renewable Purchase Obligation (RPO) which is made mandatory by SERC for power utilities.

Electricity Act 2003 mandates SERC with the responsibility of Renewable Energy promotion within state. Under EA 2003, the SERCs set goals for distribution companies to buy certain percentage of their total power requirement from renewable energy sources. **This target is termed as Renewable Purchase Obligation (RPO).**

Indian Energy Exchange

On 6th February 2007, the CERC gave guidelines for grant of permission to set up power exchanges in India. Financial Technologies (India) Ltd replied by proposing then tentatively named 'Indian Power Exchange Ltd' and applied for grant to set it up and operate it within the parameters defined by CERC and other relevant authorities. Based on the hearing on July 10, the CERC granted its approval by its order dated 31st August, 2007. On 9th June 2008 CERC gave permission to IEX to start its operations and 27th June 2008 marked its start in the history of Indian Power Sector as Indian Energy Exchange Ltd (IEX).

Another key aspect related to supply of RE based power is the level of RE potential in many states. For example, largely solar potential is available in Rajasthan and Gujarat and along with these there are states like Chhattisgarh, Uttarakhand and Himachal Pradesh which have substantial Renewable Energy potential. This variation in the availability of potential makes it difficult for states to comply with the RPO's and thus this gives rise to the idea of Renewable Energy Certificates (REC's).

Renewable Purchase obligation (RPO) Trajectories as decided by MNRE:

RPO Trajectory for all Renewable Energy sources

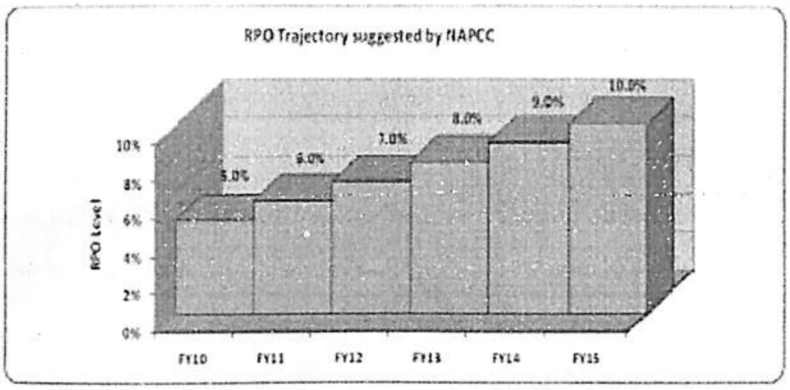

FIGURE: RPO TRAJECTORY FOR ALL RENEWABLE ENERGY SOURCES

RPO Trajectory for Solar Energy

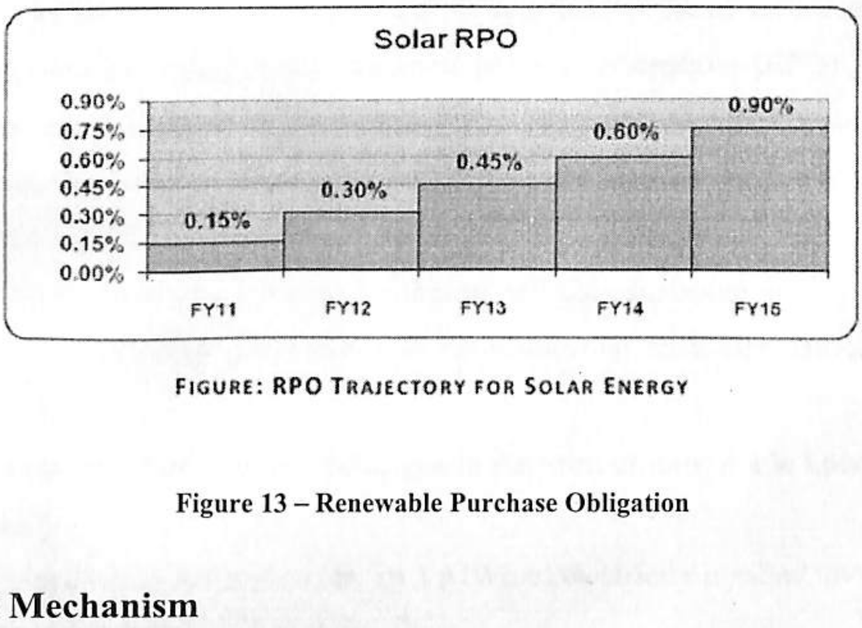

FIGURE: RPO TRAJECTORY FOR SOLAR ENERGY

Figure 13 – Renewable Purchase Obligation

2.10.2 REC Mechanism

As explained earlier, RE potential is **state specific**. Some states have abundant RE potential where as others do not. However, the states which are capturing more RE based power are also dealing with the burden of high cost of RE power. To minimize this effect of state specific availability, REC mechanism provides an excellent method to make sure that all states contribute in the development of RE power.

REC mechanism gives the potential to broaden the market for renewable by expanding the availability and scope of power products which are available to customers.

The concept of RECs is based on diversifying the environmental or green power attribute of renewable generation from the prevalent electrical energy. This creates two separates but related products for sale by the owner of the generation asset(s):

(1) Commodity electricity; and

(2) Renewable attributes (alternatively known as renewable certificates, green certificates, green tags, and environmental attributes).

A renewable energy certificate represents the environmental attributes of 1 MWh of renewable energy. The environmental attributes may be sold separately or combined with system electricity at the point of sale by a manufacturer.

2.10.3 Salient Features of REC Framework

Renewable Energy Certificate (REC) mechanism is a market based instrument to promote renewable energy utilization and fulfill renewable purchase obligations (RPO)

• REC mechanism is focused at minimizing the mismatch between availability of RE resources in state and the requirement of the obligated entities to fulfill the renewable purchase obligation (RPO).

• RE generators will have two options i) either to sell the renewable energy at preferential tariff or ii) to sell electricity generation and environmental attributes associated with RE generations separately.

• The environmental attributes can be exchanged in the form of Renewable Energy Certificates (REC)

• REC will be issued to the RE generators for 1 MWh of electricity injected into the grid from renewable energy sources

• REC would be granted to RE generators only

• Grid connected RE Technologies with minimum capacity of 250 KW and approved by MNRE would be eligible under this scheme.

• Central Agency would issue REC to RE generators for specified quantity of electricity injected into the grid.

• REC would be exchanged only through the CERC approved power exchanges.

• Price of electricity of RE generation would be equivalent to the weighted average power purchase cost of the DISCOM including short term power purchase but excluding renewable power purchase.

REC would be exchanged within the forbearance price and floor price. This forbearance and floor price would be determined by CERC in consultation with Central agency.

• In case of default, SERC may directly obligate entity to deposit into a separate fund to purchase the shortfall of REC at forbearance price.

Applicable prices for RE Certificates

	Solar REC (up to 2012)	Solar (2012)
Forbearance Price (Paisa)	17000	13400
Floor Price (Paisa)	12000	9300

*1 REC = 1 MWhr

Hence Net Tariff = Price for RE certificate + Price of Electricity

Requirement of Solar capacity in MW in different states of the country to meet the RPO obligations and avoid penalty

State	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Assam	1.8	4.0	7.0	10.7	15.1	20.2
J & K	-	-	-	-	-	-
Kerala	27.4	29.1	31.0	66.5	71.1	75.7
Tripura	1.8	2.0	2.2	4.8	5.2	5.6
Uttarakhand	0.0	1.5	3.3	52.6	7.5	10.0
Gujarat	109.8	237.7	515.5	695.1	894.9	1115.1
Himachal Pradesh	4.3	4.6	5.0	10.8	11.5	12.3
Mizoram	4.6	5.0	5.5	11.9	12.9	14.0
Manipur	4.6	5.0	5.5	11.9	12.9	14.0
Jharkhand	56.4	63.0	70.9	157.3	172.9	188.5
Maharashtra	159.6	181.0	192.9	411.4	436.9	462.4
Orissa	82.4	123.6	182.6	248.3	322.0	403.8
Uttar Pradesh	98.0	214.0	466.9	629.9	811.4	1011.3
Bihar	17.3	20.2	23.3	52.6	58.6	64.7
Haryana	47.8	52.1	56.7	61.4	66.1	70.8
Goa	5.0	6.6	9.6	11.9	14.4	17.1
Delhi	39.9	86.3	139.9	203.5	275.5	330.7
Punjab	67.0	146.0	238.4	341.0	455.3	581.1
Rajasthan	66.2	142.4	230.1	330.4	442.6	566.6
Karnataka	73.0	157.6	255.9	374.9	510.8	663.6
Andhra Pradesh	121.6	266.5	437.2	639.4	869.8	1128.4
West Bengal	53.9	114.9	184.2	268.6	364.6	472.0
Madhya Pradesh	62.2	133.7	216.0	312.7	421.7	543.0
Chhattisgarh	26.5	58.0	95.1	140.0	191.4	249.4
Meghalaya	2.5	5.5	8.8	12.5	16.6	21.1
Captive power plant	333.3	720.0	1166.4	1679.6	2267.5	2938.7

Total	1467	2780	4550	6740	8729	10980
Expected Installations through PPA						
JNNSM	100	350	1100	2100	3100	4100
Rajasthan State policy	50	150	250	350	450	650
Gujarat State policy	110	250	550	700	900	1200
Madhya Pradesh State policy	0	100	200	300	400	500
Maharashtra State policy	50	125	200	300	425	550
Total	310	975	2300	3750	5275	7000
Expected Installations through REC (Total Requirement-Expected through PPA)	1157	1805	2250	2990	3454	3980

Table 5 – Solar Capacity Requirement of each State

3 Theoretical Development of Thesis

3.1 Site Details

3.1.1 Location

The proposed location of the solar power plant is based at a village called Kolayat (Latitude 27.50°N, Longitude 72.57°E) in the Bikaner district of Rajasthan. (The proposed site of the plant is well connected with the state highway SH 3 (Ganganagar- Bikaner) and national highway NH 15 (Bikaner-Jaisalmer). The site has almost flat terrain and is located very close to 33/132 kV sub-station from where power can be easily fed into the grid.

Nearest Railway Station: Bikaner junction Railway Station

Nearest Airport: Jodhpur

Nearest State Highway: SH 3

Nearest National Highway: NH 15

3.1.2 Seismic Zone Data

The project area does not have any history of severe earthquake damage. As per state wise seismic zonation, the project site lies within Zone-III of Seismic activity zone of the country (National Informatics Centre). The required construction including structures will be such designed to withstand the level of seismic activity for Zone-III. Seismic zone as per IS 1893: Zone III

3.1.3 Water Source

The plant requires about 1.6 ML of water per year for 1 MW capacity, which is mainly for cleaning the solar PV panels. Since the requirement is less, this will be met from ground water. Water harvesting system shall be used.

Description	Wet cooling (ML per year)	Remarks
General services	2	Estimated
PV Panel Cleaning	1	Estimated
Total	3	

Table 6 – Water Requirement

3.1.4 Road Access Point

Road access to the site been taken care during marking of the land and water and wastewater connections and approvals will be taken from the state authority.

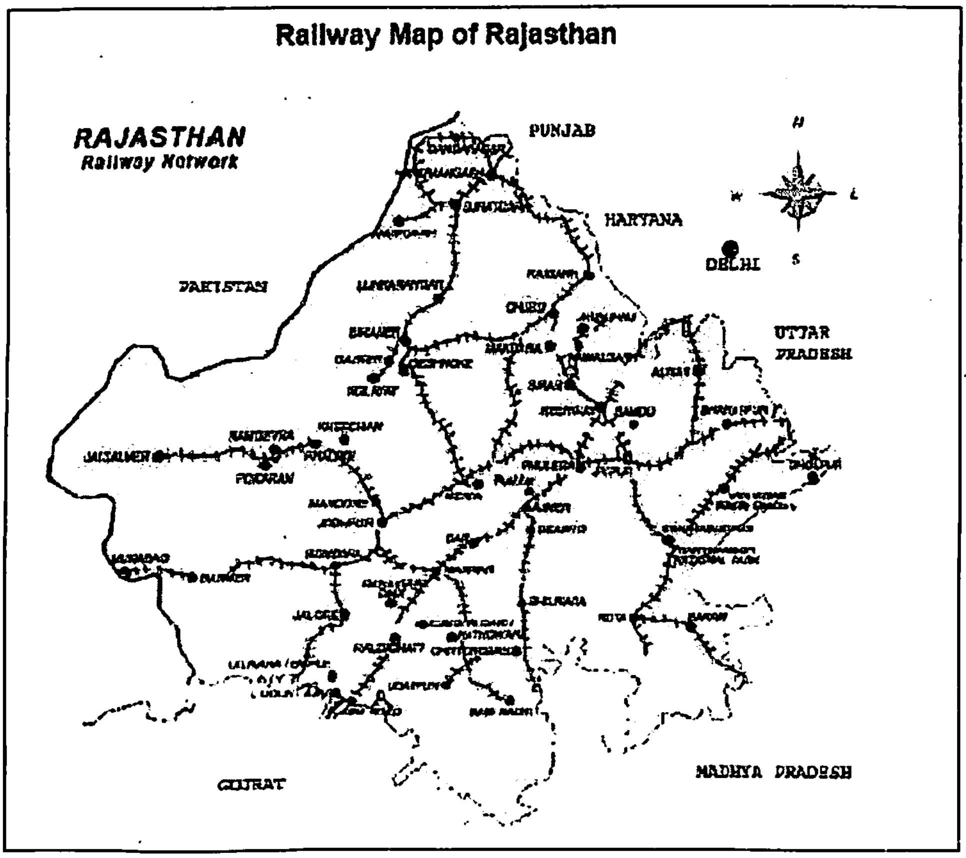

Figure 14 – Road Access Point

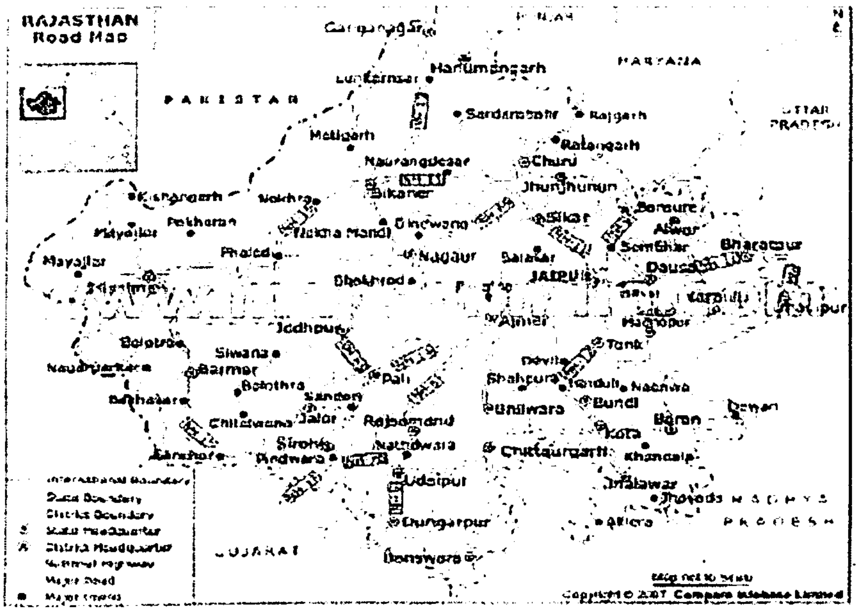

Figure 15 – Road Access Map

3.2 General Description of the Proposed Plant

3.2.1 Introduction

The proposed site has good solar potential available i.e. **5.71 kWh/m2/day**. Considering the good potential available and also the thrust given by the government to promote solar energy in the Rajasthan state, Man Solar Company proposed to set up a grid-connected solar PV plant of 1 MWp. The proposed Power Plant site is well connected & all necessary infrastructure facilities are available in & around the site. The proposed plant will have, thin film modules, mounting structures, inverters, power transformers, control room & all accessories as the major components.

The solar PV power plant shall consist of a solar PV array of 1 MWp; however the system will generate DC power. The DC power will be fed into a battery of a PCU to convert DC power to AC power at three phase; 415 V 50 Hz. The output of the PCU will be connected through proper isolation and circuit breaking arrangement to transformers to step up the 415 V, 3 phase AC supply to 33 kV. The electrical power at 33/66 KV level is evacuated to the feeder from power plant. Synchronization arrangements effected through electronics provided in the PCU's ensure adequate synchronization of the two sources of power supply namely, the grid power and the solar power. Necessary metering and protection will be provided to ensure mutually acceptable billing and safety to men and machine.

3.3 System Design

3.3.1 Basic Operating System

PV arrays convert sunlight directly into DC power

- This generated DC power is passed through the inverter to convert DC power into AC power
- The PCU converts to AC power which is then stepped up using a step-up transformer to desired 33 KV.
- AC Power at 33 KV is connected to the grid by using synchronizing equipments.
- Both on DC side of generation as well as AC side of conversion, and at grid inter connection, protection & safety devices are provided to ensure safe & reliable operation of the complete Solar Power generating system.
- Monitoring metering & analysis system provided with the power plant will record, store & transfer data that are essential for the relevant purpose

3.3.2 Solar Photovoltaic Array

SPV array is a collection of solar photovoltaic modules, which are made up of several interconnected solar cells. The cells convert solar energy into direct current electricity by photoelectric effect. **The modules in the PV array are usually first connected in series and then individual strings are connected in parallel to enable system to produce more current.** PV arrays use inverter to convert the DC current generated by the system into AC current.

The proposed PV array will consist of PV modules based on poly crystalline silicon. The total installed capacity of the proposed plant will be 1 MW.

3.3.3 Modules

The proposed system will consist of **Poly Crystalline Silicon (C-Si)** from trusted & reputed manufacturer & supplier. The modules will be fixed with Al Frames and terminal box from bringing out the output. Each panel is fitted with weather resistant cables for easy connection in the array and, one by-pass diode is provided.

3.3.4 Module Mounting Structure

Mounting system is a modular and flexible support structure for PV modules installation. It has to be robust enough to withstand the weight of PV modules, local environmental conditions and weather influences. Mounting structures are generally made up aluminum, stainless steel and galvanized steel.

In proposed system, solar modules will be mounted on the ground using mounting structures with **tilt of 24° facing south**, in order to increase the energy generation. The ground structure can be made in either aluminum or carbon steel with galvanization.

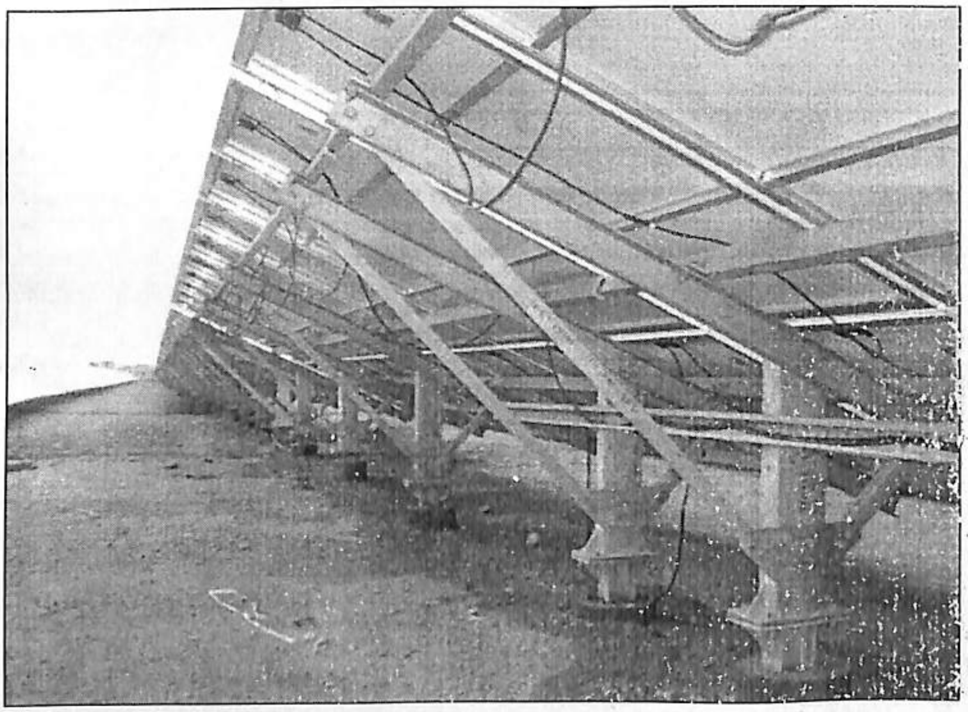

Figure 16 – Module Mounting Structure

The array structure shall be designed in such a manner that it will occupy minimum space without scarifying the output from SPV panels

• Design drawings with material selected shall be submitted for prior approval before submitting the offer

• The structure shall be designed to allow easy replacement of any module & shall be in line with the site requirements

The array structure shall be made of hot dipped galvanized MS angles or pipes of suitable size

• All the structure components shall be concreted properly

• The support structure design & foundation shall be designed to withstand wind speed up to **150 kmph using relevant Indian wind load codes.**

• The module alignment & tilt angle shall be calculated to provide the maximum annual energy output. This shall be decided based on the location of array installation

• The array structure shall be grounded properly using maintenance free earthing kit

• Layout of panel and site will be provided by Technology Provider

• The material used will be MS Tubes with min. **thickness of 120 microns of galvanization**

Technical Specifications

Type	Ground Mounted
Material	MS Galvanized
Overall Dimension	As per design
Coating	Hot dip galvanized
Wind Rating	150 km/hr
Tilt Angle	24 °
Foundation	PCC
Fixing Type	SS 304 fasteners

Table 7 – Technical Specifications

3.3.5 Fasteners

MS galvanized fasteners with nuts and SS 304 fasteners with nuts are planned to be used to arrest carbon pickup and also to enhance the life span of the fasteners. These fasteners are planned to be sourced from Indian manufacturers and the products are normally available incompliance with ASME, DIN, IS standards. Quantity, type, length etc is derived from detailed engineering.

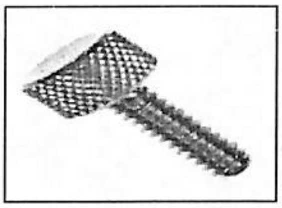

Figure 17 - Fasteners

3.3.6 Array Foundation Base

The base columns will be made with reinforced cement concrete as per design based on site related data, keeping in mind local conditions. The minimum distance between lower edge of the Solar PV Panels and GL shall conform to international standards.

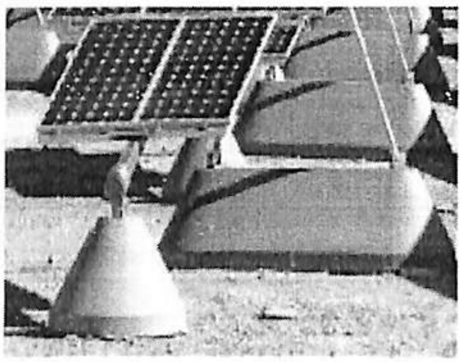

Figure 18 – Array Foundation Base

3.3.7 Array Junction Box, Main Junction Boxes

DC Cables from the series connected modules are taken into the junction boxes for parallel connection, where in the amperage of string are increased without increasing already designed higher system voltage. These junction boxes are of IP65/IP54 depending upon location and environment. The above compliance will help in achieving fulfillment of requirements like dust free, vermin free and weather proof. The junction box could be either made from MS sheet metal, aluminum die cast or thermoplastics. Low diameter DC cables with cable glands from strings will be fed into I/P side and higher diameter DC cables from O/P side of junction boxes.

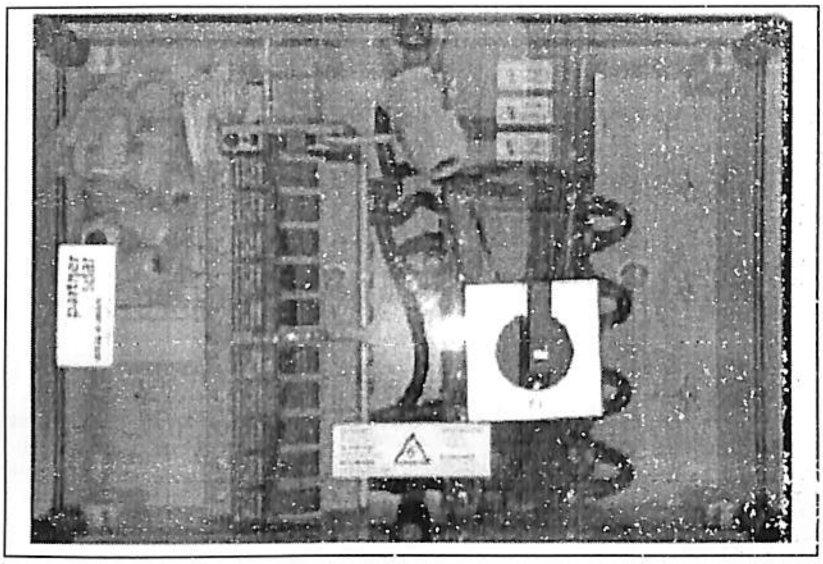

Figure 19 – Array/ Main Junction Boxes

3.3.8 LV DC Protection

Low voltage DC system protection is planned to be provided to ensure proper functioning of strings. This is a simple protection device with fuses. Sometimes this can also be mounted into the junction box/panel.

3.3.9 Power Cables

XLPE (Cross linked polyethylene) cables as per Indian Standard IS: 7098 part 1 will be used. They are ideal for transmission and distribution of power because of their high corrosion resistance under pollutes atmosphere and against chemicals and corrosive substances.

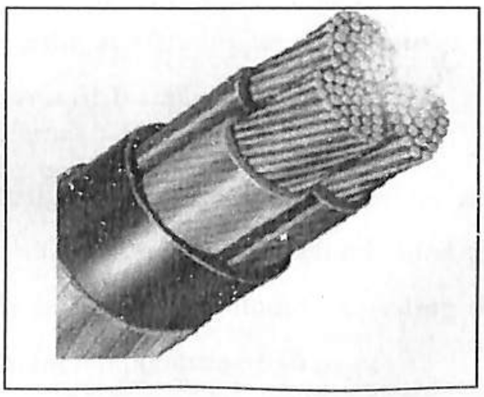

Figure 20 – Power Cables

Advantages of XLPE over PVC Cables

- Longer life
- Small dielectric losses
- Higher current carrying capacity
- Higher short circuit rating of 250°C as against 160°C for PVC cables
- 100 times more moisture resistance capacity compared to PVC cables
- Have higher emergency overload capacity (up to 60%)
- Low installation cost due to light weight

3.3.10 Inverters

A multi function power conditioning system combining the functionality of grid-interactive solar inverter with a highly efficient conversion unit will be used. The proposed system will use inverter of capacity 630 and 315 kWp each. The inverter has an efficiency of 98%. The inverter is designed in such a way that it will sense the array power and grid power; if both are available it starts and stops automatically in the morning and evening respectively.

3.3.11 Transformer

The proposed system will consist of copper wounded 1250 kVA transformer. The transformer shall be placed outdoor and would be suitable for hot, humid and tropical climate. The transformer will conform to the allowable noise standards and will be free from annoying hum and vibration even operating at 10% higher voltage over the rated voltage. **The loss in the transformer would be around 1-1.5%.**

The transformer will be designed and constructed so as not to cause any undesirable interference in radio or communication circuits. The oil filled transformer will be capable of operating continuously at its rated output without exceeding the temperature rise limits as given below over design ambient temperature of 50 deg C

- In Oil by thermometer 50 deg C
- In winding by resistance 55 deg C

The transformer will be designed to withstand without injury, the thermal and mechanical effect of short circuit at its terminal with full voltage maintained behind it for a period of 1 second. The transformer will be capable of continuous operation at the rated output under voltage and frequency variation without injurious heating at that particular tap for all tap positions.

Technical Specifications

Rating in kVA	**1250 kVA**
Type	Copper Wounded
No. of phases	3
Rated Primary Voltage	Suitable to inverter output
Rated secondary Voltage	33 KV
Cooling type	Oil cooled
Installation	Outdoor
Applicable standard	IS 2026

Table 8 – Technical Specifications of Transformer

3.3.12 Protective Relays

The SPV system and the associated power evacuation system shall be protected as per Indian Standards. Over Current Relays, Reverse Power Relays and Earth fault Relays are the minimum\ requirements. Detailed design calculations shall be provided on Fault power computations and the philosophy of Protective Relaying with respect to Short Circuit KVA calculations.

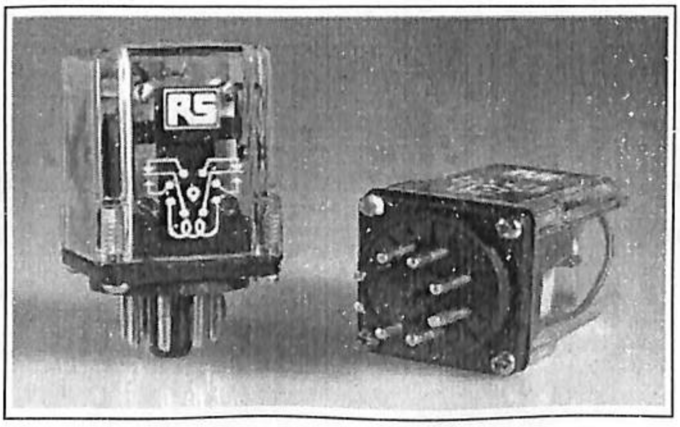

Figure 21 – Protective Relays

3.3.13 Earthing Protection

Each array structure of the PV yard is grounded properly as per IS: 3043-1987. In addition lightning arrester/ masts provided inside the array field. Provision kept for shorting and grounding of the PV array at the time of maintenance work. All metal casting/shielding of the plant is thoroughly grounded in accordance with Indian Electricity Act/ IE Rules.

On LT Side

The earthing for array and LT power system shall be made with GI pipe 4.5m long, 40mm diameter including accessories and providing masonry enclosure with case iron cover plate having locking arrangement, watering pipe using charcoal or coke and salt as required as per provisions of IS 3043. Necessary provisions shall be made for bolted isolated joints of each earthing pit for periodic checking of earthing resistance.

Each array structure of the Solar PV Yard shall be grounded properly. The array structures are to be connected to earth pits as per IS standards.

The earthing for the power plant equipment shall be made as per provisions of IS. Necessary provision shall be made for bolted isolating joints of each earthing pit for periodic checking of earthing resistance. The earthing conductions shall run through appropriate pipes partly buried and partly on the surface of the control room building. The complete earthing system shall be mechanically and electrically connected to provide independent return to earth. All equipments shall have two distinct earth connections. An Earth Bus shall be provided inside the control room.

In compliance to Rule 33 and 61 of Indian Electricity Rules, 1956 (as amended up to date) all non current carrying metal parts shall be earthed with two separate and distinct earth\ continuity conductors to an efficient earth electrode. Earth resistance of the earth pits shall be tested in presence of the representative.

On HT Side

The 33kV equipments and parts shall be earthed as required as per provisions of the applicable IS specifications.

3.3.14 String Monitoring System

The string monitoring system will maintain and provide all technical information on daily solar radiation availability, hours of sunshine, and duration of plant operation and quantum of power fed to the grid. It also monitors the current in the individual strings. Any malfunctions that occur in the PV generator will be safety and reliable detected and then analyzed in the system.

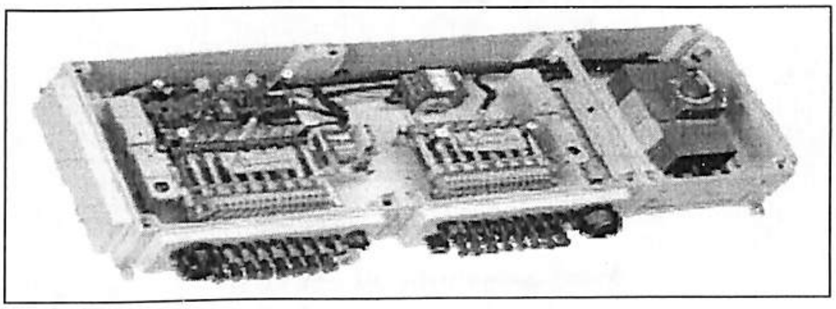

Figure 22 – String Monitoring System

The system monitors the whole plant to each array string level and assist in the following features:

- Monitors the performance of the entire power plant (string wise monitoring, junction boxes, inverters etc)
- Evaluates (Strings, inverters, nominal/actual value)
- Measures instantaneous irradiation level and temperature at site. It also measures module back surface temperature
- Alerts in case of error (discrepancy in case of components, like module string/ diodes/inverter/junction box/loose contacts/etc,) to facilitate recognition and correction of faults with minimum downtime
- Visualizes nominal status of the connected components via Control Centre PC Software (diagnosis on site or remote)

3.3.15 DC Distribution Board

DC distribution panel is provided to receive the DC output from the array field with analog measurement panel for voltage; current from different MJB's to check any failure in the array field. It has MCCB of suitable rating for connection and disconnection of array section.

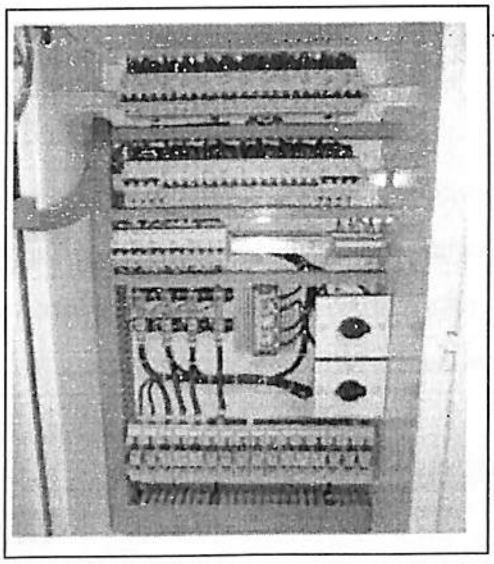

Figure 23 – DC Distribution Board

3.3.16 Meter

The meter for energy measurements are being stipulated by CERC as microprocessor based energy meters. The meters shall be 3-phase 4 wire 0.2s accuracy class static electronic trivector energy meters with ABT compatibility.

Technical Specifications

Max. ambient air temperature (°C)	50
Min. ambient air temperature (°C)	0
Avg. daily ambient air temp. (°C)	35
Max. Relative humidity (%)	Up to 95%
Max. altitude above mean sea level	1000
Average Annual rainfall (mm)	1500
Seismic level (horizontal acc.)	0.3

Table 9 – Technical Specification of Meter

3.3.17 SCADA System

An integrated SCADA shall be supplied which will be capable of communicating with the Inverters and provide information of the entire Solar PV grid connect power plant. The SCADA will provide information of the instantaneous output energy and cumulative energy for each of the inverters as well as for the entire power plant.

- Computer Aided Data Acquisition Unit shall have features for simultaneous monitoring and recording of various parameters of different sub-systems, power supply of the Power Plant on DC and AC side
- Computer Aided Data Acquisition Unit (in the form of Personal Computer (PC)) shall be a separate and individual system comprising of different transducers to read the different variable parameters, A/D convertor, Multiplexer, De-multiplexer, Interfacing Hardware & Software, Industrial type PC, which will be robust and rugged inside to operate in the control room environment
- Reliable sensors for Solar Radiation, Temperature and other electrical parameters are to be supplied with the data logger unit
- The PC shall be of industrial type, rugged and robust in nature to operate in a hostile environment. The PC shall have minimum Intel Core 2 Duo Processor having 2 x 150GB HDD with 2GB RAM. The PC shall also have 17" TFT Color monitor, DVD drive with writer,

Floppy Drive, Scroll Mouse and UPS for 4 hours Power back up

- The printer shall be of industrial type, rugged & robust in nature. The printer shall be equipped for printing, scanning, copying and fax.

The data acquisition system shall perform the following operations:

Measurement and continuous monitoring of:

- Ambient Air Temperature near Array Field
- Control room temperature
- Module back surface temperature
- Wind speed of the level of Array frame
- Solar Radiation Incidental to Array Plane
- PCUs output

- System Frequency
- DC Bus output
- Energy delivered to the grid in KWH

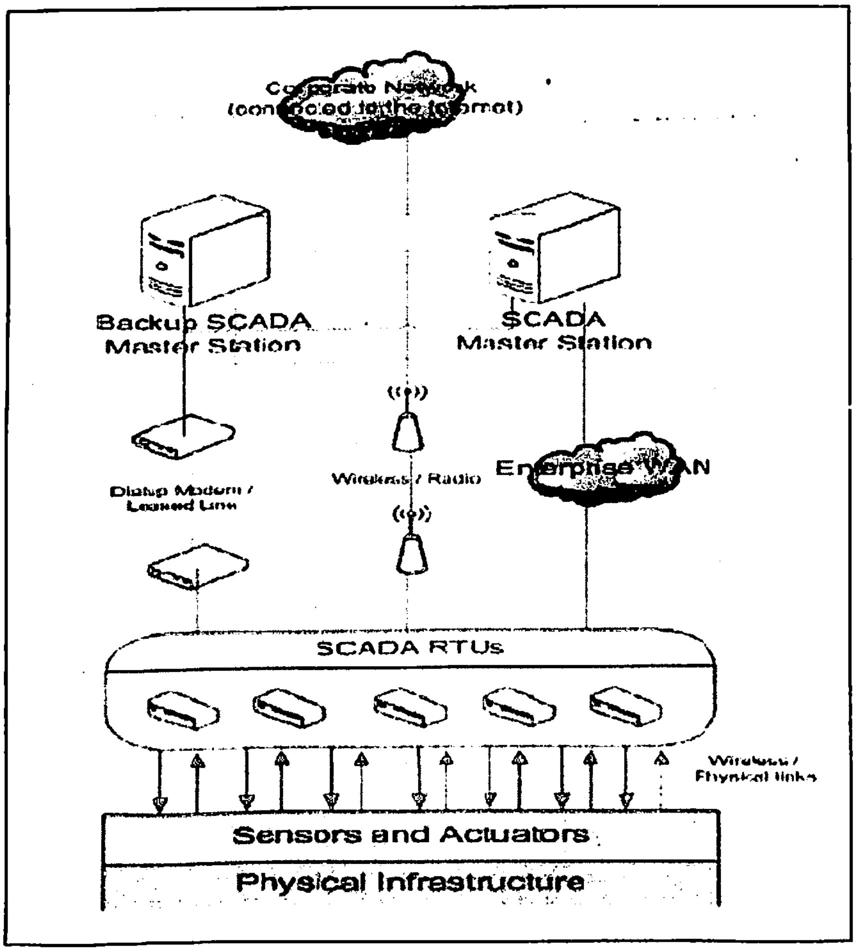

Figure 24 – SCADA System

All data will be recorded chronologically date wise. The data file can be MS Excel compatible.

The data logger will have internal reliable battery backup and data storage capacity to record all sorts of data simultaneously round the clock. All data will be stored in a common work sheet chronologically. All instantaneous data can be shown in the Computer Screen. All the above data will also be remotely monitored. For remote monitoring all the works including communications system and the relevant approvals will to be taken by the customer.

3.3.18 Lightning Arrestors

The lightning arrestors shall be of pedestal mounting type suitable for outdoor installation on steel pole mounted structures. All the clamps bolts, nuts and washers etc., required for mounting the lightning arrestors on the structure shall be supplied along with the arrestors and shall be galvanized. The top metal cap and the base of the lightning arrestors shall be galvanized. The top cap shall be provided with terminal arrangements Suitable for both horizontal and vertical take-off. The base of the lightning arrestors shall be provided with two separate terminals distinctly marked to connection to earth.

The lightning arrestors shall be hermetically sealed to avoid ingress of moisture. A suitable pressure relieving device shall be provided to avoid damage to the external insulator in case of a severe discharge.

3.3.19 Data Logger Hardware

The hardware shall essentially be a compact and small format hardware offering high functionality, and comply or exceed with the following minimum requirement.

- 1 MB of user memory
- 2 ports of RS-485 serial interface with Modbus RTU
- 4 analog inputs of 4-20 ma
- 4 RTD inputs
- 16 digital inputs.
- 4 digital outputs

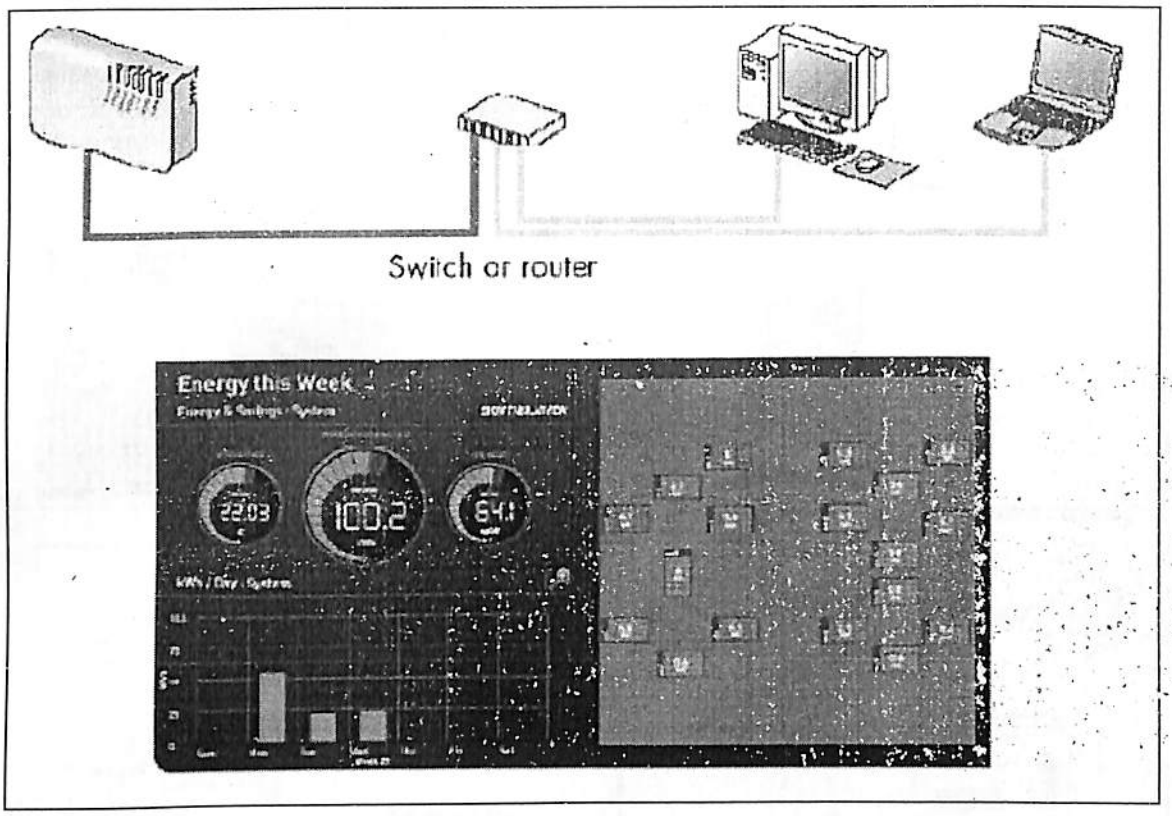

Figure 25 – Data Logger Hardware

The unit should be configurable with suitable programming software complying with IEC 61131- 3. The user program should have removable data card of any industry standard format and the battery backup for data buffering.

The data-logger hardware shall be housed in a poly carbonate enclosure of IP 22, The enclosure shall have provision for cable entry, and have a power strip with 6 Switched sockets of 5 A, and suitable ventilation fan with removable filter module.

3.3.20 Communication Schematics

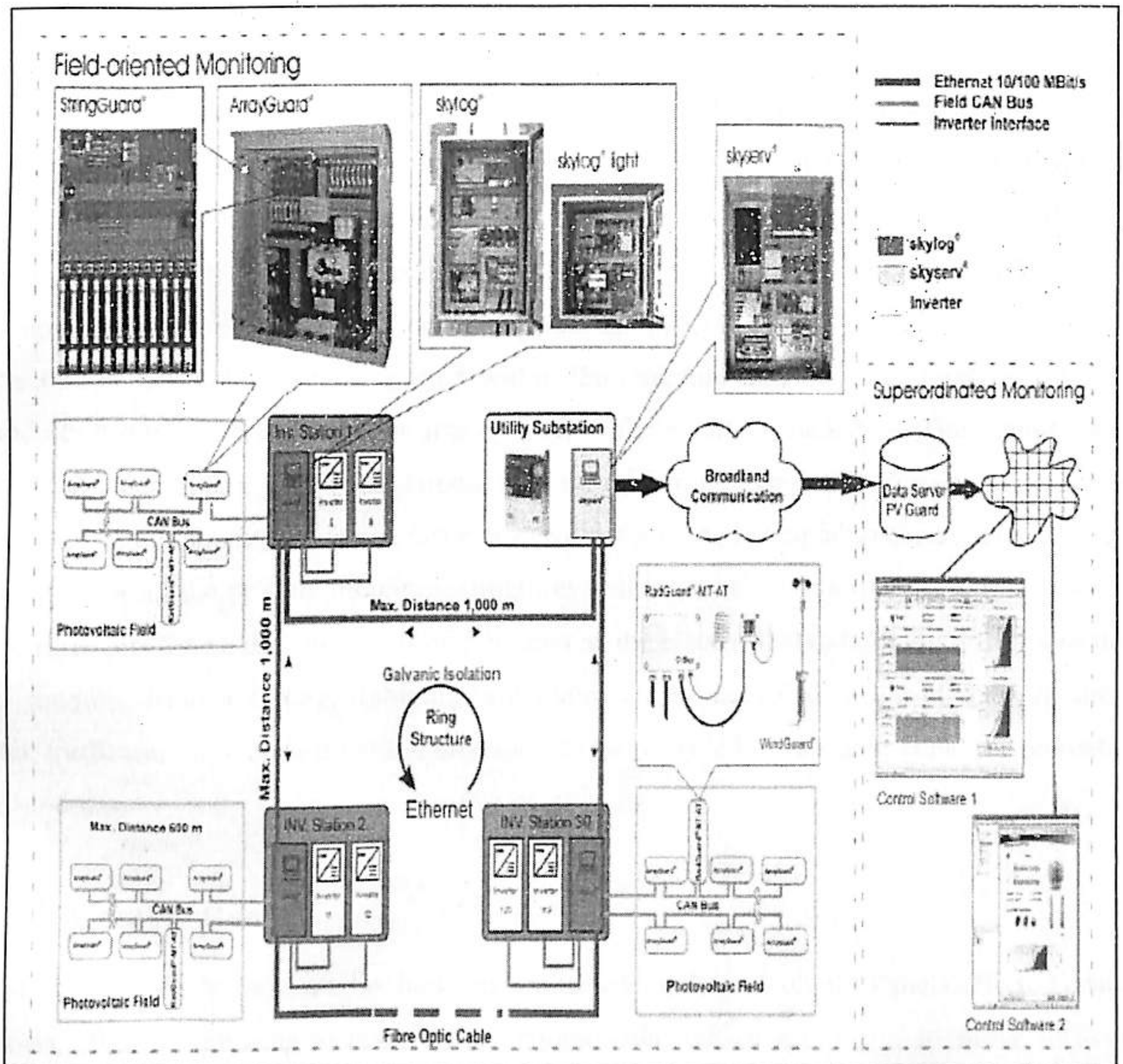

Figure 26 – Communication Schematics

3.4 Power Plant Layout

The Power Plant will be located in the proposed site. The Power Plant layout can be divided into two sections as follows:

1. Module Mounting Area
2. Control room

3.4.1 Module Mounting Area

The major portion of the site will be used for module mounting. As described in the Power Plant

Scheme the module will be mounted in a steel structure which will be installed facing South direction for best efficiency & optimal power output. The steel structure will be grouted using RCC foundation. The proposed structure is designed to hold modules per structure and which can withstand wind speed up to 150km/hr. The structure is designed in such a way that it will occupy minimum required space without sacrificing the performance.

The interconnection cables are routed within the structure and the output cables from the modules are taken through proper size conduit to the smart connect box. The output cables from the junction boxes are routed under the ground through conduits or cable trenches. Man holes for regular maintenance and inspection will be provided at equal distances as required. Earthing for all the module mounting structures will be done using copper or GI conductors. The earth pits for module area will be provided as the electrical standards. In order to protect the modules from lightning, lightning protection will be provided in the module mounting area. Sufficient number of lightning arrestor will be provided in this area alone for protection of Modules.

3.4.2 Control Room

The control will be utilized for housing the inverters, Low Voltage Panels, High Tension Panels, Plant Monitoring system, Safety equipments, Office room etc. In order to avoid shading effect the control room is proposed to be constructed on the North side of the layout.

The control room will be provided with Air conditioning if required or else natural air flow technology will adopted in the CR unit in order to maintain the desired temperature of the equipments like inverters for better performance. The office space will be provided inside the control room with basic amenities. The performance of the Power Plant can be monitored from the Office room.

The control room will be equipped with all necessary safety equipments as the safety rules. The equipments will be erected as per the Indian Electrical Standards. The cables will be routed through cables trenches or cable trays as required. Alarm system will be provided to alert the operator in case of emergency or plant break-down. The control room will also house the power evacuation system expect the transformer. The proposed transformer will be installed in outdoor next to the control room.

3.4.3 Civil Works

The civil engineering and building works shall include the design, detailing, and construction of all foundations, structures, buildings, installation and service of facilities required for the installation; commissioning, operation and maintenance of all equipment associated with the Power Plant.

The civil works includes the following: Preliminaries, additional survey, soil exploration, piling if needed, ground improvement, foundations, and all necessary site investigation associated with the operations. Site roads, site leveling and grading with boundary fences and gates are also included. In order to avoid flooding, rain water drainage system is provided all around the plant layout.

We proposed 6 feet boundary wall of stone masonry around the power plant for security. The chain linked fencing of 2 feet is also provided at the top of the boundary wall.

3.4.4 Other

The other important requirement for the Power Plant is Water, which will be used predominantly for module cleaning. The water table is very good in the proposed site and bore well for required depth will be erected to meet the requirement. An over-head tank / underground sump will be constructed as per the requirement for the water storage. Normally the cleaning of the module will be done manually.

3.5 Plant Operation and Maintenance

3.5.1 Operation Requirements

On the whole the operation of Power Plant can be divided into two categories:

- Direct Current (DC) side

• Alternating Current (AC) side

Important modes of operation of the Power Plant are listed below:

DC side:

• PV modules convert Sun light into DC Power

• PV modules are connected in series & parallel to create necessary voltage & current. The series & parallel connections are done as per the design

• The output of PV array is connected to junction boxes and outputs of the several junction boxes are connected to main combiner box

• This generated DC power is passed through the Inverter to convert DC power into AC power

AC side:

• The output of the Inverter will be AC power at 415V

• This converted AC power at 415V is connected to LV panel and stepped up to 132/33kV using a step-up transformer

• The stepped up power is connected to HT panel and from HT panel to Double Pole conductor

• AC Power is transmitted through overhead line up to nearest sub-station

• AC power at 132/33kV is connected to the Grid at the same voltage

• Both on DC side of generation as well as AC side of conversion, protection and safety devices are provided to ensure safe and reliable operation of the complete Solar Power Generating system

3.5.2 Maintenance Requirement

The main objectives of the maintenance section focus on keeping the plant running reliably and efficiently as long as possible with any break down. Reliability is impaired when a plant is thrown to forced and unforeseen outages.

The following measures will help in reducing the break down maintenance and also help in planning for preventive maintenance:

- Careful logging of operation data and periodically processing it to determine abnormal or slowly deteriorating conditions
- Careful control and supervision of operating conditions. Wide and rapid variations in voltage and frequency conditions do contribute to increased maintenance
- Regulate routine maintenance work such as keeping equipment clean, cleaning of module, proper maintenance of inverters etc
- Correct operating procedures
- Frequent testing of plant equipment by 'Walk Down' checks to internal condition of equipments such as module performance, inverter efficiency test, monitoring system testing etc
- Close co-ordination with the manufacture to effect improvements in plant layouts and design, use of better material, introduction of such facilities as lightning protection, etc

4 Calculations and Drawings

4.1 Scope

This electrical design data defines the design requirements applicable for this project in addition to the Specification for Solar Power Generation System.

4.2 Site Conditions

S. No.	Parameters	Details
1	Project Name	1 MW Grid Tied Solar Power Project at Bikaner, Rajasthan
2	Plant Capacity	1 MW
3	Location	Sarah Kishnayat Village, Bikaner, Rajasthan
4	Location Details	Latitude: 27° 53' 47.36"N Longitude: 72° 56' 40.76" E Elevation - 831 ft above Mean Sea Level
5	Climate	Avg. Max. Temperature (Yearly): 41.9^{0}C Avg. Min. Temperature (Yearly): 6.5^{0}C Average Monthly Precipitation: 3.51 mm/day
6	Soil Resistivity	As per Soil Analysis report
8	Average Rainfall	Scanty; 26 to 44 mm
9	Isolation Data	1925 kWh/m2/year @ Horizontal 2036 kWh/m2/year @ 24° Tilt

Table 10 – Site Conditions

The insolation data is gathered from industry standard software i.e., Meteonorm. Insolation is taken at different angles and the optimum inclination angle is found to be 24° (degree) to get maximum incident of sun rays over solar panels. Therefore the angle of inclination is considered as 24° (degree) of module mounting structures.

4.3 Meteorological Data

The meteorological data for the site has been taken from Meteonorm and NASA. For PV

Syst generation analysis Meteonorm data has been preferred as the ground based station is available for the site which gives accurate result as compared to satellite based NASA data.

Interval Beginning	Global Horizontal kWh/m².mth	Diffused Horizontal kWh/m².mth	Ambient Temperature °C	Wind Velocity m/s
January	166	45	15.3	0.9
February	197	64	19.4	1.2
March	237	80	25.8	1.4
April	257	98	30.9	1.6
May	273	119	35.1	2.5
June	267	127	35.1	2.9
July	228	125	33.3	2.5
August	228	128	32.3	2.2
September	229	88	31.8	1.5
October	204	79	28.2	0.9
November	174	51	22.4	0.7
December	155	40	17.3	0.7
Year	**218**	**87**	**27.2**	**1.6**

Table 11 – Meteorological Data

Based on above data the tilt angle to get yearly maximum radiation on collector plane is selected which is 24 degrees. The radiation received on panel surface at this tilt angle is 2018 kWh/m^2/month.

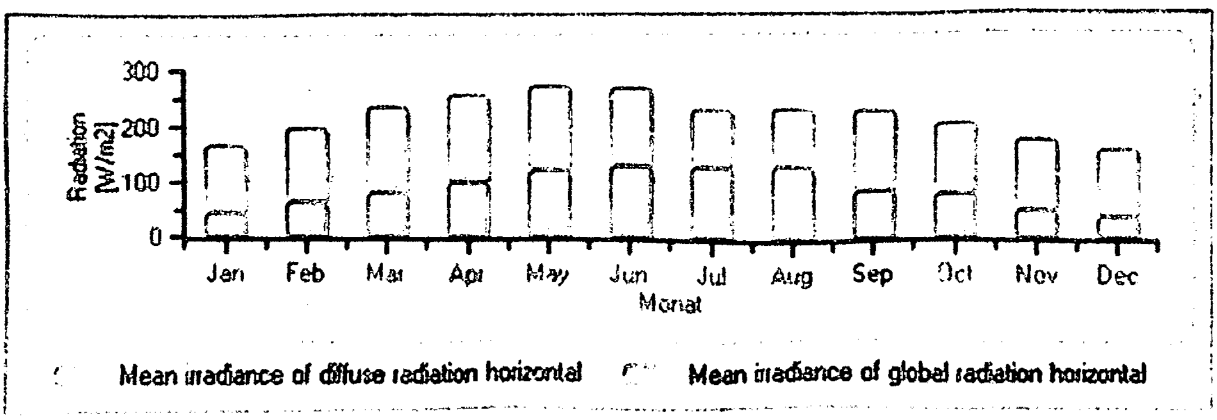

Figure 27 – Mean Irradiance of Diffused and Global Radiation

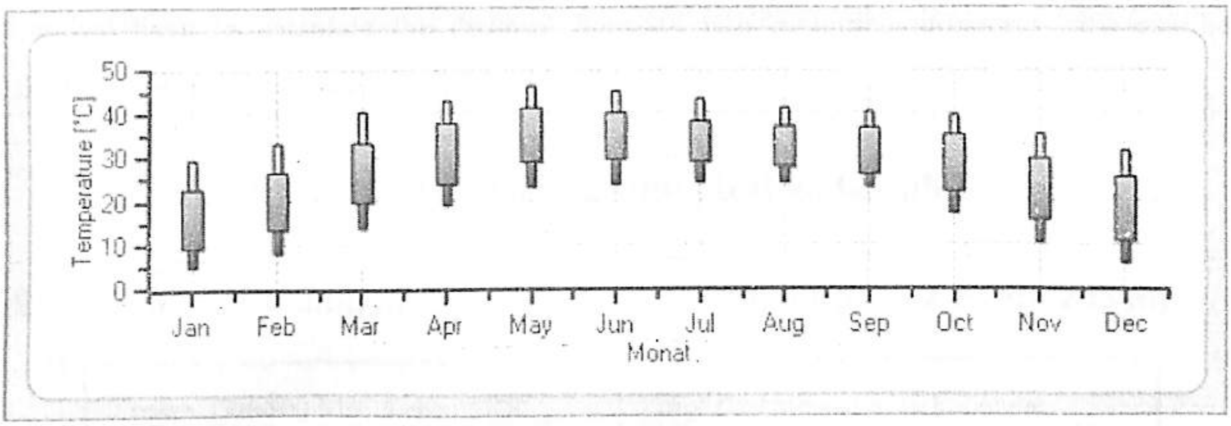

Figure 28 – Temperature Graph

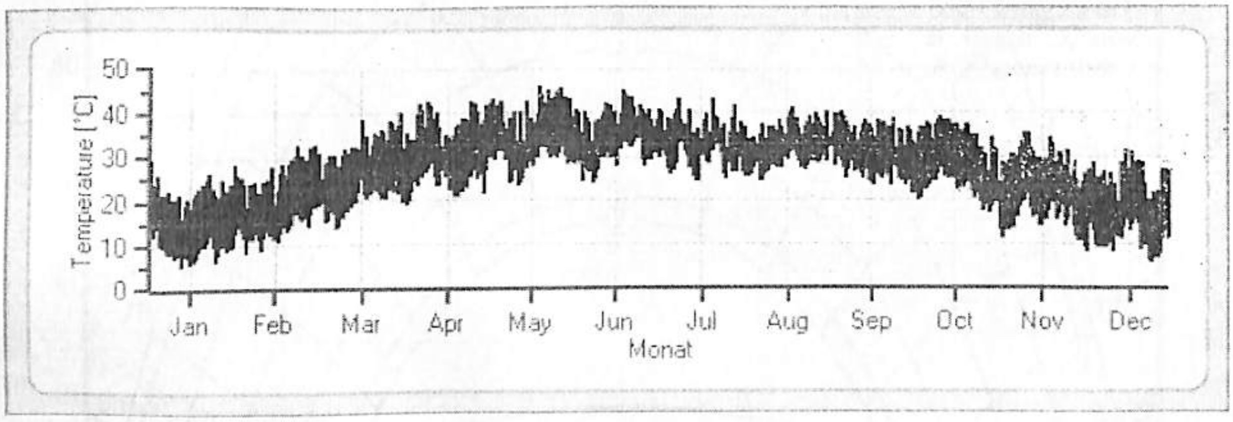

Figure 29 – Temperature Graph

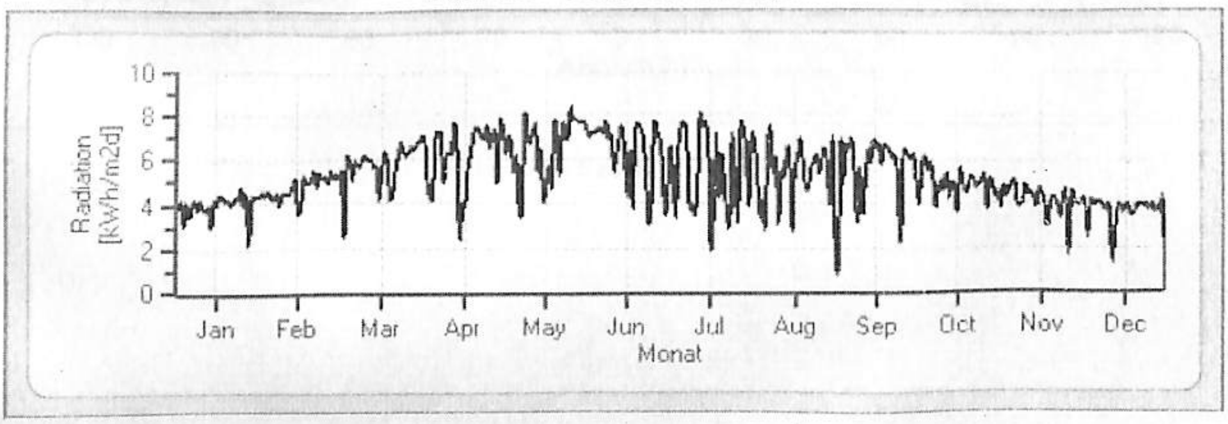

Figure 30 –Radiation Graph

4.4 Module Mounting Structures

Solar panels will be mounted on steel support structures adjustable with the wind loads and other related factors at a fixed inclination angle of 24° (degree).

Now we have to calculate the distance between two mounting structures, this can be calculated by method given below.

4.5 Sun path Graph and Shading Optimization Graph

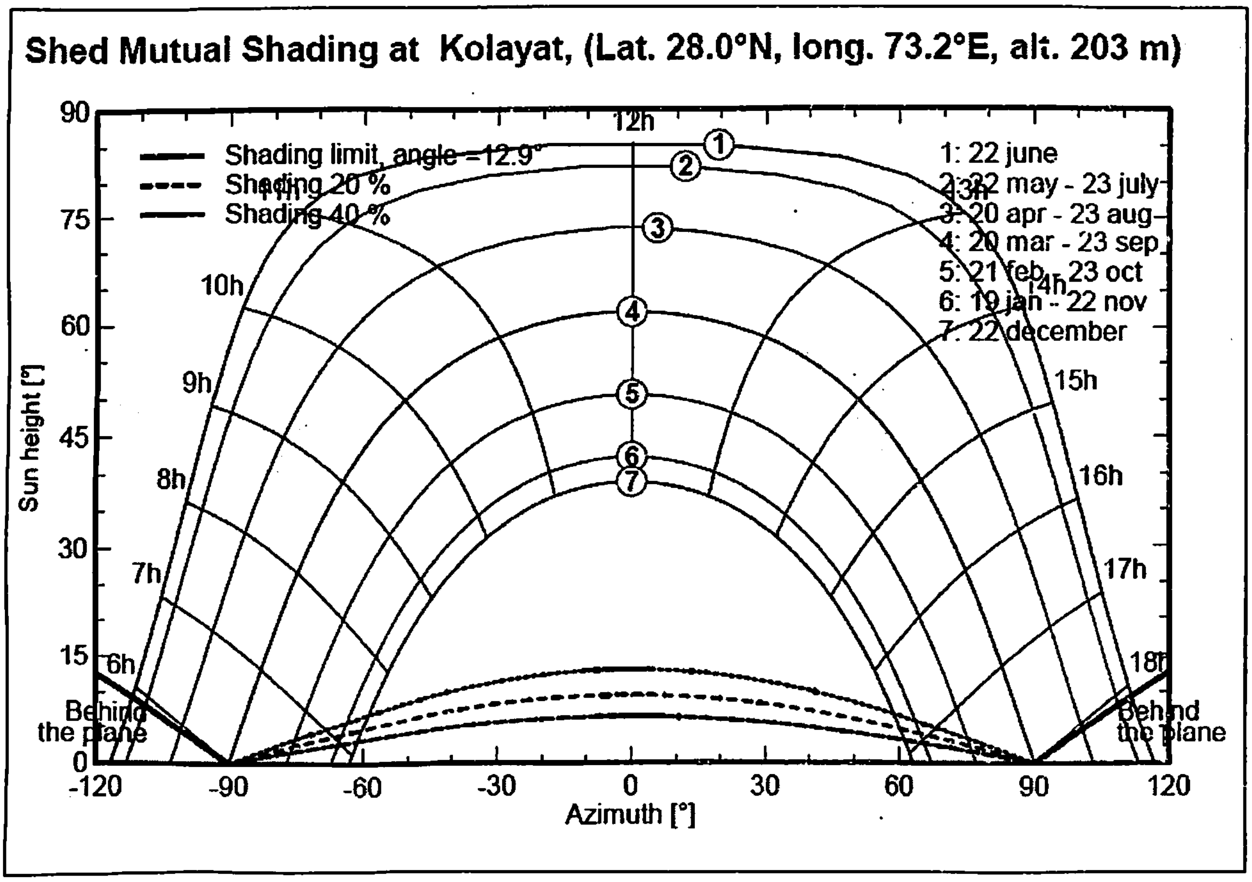

Figure 31 – Sun path diagram

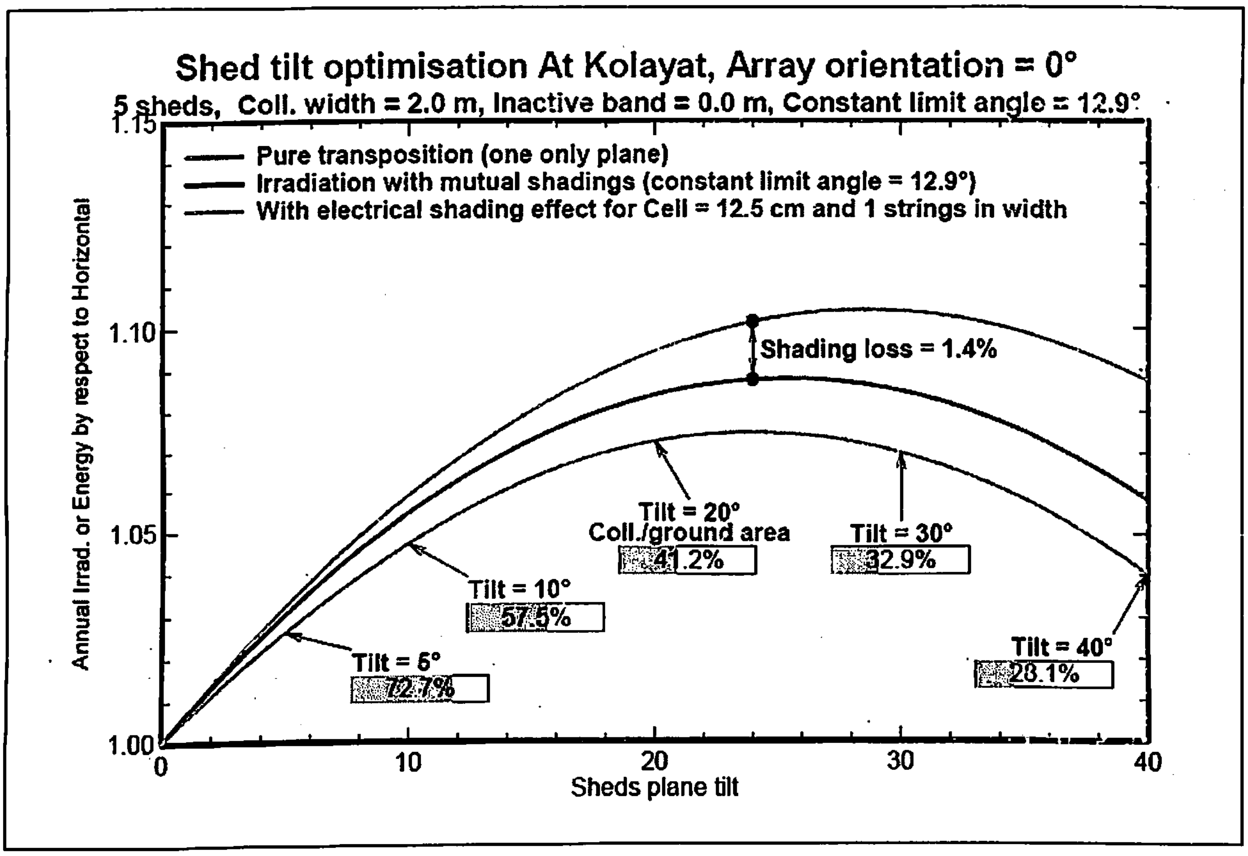

Figure 32 – Shadow Analysis

We find that the maximum elevation angle of the sun at 180 degree azimuth angle is about 36.6 degree (Dec 21st, 13:00) when the sun is passing the solstice, or solstitial point namely December 21st.

On December 21st at 9:00hrs the angle of the sun is about 11.52° but on same date at 17:00hrs the angle of the sun will be about 13.84°, therefore the elevation angle of sun at 178.11° azimuth angle is considered as optimal elevation angle on the same day at 13:00 hrs to calculate the distance between the two rows.

A small drawing will help us to understand the calculations:

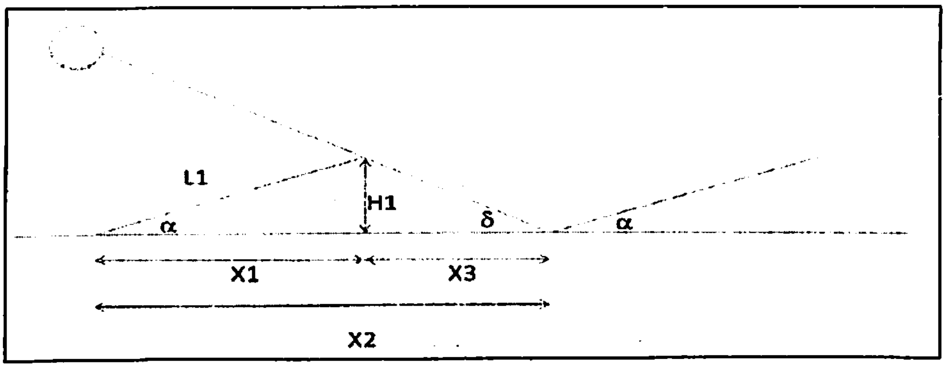

Figure 33 – Calculation Diagram

H1 is height of the structure up to top edge of solar module

α is the inclination angle for mounting structure (i.e., 24 degree)

δ is the sun elevation in December (i.e., 38.64 degree)

X1 is width of structure falling at ground

X2 is pitch between two legs of structures

X3 is the minimum distance from end of one structure to start of second structure

L1 is the width of structure at an angle α supporting four modules in four parallel rows

Note: Dimensions of PV Module are 1954mm x 982 mm x 40mm.

Therefore, the width L1= 4.098 meters (Span of Vertical Member in Structure Design)

$X1 = L1 \cos(\alpha) = 4.089 \times \cos 24$ degree = 3.735 meters

The minimum distance between the two rows can be calculated with the following formula:

$X3 = L1 (\sin(\alpha)/ \tan(\delta)) = 2.084$ meters

The distance between the two rows of structures should be **minimum 2.084 meters.** Therefore, after doing analysis on various distances required to minimize the shading losses in a year along with other parameters such as DC Wiring, Land Utilization, and performance of plant. The pitch (X2) between two legs of structure rows has been decided as **5.5 meters (Minimum).**

X3 = X2 – X1 = 5.5 – 3.375 meters = 2.125 meters

Hence the distance (X3) is taken as **2.125 meters (Minimum)** as in PV Modules-General Arrangement Layout drawing.

4.6 Power Source

Photovoltaic array is a collection of solar photovoltaic modules, which are made up of several interconnected solar cells. The cells convert solar energy into direct current electricity by "**photoelectric effect**". Individual solar modules are connected in suitable series– parallel combinations to make solar panel array to obtain the required voltage and current rating to meet the input requirement of Inverter. **The modules in the PV array are usually first connected in series to make up the voltage and then individual strings are connected in parallel to enable system to produce more current.** PV arrays use inverter to convert the DC current generated by the system into AC current.

The solar panel array is designed based upon input data required for Inverter and following design conditions:

i) Output current to be considered at operating point based on following operating conditions:

a) Cell temperature while delivering current corresponding to Pmax point on the I-V curve at specified ambient temperature.

b) Operating voltage considering - Voltage drop in cables between solar array and string/array combiner box and loss due to dust deposit over solar panels.

The company has considered the use of the crystalline technology for this solar power plant. We have decided to use **280 Watts Poly-Crystalline Silicon Modules** based on **POLYCRYSTALLINE SILICON PHOTOVOLTAIC TECHNOLOGY** as our preferred technology after doing general comparisons based on various parameters such as temperature & efficiency, cost effectiveness, durability, etc.

General parameters under Standard Test Conditions (STC) of irradiance of 1000W/Sq.m, spectrum AM 1.5 and cell temperature of 25°C of selected mono-crystalline modules are given below:

PV MODULES :

Electrical Parameters	
Model	CS6X-280P
Make	Canadian Solar
Reference Conditions	1000 W/m^2
Technology	Poly-Crystalline
Short Circuit Current	8.42 A
Maximum Power Point Current	7.86 A
Open Circuit Voltage	44.2 V
Maximum Power Point Voltage	35.6 V
Temperature Co-efficient	
Pmax	-0.43 %/°C
Voc	-0.34 %/°C
Isc	0.065 %/°C
Mechanical Specification	
Length	1954 mm
Width	982 mm
Thickness	40 mm
Weight	27.00 Kg

Table 12 – PV Module Technical Specification

INVERTERS - 630kW Unit:

Inverter- Technical Specifications	
Make	**ABB**
Input (DC)	
Max. DC power	756 kW
Max. input voltage	1000 V
MPP voltage range	525 V – 825 V
Max. input current	1240 A
Number of DC inputs	4, 8,12 or 16
Output (AC)	
Rated power	630 kW
Nominal AC voltage	350 V
Rated power frequency	50 Hz
Max. output current	1040 A
Max. THD	3 %
Efficiency	
Max. efficiency / European efficiency	98.6% / 98.4 %

INVERTERS - 315kW Unit:

Inverter- Technical Specifications	
Make	**ABB**
Input (DC)	
Max. DC power	378 kW
Max. input voltage	1000 V
MPP voltage range	525 V – 825 V
Max. input current	615 A
Number of DC inputs	2,4, or 8
Output (AC)	
Rated power	315 kW
Nominal AC voltage	350 V
Rated power frequency	50 Hz
Max. output current	520 A
Max. THD	3 %
Efficiency	
Max. efficiency / European efficiency	98.6% / 98.3 %

Table 13 – Inverter Specification

4.7 Sizing of String

For composition of a string, the below three conditions should be satisfied

Condition I: At the coldest daytime temperature the open circuit voltage of the array must never be greater than the maximum allowed input voltage for the inverter. The Open Circuit voltage (Voc) is used because this is greater than the MPP voltage and it is the applied voltage when the system is first connected prior to the inverter starting to operate and connecting to the grid. In early morning, at first light, the cell temperature will be very close to the ambient temperature i.e., approximately 6.5° C) because the sun has not had time to heat up the module but in worst case scenario the minimum of -2°C is considered for calculation.

a) The open circuit voltage is 44.2V at 25°C (at STC) but the open circuit voltage at minimum temperature (at -2°C) can be calculated as:

Voc (min t°C) = Rated Voc × {1 + [(Min. Temp. °C - 25°C) × Voltage Coefficient %/°C]}

Voc (at -2°C) = 44.2 Voc × {1+ [(-2°C - 25°C) × -0.35%/°C]}

Voc (at -2°C) = 44.2 Voc × {1 + [-27°C × -0.35%/°C]})

Voc (at -2°C) = 44.2 Voc × {1 + 9.45%}

Voc (at -2°C) = 44.2 Voc × 1.0945

Voc (at -2°C) = 48.37 V

b) For calculating maximum number of modules in a string, we consider maximum voltage that is the open circuit voltage of module. Voltage drop in the DC Wiring losses will be considered only in calculation for minimum voltage condition.

Maximum number of Modules = Maximum allowed input voltage at inverter/ Maximum Voc Voltage of module at minimum temperature

= 1000 V / 48.37 V = 20.67 (Round down to 20 Modules)

Therefore the maximum number of modules i.e., 20 Module should be connected in series.

c) Thus, condition for maximum number of 20 modules at minimum temperature i.e.

Number of modules x Voc (at -2°) < inverter Vmax

20 x 48.37 V < 1000 V

967.4 V < 1000V (Correct)

Voc at minimum temperature is satisfying the maximum input voltage of Inverter. Therefore,

20 Modules can be connected in series forming a string in both inverter units (630kW & 315kW).

Condition II: When the temperature is at a maximum then the maximum power point voltage (Vmpp) of the array must never fall below the minimum operating voltage of the inverter. The actual voltage at the input of the inverter is not just the Vmpp of the array at maximum temperature, the voltage drop in the DC wiring is also be included when determining the actual inverter input voltage.

a) The effective cell temperature can be calculated as:

Effective cell temperature	$t_{eff\_cell} = t_{avg\_ambient} + 25\ °C + t_{global\ warming}$

teff_cell is the Effective Cell temperature to calculate minimum voltage.

tavg_ambient is the ambient or surrounding temperature at in daytime.

tglobal warming is taken for future (5 °C) increase in temperature due to global warming effect.

teff_cell = 42 °C + 25 °C + 5 °C

= 72 °C

b) The maximum power point voltage (Vmpp) is 35.6V at 25°C (at STC) but the Vmpp at maximum temperature (at 72°C) can be calculated as:

Vmpp (max t°C) = Rated Vmpp × {1 + [(Effective Cell Temp. °C - 25°C) × Module Coefficient %/°C]}

Vmpp (at 72°C) = 35.6 Vmpp × {1+ [(72°C - 25°C) × -0.35%/°C]}

Vmpp (at 72°C) = 35.6 Vmpp × {1+ [(47°C) × -0.35%/°C]}

Vmpp (at 72°C)= 35.6 Vmpp × {1+ (16.45%/°C]}

Vmpp (at 72°C) = 35.6 Vmpp × {1+ (-0.164)}

Vmpp (at 72°C) = 35.6 Vmpp × 0.835

Vmpp (at 72°C) = 29.726 V

c) For calculating minimum number of modules in a string, we consider the voltage drop in the wiring, if we assume a maximum voltage drop in the cables of maximum of 5% then the voltage at the inverter for each module would be

Voc (at 72°C) = 0.95 x 29.726 = 28.23 V

Minimum number of Modules = Minimum Input voltage of Inverter/ Minimum MPP voltage of Module
= 525 V/ 28.23 V = 15.6 (Say 16 Modules)

Therefore the minimum number of modules i.e., 16 Module can be connected in series and the maximum of 20 modules can be connected in Inverter unit i.e., 630kW & 315kW. Hence, the range of 16-20 modules can be connected in series to form a string.

d) Thus, Condition for connecting 20 Modules in series at maximum temperature i.e.

Number of Modules X Vmpp (At 72^{0}) > inverter Vmin

20 x 28.23 V > 525V

564.4 V > 525V (Correct)

The voltage Vmpp at maximum temperature is satisfying the minimum input voltage of Inverter.

Condition III:

The total Isc current for strings in parallel must be lower than the maximum input current for the inverter.

For 630kW Inverter Unit:

The total number of strings to 630kW Inverter i.e., 114 Strings (20 numbers of modules in an each string) connected to Inverter and the condition can check as:

Isc strings < inverter I max

114 Strings x 8.42 Amp < 1240 Amp

959.88 Amp < 1240 Amp

Hence 20 modules can be connected in series to form a string.

For 315kW Inverter Unit:

The total number of strings to 315kW Inverter i.e., 65 Strings (20 numbers of modules in an each string) connected to an Inverter and the condition can check as:

Isc strings < inverter I max

65 Strings x 8.42 Amp < 615 Amp

547.3 Amp < 615 Amp

Hence 20 modules can be connected in series to form a string.

4.8 Sizing of Array

Total number of PV modules is connected in series-parallel combination to make arrays for 1 MW DC project and it can be calculated as

Total number of PV modules in 1 MW Project is

1 MW / wattage of 1 PV Module = 1000000 W/ 280 W = 3574.4 (say 3572 modules)

Total number of Strings can be calculated as:

Total No. of PV Modules in 1 MW/ No. of modules in series in a string = 3572/20 = 178.6 (Say 179 Strings in parallel)

The total numbers of strings are 179 strings and the 114 Strings will be connected to 630kW inverter Unit & 65 strings will be connected to 315kW Inverter Unit.

4.9 String Combiner box

DC Cables from the series connected modules are taken into the junction boxes for parallel connection; where in the amperage of arrays are increased without increasing already designed system voltage. These junction boxes are of IP65/IP54 depending upon location and environment. So number of junction boxes with 24 inputs and 1 output are:

Number of Junction Box = Total No. of Strings/ No. of inputs in 1 Junction Box = 179/24 = 7.45 (Say 8)

Therefore, in this project 8 numbers of junction box (maximum number of inputs configuration available in market to reduce the number of combiner box) will be used in this project.

1Cx4sqmm DC cables with cable glands from strings will be fed into Input side and 1Cx 120sqmm DC cables from O/P side of junction boxes and will be given into Input of Inverter.

Note: Quantity of string combiner boxes may vary with respect to change in location of SCB and cable routing during detailed engineering of DC part of Plant.

4.10 Cable Sizing

The Cable Sizing depends on the Following Excel Sheet:

Parameters	Symbol	String to String Box	MCB to Inverter	Units
Type of Connection (Series/Parallel)		S	P	
Design Inputs (Maximum Condition)				
Inputs		1	1	
Module Voltage (Max Power Voltage)	Vmp	35.6	35.6	V
Module in Series		20	20	
System Voltage	V	712	712	V
Current (Short Circuit)	Isc	8.42	8.42	A
No of Strings/Inputs		24	1	
Full Load Current	IL	10.53	10.535	A
Apparent Power of Load	S	7494	7493.8	W
Length of cable		10	4.37	
Max Length of Cable	L	50	180	m
Maximum allowable Steady state voltage dropt at load Terminal	Vda	1	1	%
Cable Data				
Voltage grade	Vc	1	1	kV
No. of Cores		1	1	Nos
Cross Section Area	A	4	120	Sq mm
Conductor Material (Copper / Aluminium)		Cu	Cu	
Insulation		XPLE	XPLE	
Current carrying Capacity	Ic-Air	42	300	A
Current carrying Capacity	Ic-Gd	47	336	A
Resistance for unit length of cable	Rc	3.08	0.0754	Ω/km
Resistance of cable for selected length	RL (Rc*L)	0.154	0.013572	Ω
Type of Laying				
Laying in Ground				
Ground Temperature		35	35	°C
Depth of Laying		0.8	0.8	m
Formation (Horizontal / Vertical)			H	
Touching / Spacing / Trefoil Spacing			T	
No. of Cables		2	2	

Checking of Thermal Ampacity				
Calculation of De-rating factor for laying in Ground				
De-rating factor for variation in Ground Temperature	G1	1	0.96	
De-rating factor for Depth of Laying	G2	1	0.91	
Touching or Spacing or Trefoil spacing	G3	0.87	0.87	
Over all derating factor for Ground	K-Gd (G1*G2*G3)	0.87	0.760032	
Calculation of De-rated current carrying capacity				
De-rated Current Carrying capacity of Cable in Ground	Ic-DRG(K-Gd*Ic-Gd)	40.89	255.37	A
Full Load Current	IL	10.53	10.53	A
Power loss	Sd=(IL²*RL)	17.06	1.50	W
% Power loss	%Sd =(Sd/S)	0.23%	0.02%	%
RESULT				
Cross Section Area	sq mm	4	120	
Conductor Material	Cu/Al	**Cu**	**Cu**	
Thermal Ampacity				
Calculated Value	A	40.89	255.37075	
Actual/Required Value	A	10.53	10.525	
Acceptable (Yes/No)		Y	Y	
Power Loss				
Calculated Value	%	0.23%	0.02%	
Actual/Required Value	%	1%	1%	
Acceptable (Yes/No)		Y	Y	

4.11 Transformer Sizing

Transformer loading is usually done upto 1.25% more than the normal practice to overcome the losses and the transformer is designed with a safety factor of 1.25 overloading which is correct as per general industrial practice.

Normative Power Factor of 0.8 to 0.9 is considered in usual practice.

Usually the transformers used are of double winding but in our power plant, the transformer used is a triple winding Transformer as two inverters of different capacities are used and this directly steps it to a voltage of 33 kV thereby reducing the overall system cost which could have been more if two different transformers were used separately for the two inverters.

4.12 PV Syst Reports

4.12.1PV Syst report – 1

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Grid-Connected System: Simulation parameters

Project :	**1 MW Grid Connected Solar Power Project**				
Geographical Site		**Kolayat**		**Country**	**India**
Situation		Latitude	28.0°N	Longitude	73.2°E
Time defined as		Legal Time	Time zone UT+6	Altitude	203 m
		Albedo	0.20		
Meteo data :	Kolayat. Meteonorm SYN File				

Simulation variant :	**New simulation variant**				
		Simulation date	20/03/13 17h19		

Simulation parameters					
Collector Plane Orientation		Tilt	27°	Azimuth	0°
5Sheds		Pitch	10.5 m	Collector width	4.10 m
Inactive band		Top	0.00 m	Bottom	0.00 m
Shading limit angle		Gamma	15.21 °	Occupation Ratio	39.0 %
Horizon		Free Horizon			
Near Shadings		Mutual shadings of sheds			
PV Arrays Characteristics	(2 kinds of array defined)				
PV module	Si-poly	Model	CS6X - 280P		
		Manufacturer	Canadian Solar Inc.		
Array#1:	Number of PV modules	In series	20 modules	In parallel	114 strings
Total number of PV modules		Nb. modules	2280	Unit Nom. Power	280 Wp
Array global power		Nominal (STC)	638 kWp	At operating cond.	568 kWp (50°C)
Array operating characteristics (50°C)		U mpp	634 V	I mpp	896 A
Array#2:	Number of PV modules	In series	20 modules	In parallel	65 strings
Total number of PV modules		Nb. modules	1300	Unit Nom. Power	280 Wp
Array global power		Nominal (STC)	364 kWp	At operating cond.	324 kWp (50°C)
Array operating characteristics (50°C)		U mpp	634 V	I mpp	511 A
Total	Arrays global power	Nominal (STC)	1002 kWp	Total	3580 modules
		Module area	6869 m²	Cell area	6274 m²
Array#1 : Inverter		Model	PVS800-57-0630kW-B		
		Manufacturer	ABB		
Characteristics		Operating Voltage	525-825 V	Unit Nom. Power	630 kW AC
Array#2 : Inverter		Model	PVS800-57-0315kW-B		
		Manufacturer	ABB		
Characteristics		Operating Voltage	525-825 V	Unit Nom. Power	315 kW AC
PV Array loss factors					
Thermal Loss factor		Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)				NOCT	45 °C
Wiring Ohmic Loss		Array#1	12 mOhm	Loss Fraction	1.5 % at STC
		Array#2	21 mOhm	Loss Fraction	1.5 % at STC
		Global		Loss Fraction	1.5 % at STC
Array Soiling Losses				Loss Fraction	1.5 %
Module Quality Loss				Loss Fraction	0.1 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP

Grid-Connected System: Simulation parameters (continued)

Incidence effect, ASHRAE parametrization IAM = 1 - bo (1/cos i - 1) bo Parameter 0.05

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

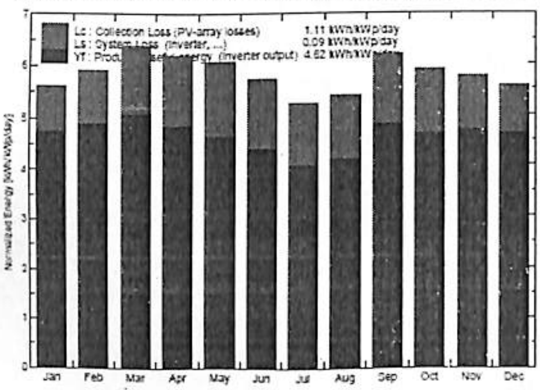
Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

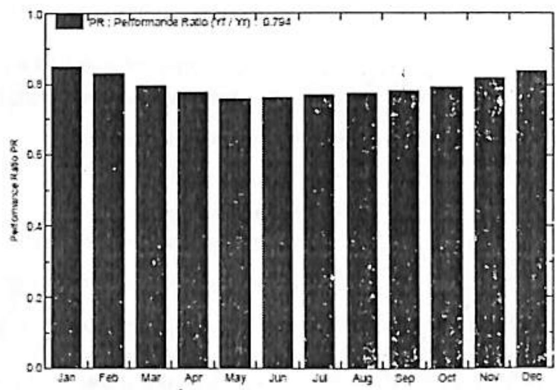
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	27°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1691526 kWh/year**	Specific prod.	1687 kWh/kWp/year
	Performance Ratio PR	79.4 %		

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	124.0	15.38	174.1	168.4	150944	147965	12.62	12.37
February	131.6	19.34	165.7	159.8	140659	137894	12.35	12.11
March	176.5	25.93	197.6	189.9	160816	157769	11.85	11.62
April	185.6	30.53	186.0	177.5	147468	144752	11.54	11.33
May	202.3	35.14	187.8	178.3	145130	142434	11.25	11.04
June	189.9	34.76	171.5	162.1	133209	130671	11.31	11.09
July	175.7	33.44	161.7	152.6	126805	124370	11.41	11.19
August	170.9	32.31	166.2	157.5	131218	128757	11.50	11.28
September	173.3	31.30	185.9	178.1	147729	144985	11.57	11.35
October	152.9	28.29	182.9	176.1	147829	145035	11.76	11.54
November	125.8	22.07	172.5	166.5	144503	141807	12.20	11.97
December	116.6	17.36	172.4	166.4	147937	145087	12.49	12.25
Year	1925.1	27.19	2124.3	2033.2	1724247	1691526	11.82	11.59

Legends:			
GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

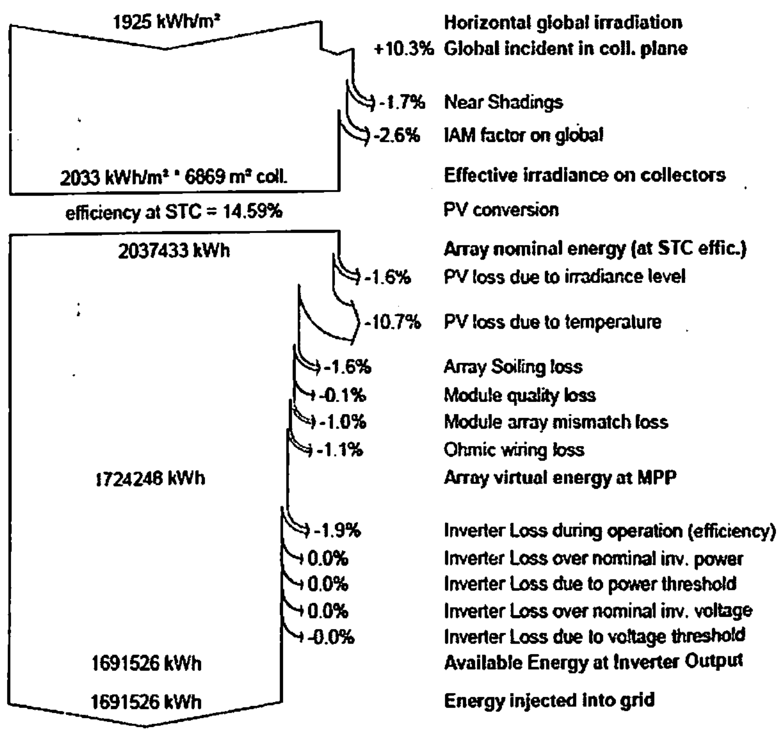
Grid-Connected System: Loss diagram

Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	27°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



4.12.2 PV Syst Report – 2

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Grid-Connected System: Simulation parameters

Project :	**1 MW Grid Connected Solar Power Project**				
Geographical Site		**Kolayat**		**Country**	**India**
Situation		Latitude	28.0°N	Longitude	73.2°E
Time defined as		Legal Time	Time zone UT+6	Altitude	203 m
		Albedo	0.20		
Meteo data :	Kolayat, Meteonorm SYN File				

Simulation variant :	**New simulation variant**				
		Simulation date	20/03/13 17h39		

Simulation parameters					
Collector Plane Orientation		Tilt	24°	Azimuth	0°
5Sheds		Pitch	5.50 m	Collector width	2.05 m
Inactive band		Top	0.00 m	Bottom	0.00 m
Shading limit angle		Gamma	12.95 °	Occupation Ratio	37.3 %
Horizon		Free Horizon			
Near Shadings		Mutual shadings of sheds			
PV Arrays Characteristics	**(2 kinds of array defined)**				
PV module	Si-poly	Model	**CS6X - 280P**		
		Manufacturer	Canadian Solar Inc.		
Array#1: Number of PV modules		In series	20 modules	In parallel	114 strings
Total number of PV modules		Nb. modules	2280	Unit Nom. Power	280 Wp
Array global power		Nominal (STC)	**638 kWp**	At operating cond.	568 kWp (50°C)
Array operating characteristics (50°C)		U mpp	634 V	I mpp	896 A
Array#2: Number of PV modules		In series	20 modules	In parallel	65 strings
Total number of PV modules		Nb. modules	1300	Unit Nom. Power	280 Wp
Array global power		Nominal (STC)	**364 kWp**	At operating cond.	324 kWp (50°C)
Array operating characteristics (50°C)		U mpp	634 V	I mpp	511 A
Total Arrays global power		Nominal (STC)	**1002 kWp**	Total	3580 modules
		Module area	**6869 m²**	Cell area	6274 m²
Array#1 : Inverter		Model	**PVS800-57-0630kW-B**		
		Manufacturer	ABB		
Characteristics		Operating Voltage	525-825 V	Unit Nom. Power	630 kW AC
Array#2 : Inverter		Model	**PVS800-57-0315kW-B**		
		Manufacturer	ABB		
Characteristics		Operating Voltage	525-825 V	Unit Nom. Power	315 kW AC
PV Array loss factors					
Thermal Loss factor		Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)				NOCT	45 °C
Wiring Ohmic Loss		Array#1	12 mOhm	Loss Fraction	1.5 % at STC
		Array#2	21 mOhm	Loss Fraction	1.5 % at STC
		Global		Loss Fraction	1.5 % at STC
Array Soiling Losses				Loss Fraction	1.5 %
Module Quality Loss				Loss Fraction	0.1 %
Module Mismatch Losses				Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization		IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

Project : **1 MW Grid Connected Solar Power Project**

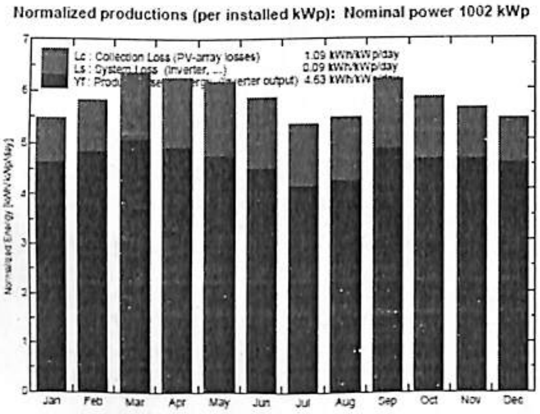
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	24°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

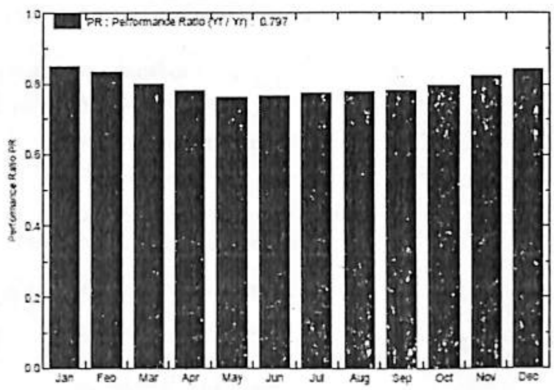
Main simulation results

System Production	**Produced Energy**	**1693051 kWh/year**	Specific prod.	1689 kWh/kWp/year
	Performance Ratio PR	79.7 %		

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	124.0	15.38	170.0	164.6	147725	144810	12.65	12.40
February	131.6	19.34	163.4	157.8	138998	136267	12.39	12.14
March	176.5	25.93	196.9	189.8	160778	157733	11.88	11.66
April	185.6	30.53	187.6	179.7	149255	146509	11.58	11.37
May	202.3	35.14	191.0	182.3	148263	145516	11.30	11.09
June	189.9	34.76	174.9	166.4	136560	133968	11.37	11.15
July	175.7	33.44	164.5	156.2	129722	127241	11.48	11.26
August	170.9	32.31	168.0	160.1	133301	130809	11.55	11.34
September	173.3	31.30	186.1	178.9	148374	145621	11.61	11.39
October	152.9	28.29	181.2	174.8	146816	144042	11.80	11.57
November	125.8	22.07	168.7	163.0	141699	139054	12.22	12.00
December	116.6	17.36	167.7	162.0	144264	141482	12.52	12.28
Year	1925.1	27.19	2119.9	2035.7	1725756	1693051	11.85	11.63

Legends:

GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

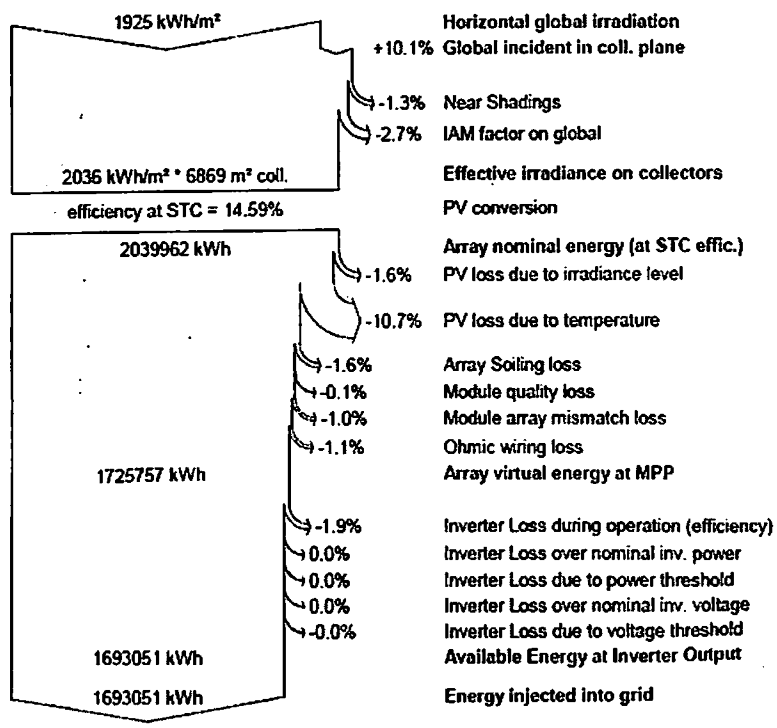
Grid-Connected System: Loss diagram

Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**			
PV Field Orientation	Sheds disposition, tilt	24°	azimuth	0°	
PV modules	Model	CS6X - 280P	Pnom	280 Wp	
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**	
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac	
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac	
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



4.12.3 PV Syst Report – 3

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Grid-Connected System: Simulation parameters

Project :	**1 MW Grid Connected Solar Power Project**			
Geographical Site	**Kolayat**		**Country**	**India**
Situation	Latitude	28.0°N	Longitude	73.2°E
Time defined as	Legal Time	Time zone UT+6	Altitude	203 m
	Albedo	0.20		
Meteo data :	Kolayat, Meteonorm SYN File			

Simulation variant :	**New simulation variant**			
	Simulation date	20/03/13 17h23		

Simulation parameters

Collector Plane Orientation	Tilt	27°	Azimuth	0°
5Sheds	Pitch	5.50 m	Collector width	2.05 m
Inactive band	Top	0.00 m	Bottom	0.00 m
Shading limit angle	Gamma	14.22 °	Occupation Ratio	37.3 %
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds			

PV Arrays Characteristics (2 kinds of array defined)

PV module Si-poly	Model	**CS6X - 280P**		
	Manufacturer	Canadian Solar Inc.		
Array#1: Number of PV modules	In series	20 modules	In parallel	114 strings
Total number of PV modules	Nb. modules	2280	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**638 kWp**	At operating cond.	568 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	896 A
Array#2: Number of PV modules	In series	20 modules	In parallel	65 strings
Total number of PV modules	Nb. modules	1300	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**364 kWp**	At operating cond.	324 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	511 A
Total Arrays global power	Nominal (STC)	**1002 kWp**	Total	3580 modules
	Module area	**6869 m²**	Cell area	6274 m²
Array#1 : Inverter	Model	**PVS800-57-0630kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	630 kW AC
Array#2 : Inverter	Model	**PVS800-57-0315kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	315 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Array#1	12 mOhm	Loss Fraction	1.5 % at STC
	Array#2	21 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Array Soiling Losses			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

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Grid-Connected System: Main results

Project : **1 MW Grid Connected Solar Power Project**

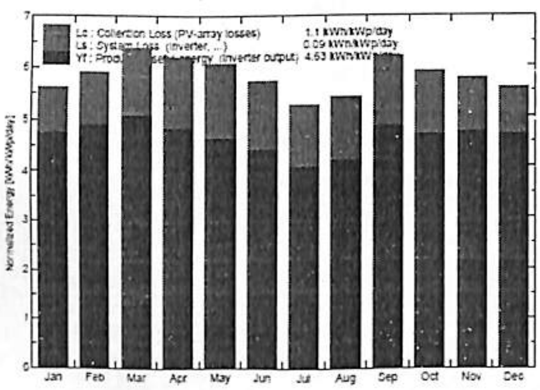
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	27°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

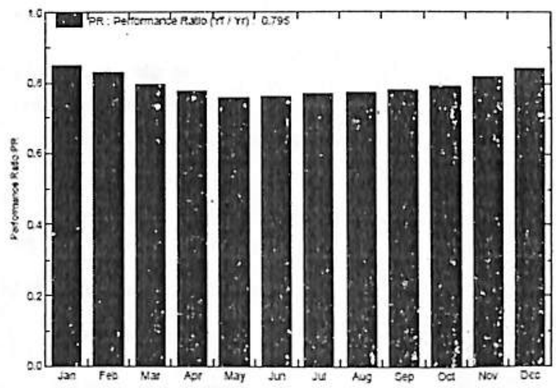
Main simulation results

System Production	**Produced Energy**	**1692613 kWh/year**	Specific prod.	1689 kWh/kWp/year
	Performance Ratio PR	79.5 %		

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	124.0	15.38	174.1	168.5	151000	148019	12.63	12.38
February	131.6	19.34	165.7	159.9	140723	137957	12.36	12.12
March	176.5	25.93	197.6	190.0	160896	157848	11.85	11.63
April	185.6	30.53	186.0	177.6	147559	144842	11.55	11.34
May	202.3	35.14	187.8	178.4	145232	142535	11.26	11.05
June	189.9	34.76	171.5	162.3	133319	130779	11.32	11.10
July	175.7	33.44	161.7	152.8	126927	124490	11.42	11.20
August	170.9	32.31	166.2	157.6	131333	128870	11.51	11.29
September	173.3	31.30	185.9	178.2	147810	145065	11.57	11.36
October	152.9	28.29	182.9	176.2	147906	145110	11.77	11.55
November	125.8	22.07	172.5	166.5	144562	141865	12.20	11.98
December	116.6	17.36	172.4	166.6	148085	145233	12.50	12.26
Year	1925.1	27.19	2124.3	2034.6	1725351	1692613	11.82	11.60

Legends:

GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

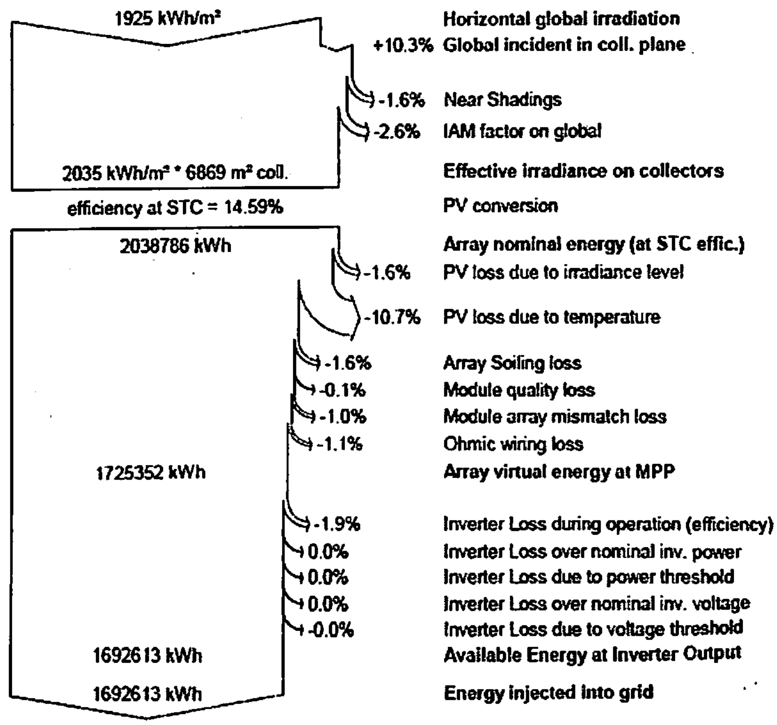
Grid-Connected System: Loss diagram

Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	27°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



4.12.4 PV Syst Report – 4

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Grid-Connected System: Simulation parameters

Project :	**1 MW Grid Connected Solar Power Project**			
Geographical Site	**Kolayat**		**Country**	**India**
Situation	Latitude	28.0°N	Longitude	73.2°E
Time defined as	Legal Time	Time zone UT+6	Altitude	203 m
	Albedo	0.20		
Meteo data :	Kolayat, Meteonorm SYN File			

Simulation variant :	**New simulation variant**			
	Simulation date	20/03/13 17h37		

Simulation parameters

Collector Plane Orientation	Tilt	24°	Azimuth	0°
5Sheds	Pitch	8.50 m	Collector width	4.10 m
Inactive band	Top	0.00 m	Bottom	0.00 m
Shading limit angle	Gamma	19.33 °	Occupation Ratio	48.2 %
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds			

PV Arrays Characteristics (2 kinds of array defined)

PV module Si-poly	Model	**CS6X - 280P**		
	Manufacturer	Canadian Solar Inc.		
Array#1: Number of PV modules	In series	20 modules	In parallel	114 strings
Total number of PV modules	Nb. modules	2280	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**638 kWp**	At operating cond.	568 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	896 A
Array#2: Number of PV modules	In series	20 modules	In parallel	65 strings
Total number of PV modules	Nb. modules	1300	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**364 kWp**	At operating cond.	324 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	511 A
Total Arrays global power	Nominal (STC)	**1002 kWp**	Total	3580 modules
	Module area	**6869 m²**	Cell area	6274 m²
Array#1 : Inverter	Model	**PVS800-57-0630kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	630 kW AC
Array#2 : Inverter	Model	**PVS800-57-0315kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	315 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Array#1	12 mOhm	Loss Fraction	1.5 % at STC
	Array#2	21 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Array Soiling Losses			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

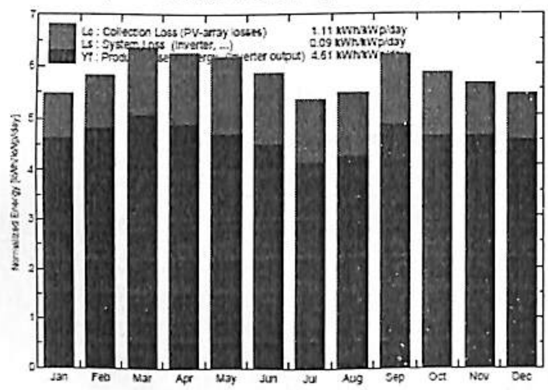
Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

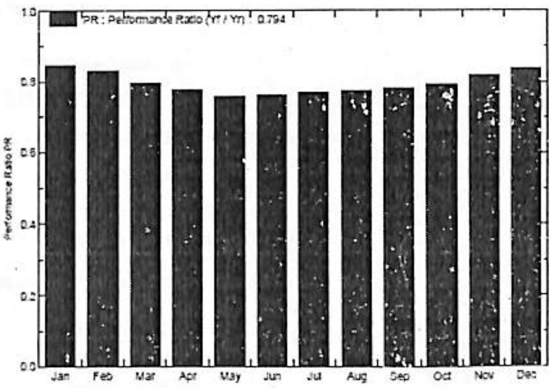
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	24°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1686592 kWh/year**	Specific prod.	1683 kWh/kWp/year
	Performance Ratio PR	79.4 %		

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	124.0	15.38	170.0	164.2	147370	144461	12.62	12.37
February	131.6	19.34	163.4	157.4	138618	135893	12.35	12.11
March	176.5	25.93	196.9	189.3	160314	157277	11.85	11.63
April	185.6	30.53	187.6	179.0	148727	145990	11.54	11.33
May	202.3	35.14	191.0	181.5	147670	144932	11.26	11.05
June	189.9	34.76	174.9	165.6	135923	133341	11.31	11.10
July	175.7	33.44	164.5	155.4	129015	126544	11.42	11.20
August	170.9	32.31	168.0	159.3	132639	130157	11.49	11.28
September	173.3	31.30	186.1	178.3	147907	145161	11.57	11.35
October	152.9	28.29	181.2	174.3	146374	143607	11.76	11.54
November	125.8	22.07	168.7	162.5	141255	138616	12.19	11.96
December	116.6	17.36	167.7	161.1	143385	140613	12.45	12.21
Year	1925.1	27.19	2119.9	2027.7	1719198	1686592	11.81	11.58

Legends:				
GlobHor	Horizontal global irradiation		EArray	Effective energy at the output of the array
T Amb	Ambient Temperature		E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane		EffArrR	Effic. Eout array / rough area
GlobEff	Effective Global, corr. for IAM and shadings		EffSysR	Effic. Eout system / rough area

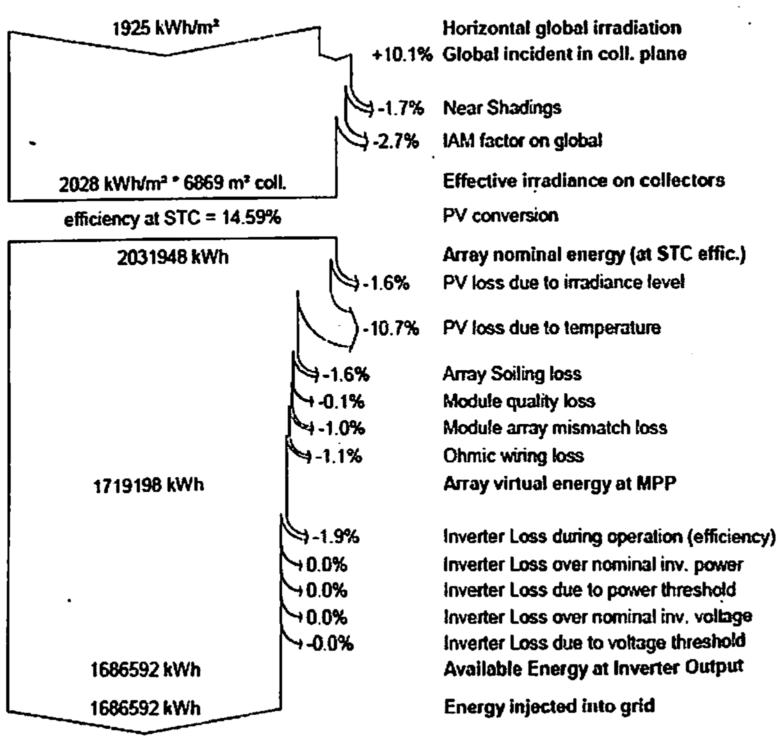
Grid-Connected System: Loss diagram

Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	24°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



4.12.5 PV Syst Report – 5

Grid-Connected System: Simulation parameters

Project :	**1 MW Grid Connected Solar Power Project**			
Geographical Site	**Kolayat**		**Country**	**India**
Situation	Latitude	28.0°N	Longitude	73.2°E
Time defined as	Legal Time	Time zone UT+6	Altitude	203 m
	Albedo	0.20		
Meteo data :	Kolayat, Meteonorm SYN File			

Simulation variant :	**New simulation variant**			
	Simulation date	20/03/13 17h35		

Simulation parameters

Collector Plane Orientation	Tilt	27°	Azimuth	0°
5Sheds	Pitch	8.00 m	Collector width	3.07 m
Inactive band	Top	0.00 m	Bottom	0.00 m
Shading limit angle	Gamma	14.83 °	Occupation Ratio	38.4 %
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds			

PV Arrays Characteristics (2 kinds of array defined)

PV module	Si-poly Model	**CS6X - 280P**		
	Manufacturer	Canadian Solar Inc.		
Array#1: Number of PV modules	In series	20 modules	In parallel	114 strings
Total number of PV modules	Nb. modules	2280	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**638 kWp**	At operating cond.	568 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	896 A
Array#2: Number of PV modules	In series	20 modules	In parallel	65 strings
Total number of PV modules	Nb. modules	1300	Unit Nom. Power	280 Wp
Array global power	Nominal (STC)	**364 kWp**	At operating cond.	324 kWp (50°C)
Array operating characteristics (50°C)	U mpp	634 V	I mpp	511 A
Total Arrays global power	Nominal (STC)	**1002 kWp**	Total	3580 modules
	Module area	**6869 m²**	Cell area	6274 m²
Array#1 : Inverter	Model	**PVS800-57-0630kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	630 kW AC
Array#2 : Inverter	Model	**PVS800-57-0315kW-B**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	525-825 V	Unit Nom. Power	315 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	45 °C
Wiring Ohmic Loss	Array#1	12 mOhm	Loss Fraction	1.5 % at STC
	Array#2	21 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Array Soiling Losses			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	0.1 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

Grid-Connected System: Simulation parameters (continued)

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

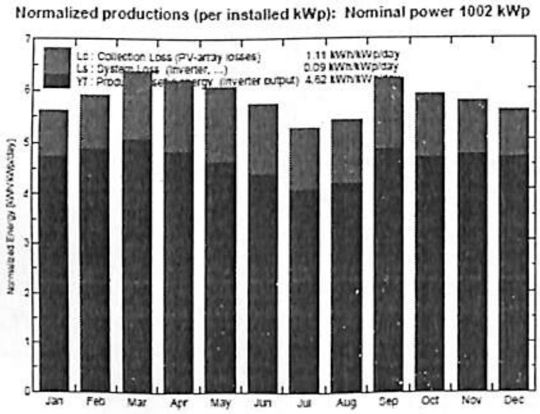
Project : **1 MW Grid Connected Solar Power Project**

Simulation variant : **New simulation variant**

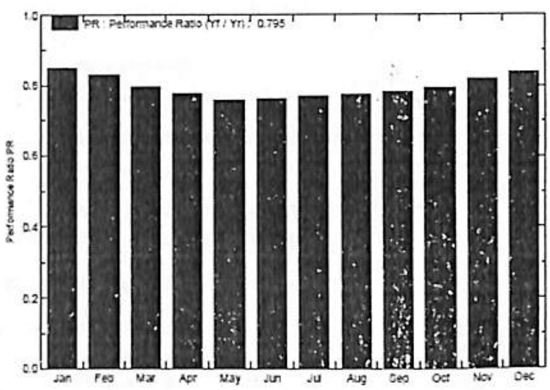
Main system parameters System type **Grid-Connected**
PV Field Orientation Sheds disposition, tilt 27° azimuth 0°
PV modules Model CS6X - 280P Pnom 280 Wp
PV Array Nb. of modules 3580 Pnom total **1002 kWp**
Inverter Model PVS800-57-0630kW-B Pnom 630 kW ac
Inverter Model PVS800-57-0315kW-B Pnom 315 kW ac
Inverter pack Nb. of units 2.0 Pnom total **945 kW ac**
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **1691940 kWh/year** Specific prod. 1688 kWh/kWp/year
Performance Ratio PR 79.5 %

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



New simulation variant
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	124.0	15.38	174.1	168.5	150965	147985	12.62	12.37
February	131.6	19.34	165.7	159.8	140683	137918	12.36	12.11
March	176.5	25.93	197.6	189.9	160846	157798	11.85	11.63
April	185.6	30.53	186.0	177.5	147502	144786	11.54	11.33
May	202.3	35.14	187.8	178.3	145168	142472	11.25	11.05
June	189.9	34.76	171.5	162.2	133250	130712	11.31	11.10
July	175.7	33.44	161.7	152.7	126851	124415	11.42	11.20
August	170.9	32.31	166.2	157.6	131261	128799	11.50	11.28
September	173.3	31.30	185.9	178.1	147759	145015	11.57	11.36
October	152.9	28.29	182.9	176.2	147858	145063	11.77	11.54
November	125.8	22.07	172.5	166.5	144526	141830	12.20	11.97
December	116.6	17.36	172.4	166.5	147999	145148	12.50	12.25
Year	1925.1	27.19	2124.3	2033.7	1724668	1691940	11.82	11.59

Legends:
- GlobHor: Horizontal global irradiation
- T Amb: Ambient Temperature
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- E_Grid: Energy injected into grid
- EffArrR: Effic. Eout array / rough area
- EffSysR: Effic. Eout system / rough area

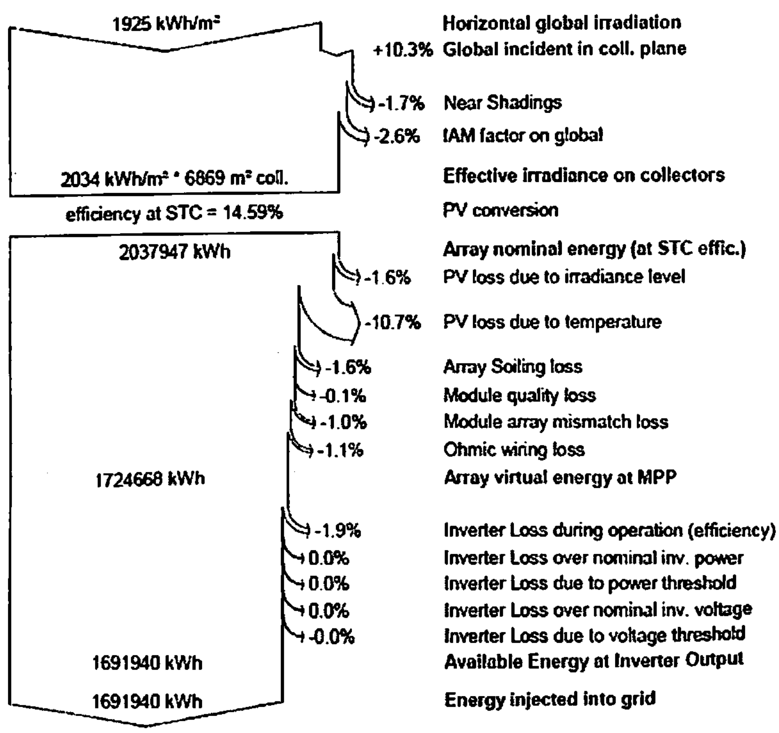
Grid-Connected System: Loss diagram

Project : **1 MW Grid Connected Solar Power Project**

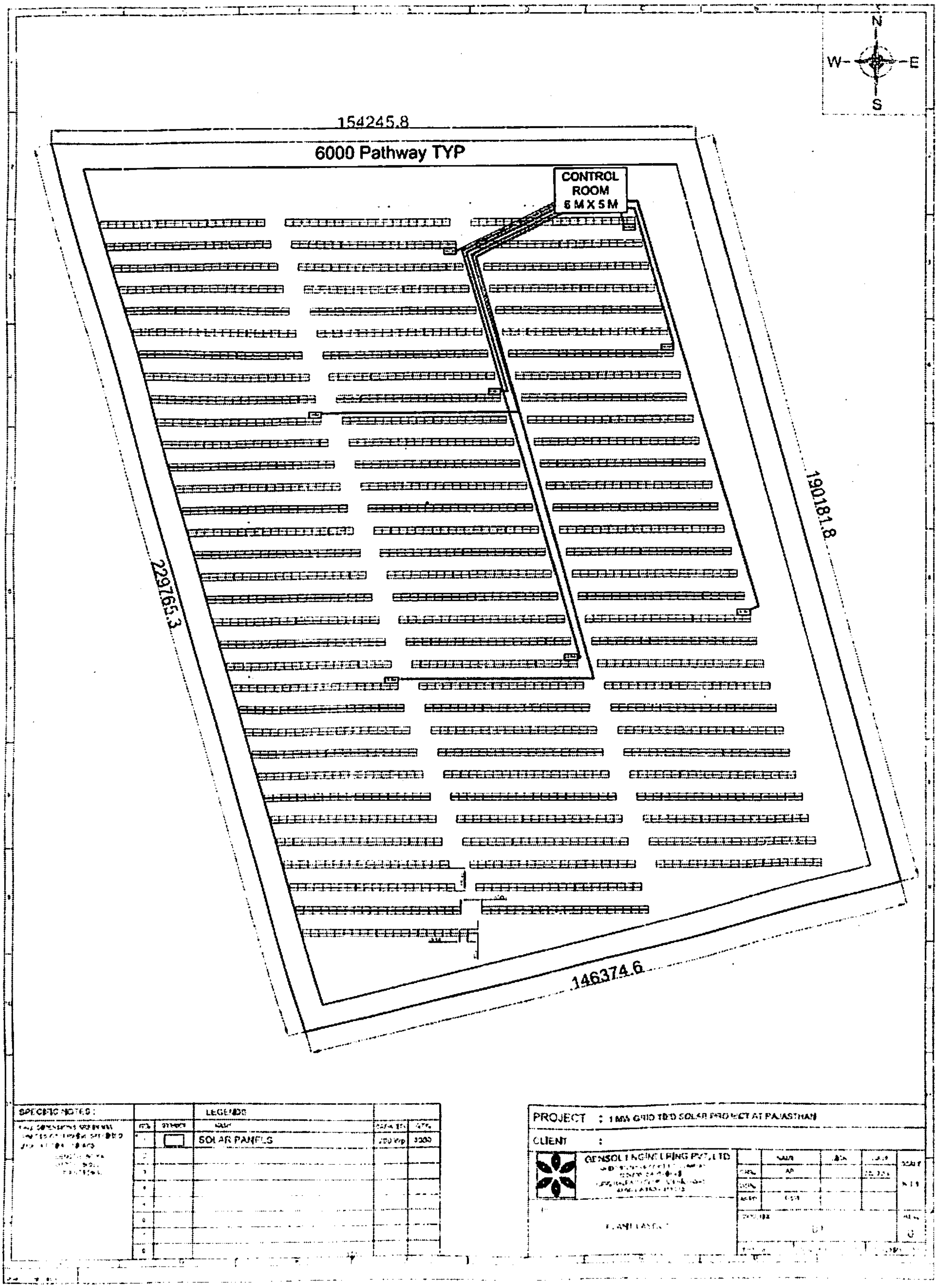
Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	27°	azimuth	0°
PV modules	Model	CS6X - 280P	Pnom	280 Wp
PV Array	Nb. of modules	3580	Pnom total	**1002 kWp**
Inverter	Model	PVS800-57-0630kW-B	Pnom	630 kW ac
Inverter	Model	PVS800-57-0315kW-B	Pnom	315 kW ac
Inverter pack	Nb. of units	2.0	Pnom total	**945 kW ac**
User's needs	Unlimited load (grid)			

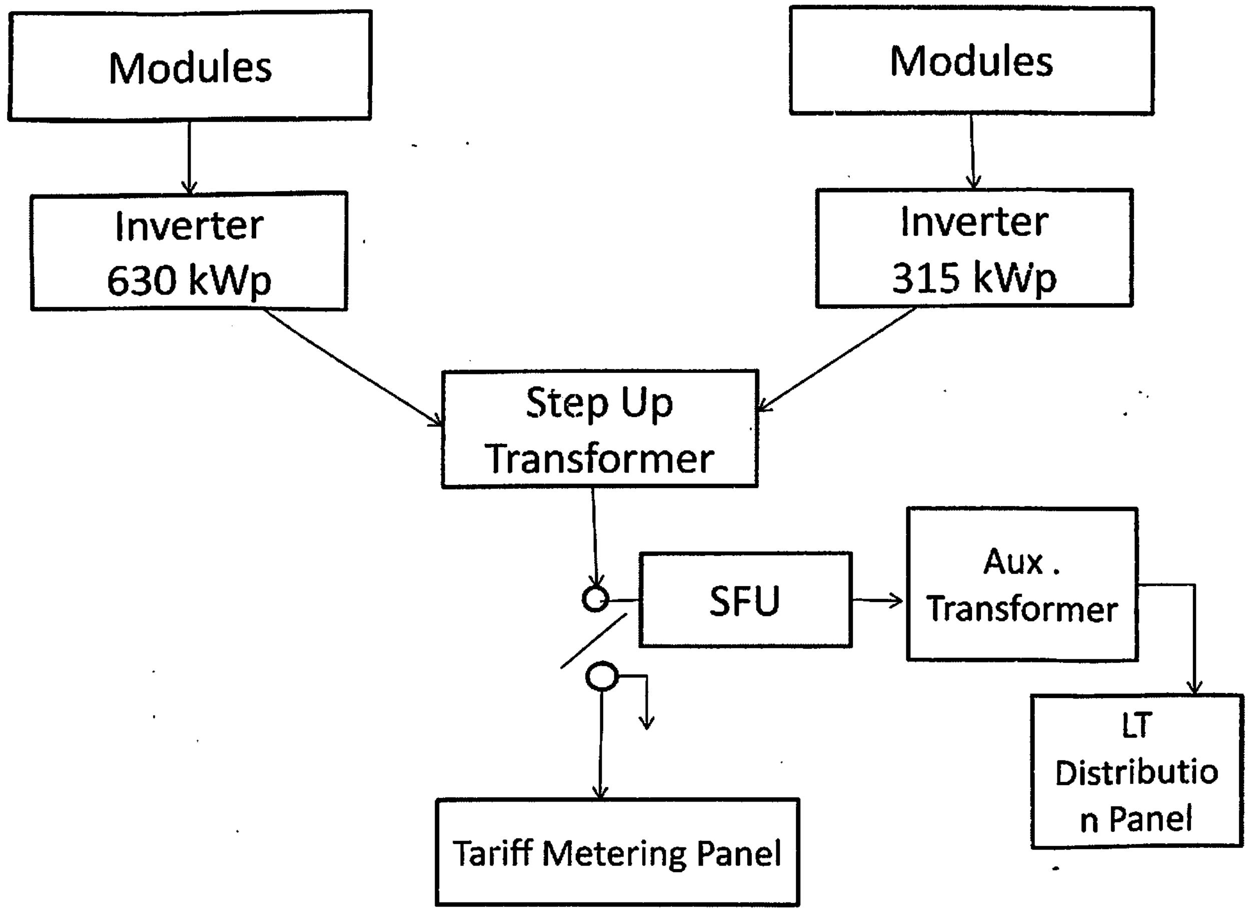
Loss diagram over the whole year

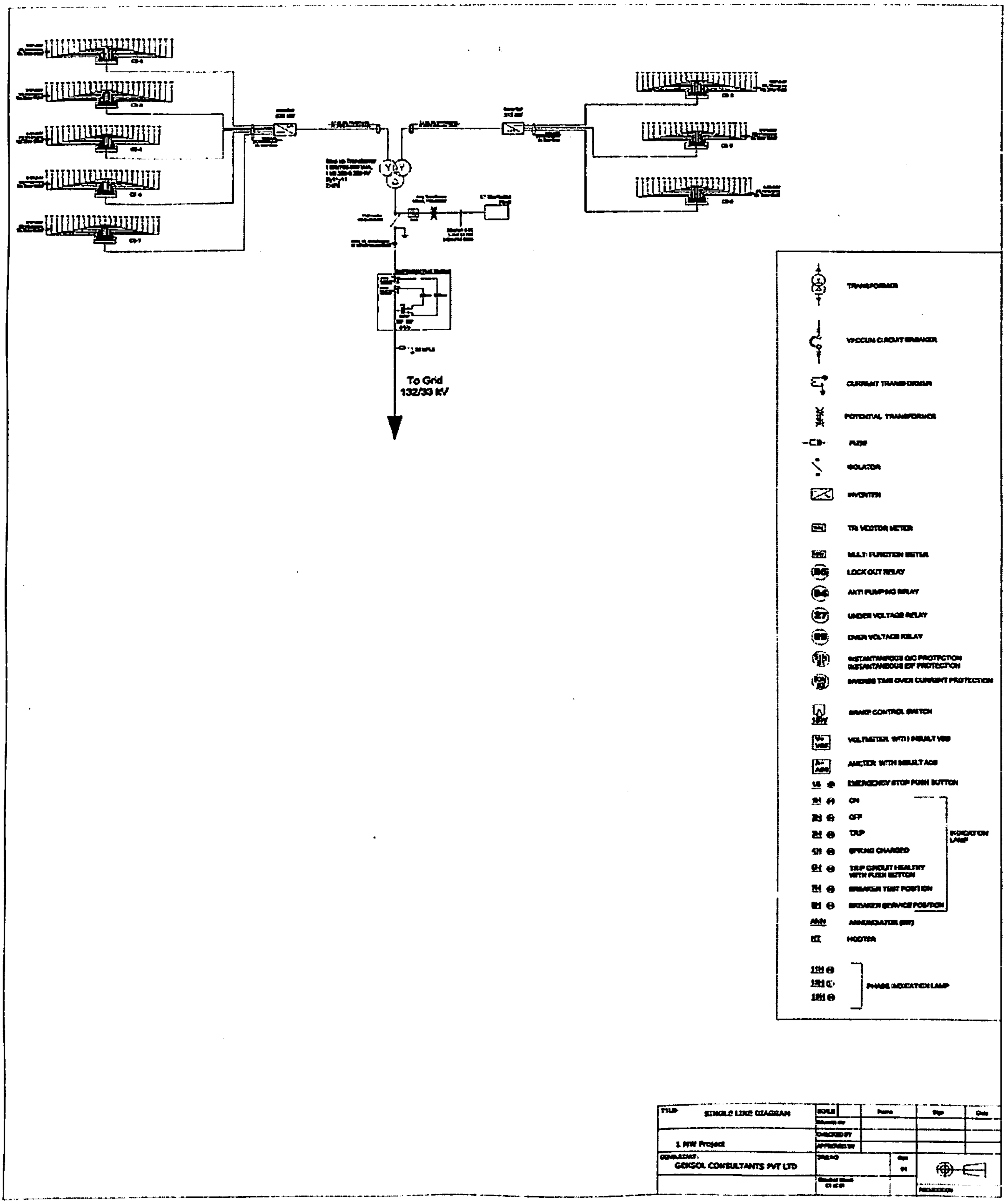


4.13 Plant Layout



4.14 Single Line Diagram of SPV Plant




To Grid
132/33 KV
LOCK OUT RELAY
SINGLE LINE DIAGRAM
1 MW Project
GENSOL CONSULTANTS PVT LTD

5 Results and Discussion

5.1 System Parameters

S.No	Details	Unit	Formula	Value
1	DC Plant Capacity	Wp		1000000
2	Wattage of PV Module	Wp		280
3	Total No of Modules	Nos	(1/2)	3580
4	Number of Modules per String	Nos	Calculated	20
5	No. of Strings	Nos	(3/4)	179
6	No. of Strings per Structure	Nos	Structure Design	2
7	Total Number of Structures	Nos	(5/6)	90
8	Open Circuit Voltage	Volts	PV Module Specification	44.2
9	Short Circuit Current	Amps	PV Module Specification	8.42
10	Number of Inverters	Nos	As per Design	2
11	No. of String Combiner Box (24 Input: 1 Output)	Nos	Calculated	8

Table 14 – System Parameters

5.2 Temperature Effect on Plant Size

S. No	Details	Unit	Value
1	DC Project Size	MW	1
2	No. of Module	No.	3580
3	Module Open Circuit Voltage (Voc)	V	44.2
4	Short Circuit Current	A	8.42
5	Temperature at STC	°C	25
6	Array Global DC Power (STC)	KWp	1002
7	Maximum Ambient Temperature	°C	50
8	Temperature Coefficient for Power (Y)	% /°C	-0.45
9	Array Global DC Power (42°C)	KWp	892
10	Array Global DC Power (0°C)	KWp	1112.4

Table 15 – Temperature Effect on Plant Size

5.3 Selection of the Tilt Angle and Pitch

S No.	Module Arrangement (Collector Width-m)	Pitch (m)	Tilt Angle (°)	Generation (kWh)	PLF of SPV Plant (%)
1	4.10	10.5	27	1691526	19.30
2	2.05	5.5	27	1692613	19.32
3	**2.05**	**5.5**	**24**	**1693051**	**19.32**
4	4.10	8.5	24	1686592	19.25
5	3.07	8	27	1691940	19.31

Table 16 – Tilt Angle and Pitch Selection

Inference:

From the above table, it is observed that Option 2 and 3 are favorable as both the plant PLF is coming out to be 19.32%.

But the Tilt Angle varies i.e. Option 2 has 27 degree and Option 3 has 24 degree.

We choose Option 3; as in this the Shadow Losses will be minimized and more Solar Insolation can be tapped by the modules thereby increasing the efficiency of the Solar Power Plant.

6 Conclusions and Recommendations

The above report concludes:

- ✓ That the Pitch is kept 5.5 m at a Tilt of 24° even when option of a tilt 27 ° was present as the shadow losses were less in the selected option
- ✓ There is a possibility for the change of the inverter sizing if more favorable option is available depending upon the operating voltages and current.
- ✓ There is possibility of Rain water harvesting by making water storage tanks or reservoirs for the various Processes of a Solar Power Plant but after getting the Soil Testing Report,
- ✓ After having the knowledge of the Water Table of the area, the option of Bore well can be thought of.
- ✓ After the Soil Analysis Report, the Load Bearing Capacity of the Structure can be calculated. Generally this value ranges between 10 – 30 Tonne/m^2.
- ✓ The Sizing of the cables can also change as the spacing and placement of the modules can be changed depending upon the Inverter Selection at a later date depending upon the favorable aspects for the power plant.

References

- *Ministry of New and Renewable Energy(MNRE)*
- *Jawaharlal Nehru National Solar Mission(JNNSM)*
- *Central Electricity Authority*
- *Rajasthan Energy Development Agency*
- *Indian Renewable Energy Development Agency*
- *NASA Meteorological Data*
- *Solarthinfilm.com*
- *Clean Technica*
- *Firstsolar.com*
- *Solardirect.com*
- *Powerfilmsolar.com*
- *Energymatters.com*
- *Solarelectricityhandbook.com*
- *Goodreads.com*
- *Books.google.com*
- *Ianmcewan.com*
- *Routeledge.com*