SOLAR PHOTOVOLTAIC POWER PLANT

By

Mr. SUSHIL KUMAR SAHU

500024854

Guided By

Mr. VIPPARTI SRINIVAS

Additional Chief Engineer

M. N. DASTUR & COMPANY (P) LTD.

A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

EXECUTIVE MASTER OF BUSINESS ADMISTRATION POWER MANAGEMENT

OF

UNIVERSITY OF PETROLEUM & ENERGY STUDIES, INDIA

CENTRE FOR CONTINUING EDUCATION

UNIVERSITY OF PETROLEUM & ENERGY STUDIES, DEHRADUN

ACKNOWLEDGEMENT

This is to acknowledge with thanks the help, guidance and support that I have received during the Dissertation.

I have no words to express a deep sense of gratitude to the management of M. N. Dastur & Company (P) Ltd. for giving me an opportunity to pursue my Dissertation, and in particular Mr. Vipparti Srinivas for his able guidance and support.

I must also thank Mr. S. Rama Swamy for his valuable support.

SUSHIL KUMAR SAHU

Brundavan Nagar
Industrial Estate
Berhampur (Gm.) - 760008
Odisha, India

Mobile: +91-8008496403
e-mail: sksahu44@gmail.com

Date: 26/10/2015

Place: Visakhapatnam

DASTUR

DECLARATION BY THE GUIDE

This is to certify that **Mr. Sushil Kumar Sahu**, a student of Executive MBA Power Management, Roll No. 500024854 of UPES has successfully completed this dissertation report on **"SOLAR PHOTOVOLTAIC POWER PLANT"** under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of Executive MBA.

V. Srinivas

V. SRINIVAS
Addl. Chief Engineer

Flat No. 101, Srilakshmi Narasimha Enclave
D.No. 49-38-15/2, Akkayyapalem, Visakhapatnam,A.P.

Mobile: +91-8332877982
e-mail: srinivas.v@dastur.com

Place: Visakhapatnam
Date: 26.10.2015

M. N. Dastur & Company (P) Ltd
Consulting Engineers

VSP Project Office, Block B
Visakhapatnam 530031
Andhra Pradesh, India

T +91 891 251 8395
F +91 891 251 8359
vizag@dastur.com
www.dastur.com

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

Renewable Energy is the energy that is extracted from resources which are continually replenished such as Wind, Rain, Tides, Waves, Solar and Geothermal heat. About 19% of energy across globe is extracted from various sources of renewable energy. Indian government is stressing upon production of energy from Sunlight as Indian government wants to save the mining of natural resources such as coal. Producing Solar energy would be beneficial in the long term. Independent solar power generation systems require optimal design. A energy balance is to be maintained by calculating the amount of radiation and the amount of battery required to maintain the energy for the required number of days. The application of the principle of energy balance can be achieved by getting the best angle square solar cell. It is cycled through the calculated number of Square solar cells. Square Solar cells along with the combination of battery capacity makes a good combination. This combination becomes the basis of economic accounting, to finalize the size of the photovoltaic system.

The aim of this project report is to calculate the approximate design of a 1MW Solar Photovoltaic Power Plant.

Chapter 1 INTRODUCTION

Harnessing of non polluting renewable energy resources to control green house gases is receiving impetus from the government of India. The solar mission, which is part of the National Action Plan on Climate Change has been set up to promote the development and use of solar energy in for power generation and other uses with the ultimate objective of making solar energy competitive with fossil-based energy options. The solar photovoltaic device systems for power generation had been deployed in the various parts in the country for electrification where the grid connectivity is either not feasible or not cost effective as also some times in conjunction with diesel based generating stations in isolated places and communication transmitters at remote locations. With the downward trend in the cost of solar energy and appreciation for the need for development of solar power, solar power projects have recently been implemented. A significant part of the large potential of solar energy in the country could be developed by promoting grid connected solar photovoltaic power systems of varying sizes as per the need and affordability coupled with ensuring adequate return on investment.

Chapter 2 What is Solar PV Technology and Its Application

The applications of solar PV power systems can be split into four main categories: off-grid domestic; off-grid non-domestic; grid-connected distributed; and grid-connected centralised. This dissertation proposal guidebook is focussed on grid-connected centralised applications. The main components of a PV power plant are PV modules, mounting (or tracking) systems, inverters, transformers and the grid connection. Solar PV modules are made up of PV cells, which are most commonly manufactured from silicon but other materials are available. Cells can be based on either wafers (manufactured by cutting wafers from a solid ingot block of material) or "thin film" deposition of material over low cost substrates. In general, silicon-based crystalline wafers provide high efficiency solar cells but are relatively costly to manufacture, whereas thin film cells provide a cheaper alternative but are less efficient. Since different types of PV modules have different characteristics (in terms of efficiency, cost, performance in low irradiation levels, degradation rate), no single type is preferable for all projects. In general, good quality PV modules are expected to have a useful life of 25 to 30 years, although their performance will steadily degrade over this period. The PV module market is dominated by a few large manufacturers based predominantly in Europe, North America and China. Selecting the correct module is of fundamental importance to a PV project, keeping in mind the numerous internationally accepted standards. When assessing the quality of a module for any specific project, it is important to assess its specifications, certifications and performance record besides the track record of the manufacturer. PV modules must be mounted on a structure. This helps to keep them oriented in the correct direction and provides them with structural support and protection. Mounting structures may be either fixed or tracking. Since fixed tilt mounting systems are simpler, cheaper and have lower maintenance requirements than tracking systems, they are the preferred option for countries with a nascent solar market and with limited indigenous manufacturers of tracking technology (such as India). Although tracking systems are more expensive and more complex, they can be cost-effective in locations with a high proportion of direct irradiation. PV modules are generally connected together in series to produce strings of modules of a higher voltage. These strings may then be connected together in parallel to produce a higher current DC input to the inverters.

Inverters are solid state electronic devices that convert DC electricity generated by the PV modules into AC electricity, suitable for supply to the grid. In addition, inverters can also perform a range of functions to maximise the output of a PV plant.

In general, there are two main classes of inverters: central inverters and string inverters. Central inverters are connected to a number of parallel strings of modules. String inverters are connected to one or more series strings. While numerous string inverters are required for a large plant, individual inverters are smaller and more easily maintained than a central inverter. While central inverters remain the configuration of choice for most utility-scale PV projects, both configurations have their pros and cons. Central inverters offer high reliability and ease of installation. String inverters, on the other hand, are cheaper to manufacture, simpler to maintain and can give enhanced power plant performance on some sites.

The efficiency of proposed inverters should be carefully considered during the development process. While there is no universally accepted method for quantifying inverter efficiency, there are a number of established methods that can help in making an informed decision. Almost half of the inverter market is dominated by SMA Solar Technology AG, which has a higher market share than the combined share of the next four largest vendors. A key parameter is the Performance ratio (Pr) of a PV power plant, which quantifies the overall effect of losses on the rated output. The Pr, usually expressed as a percentage, can be used to compare PV systems independent of size and solar resource. A Pr varying from approximately 77% in summer to 82% in winter (with an annual average Prof 80%) would not be unusual for a well-designed solar PV installation or plant, depending on the ambient conditions.

It is also important to consider the capacity factor of a PV power plant. This factor (usually expressed as a percentage) is the ratio of the actual output over a period of a year to theoretical output if the plant had operated at nominal power for the entire year. The capacity factor of a fixed tilt PV plant in southern Spain will typically be in the region of 16%. Plants in India operating within a reliable grid network are expected to have a similar capacity factor. This apart, the "specific yield" (the total annual energy generated per kWp installed) is often used to help determine the financial value of a plant and compare operating results from different technologies and systems.

Reliable solar resource data are essential for the development of a solar PV project. While these data at a site can be defined in different ways, the Global Horizontal Irradiation (the total solar energy received on a unit area of horizontal surface) is generally of most interest to developers. In particular, a high long term average annual GHI is desired. There are two main sources of solar resource data: satellite derived data and land-based measurement. Since both sources have particular merits, the choice will depend on the specific site. Land based site measurement can be used to calibrate resource data from other sources (satellites or meteorological stations) in order to improve accuracy and certainty. As solar resource is inherently intermittent, an understanding of inter-annual variability is important. At least 10 years of data are usually required to give the variation to a reasonable degree of confidence.

In India, solar resource data are available from various sources. These include the Indian Meteorological department, NASA's Surface Meteorology and Solar Energy data set, METEONORM's global climatologically database, and satellite derived geospatial solar data products from the United States national renewable Energy Laboratory. These sources are of varying quality and resolution.

Chapter 4 Project Development & Its Different Phases

The development of a PV project can be broken down into the following phases: conceptual, pre-feasibility study, feasibility study, development and design. In general, each succeeding phase entails an increased level of expenditure but reduces the risk and uncertainty in the project. In practice, the progression through these phases is not strictly linear. The amount of time and money committed in each phase will vary, depending on the priorities and risk appetite of the developer.

A typical scope for a feasibility study would include the items below

- Production of a detailed site plan.
- Calculation of solar resource and environmental characteristics.
- Assessment of shading (horizon and nearby buildings and objects).
- Outline layout of areas suitable for PV development.
- Assessment of technology options providing cost/benefit for the project location:
- Module type.
- Mounting system.
- Outline system design.
- Application for outline planning permission.
- Grid connection – more detailed assessment of likelihood, cost and timing.
- Predicted energy yields.
- Financial modelling

I. Development Phase

The development phase takes the project from the feasibility stage through to financial close and is likely to consist of:

- Preparation and submission of the permit applications for the proposed solar PV project.
- Preparation and submission of a grid connection application.
- Revision of the design and planning permissions.
- Decision on contracting strategy (turnkey EPC contract or multi- contract).
- Decision on the financing approach.
- Preparation of solar PV module

II. Tender Documentation

- Supplier selection and ranking.
- Preparation of construction tender documentation.
- Contractor selection and ranking.
- Contract negotiations.
- Completion of a bankable energy yield.
- Preparation of a financial model covering the full life cycle of the plant.
- Completion of a project risk analysis.
- Environmental impact assessment.
- Production of a detailed project report.
- Securing financing for the project.

III. Design Phase

- The design phase will prepare the necessary detail and documentation to enable the tendering and construction of the solar PV plant.

IV. Site Selection

- Selecting a suitable site is a crucial part of developing a viable solar PV project. In selecting a site, the aim is to maximise output and minimise cost. The main constraints that need to be assessed include:
- Solar resource – Global Horizontal Irradiation, annual and inter-annual variation, impact of shading.
- Local climate – flooding, high winds, snow and extreme temperatures.
- Available area – area required for different module technologies, access requirements, pitch angle and minimising inter-row shading.
- Land use – this will impact land cost and environmental sensitivity. The impact of other land users on the site should also be considered.
- Topography – flat or slightly south facing slopes are preferable for projects in the northern hemisphere.

- Geotechnical – including consideration of groundwater, resistivity, load bearing properties, soil pH levels and seismic risk.
- Geopolitical – sensitive military zones should be avoided.
- Accessibility – proximity to existing roads, extent of new roads required.
- Grid connection – cost, timescales, capacity, proximity and availability.
- Module soiling – including local weather, environmental, human and wildlife factors.
- Water availability – a reliable supply is required for module cleaning.
- Financial incentives – tariffs and other incentives vary between countries and regions within countries.

V. Energy Yield Prediction

The energy yield prediction provides the basis for calculating project revenue. The aim is to predict the average annual energy output for the lifetime of the proposed power plant (along with the confidence levels). The level of accuracy required will depend on the stage of development of the project. To estimate accurately the energy produced from a PV power plant, information is needed on the solar resource and temperature conditions of the site. Also required are the layout and technical specifications of the plant components. To make life easy for project developers, a number of solar energy yield prediction software packages are available in the market. These packages use time step simulation to model the performance of a project over the course of a year. To ensure more accurate results that would satisfy a financial institution's due diligence and make the project bankable, the analysis should be carried out by a qualified expert. Realistic allowance should be made for undermining factors such as air pollution, grid downtime and electrical losses.

Annual energy yields may be expressed within a given confidence interval (for example, the P90 annual energy yield prediction means the energy yield value with a 90% probability of exceedance). Since the energy yield simulation software is heavily dependent on the input variables, any uncertainty in the resource data gets translated into uncertainty in the yield prediction results. As the energy yield depends linearly, to a first approximation, on the plane of array irradiance it is the uncertainty in the resource data that dominates the uncertainty in the yield prediction.

VI. Plant Design

The design of a PV plant involves a series of compromises aimed at achieving the lowest possible levelised cost of electricity. Choosing the correct technology (especially modules and inverters) is of central importance. Selecting a module requires assessment of a complex range of variables. At the very least, this assessment would include cost, power output, benefits / drawbacks of technology type, quality, spectral response, performance in low light, nominal power tolerance levels, degradation rate and warranty terms.

The factors to consider when selecting inverters include compatibility with module technology, compliance with grid code and other applicable regulations, inverter-based layout, reliability, system availability, serviceability, modularity, telemetry requirements, inverter locations, quality and cost.

In designing the site layout, the following aspects are important:

- Choosing row spacing to reduce inter-row shading and associated shading losses.
- Choosing the layout to minimise cable runs and associated electrical losses.
- Allowing sufficient distance between rows to allow access for maintenance purposes.
- Choosing a tilt angle that optimises the annual energy yield according to the latitude of the site and the annual distribution of solar resource.
- Orientating the modules to face a direction that yields the maximum annual revenue from power production. In the northern hemisphere, this will usually be true south

The electrical design of a PV project can be split into the DC and AC systems. The DC system comprises the following:

- Array(s) of PV modules.
- Inverters.
- DC cabling (module, string and main cable).
- DC connectors (plugs and sockets).
- Junction boxes/combiners.
- Disconnects/Switches.
- Protection devices.
- Earthing.

The AC system includes:

- AC cabling.
- Switchgear.
- Transformers.
- Substation.
- Earthing and surge protection.

Every aspect of both the DC and AC electrical systems should be scrutinised and optimised. The potential economic gains from such an analysis are much larger than the cost of carrying it out. In order to achieve a high performance PV plant, the incorporation of automatic data acquisition and monitoring technology is essential. This allows the yield of the plant to be monitored and compared with calculations made from solar irradiation data to raise warnings on a daily basis if there is a shortfall. Faults can then be detected and rectified before they have an appreciable effect on production.

In addition, power plants typically need to provide 24-hour forecasts (in half hourly time steps) to the network operator. These forecasts help network operators to ensure continuity of supply. Selection of suitable technology and optimisation of the main electrical systems is clearly vital. Alongside, detailed consideration should be given to the surrounding infrastructure, including the mounting structures, control building, access roads and site security systems. While these systems should be relatively straightforward to design and construct, errors in these systems can have a disproportionate impact on the project.

VII. Permits and Licensing

Permit and licensing requirements vary, depending on the location of the project but the key permits, licences and agreements typically required for renewable energy projects include:

- Land lease contract.
- Environmental impact assessment.
- Buildings permit/planning consent.
- Grid connection contract.
- Power purchase agreement.

The authorities, statutory bodies and stakeholders that should be consulted also vary from state to state but will usually include the following organisation types:

- Local and/or regional planning authority.
- Environmental agencies/departments (Central Government Department).
- Archaeological agencies/departments.
- Civil aviation authorities (if located near an airport).
- Local communities.
- Health and safety agencies/departments.
- Electricity utilities.
- Military authorities.

Early engagement with all relevant authorities is highly advisable to minimise risk and maximise the chances of successful and timely implementation of the project.

VIII. Construction

The management of the construction phase of a solar PV project should be in accordance with construction management best practice. The aim should be to construct the project to the required level of quality within the time and cost deadlines. during construction, the environmental impact of the project as well as the health and safety issues of the workforce (and other affected people) should also be carefully managed.

The IFC Performance Standards give detailed guidance on these issues. Compliance with these standards can facilitate the financing of a project. Typical issues that arise during the construction of a PV project include:

- Foundations not being suited to ground conditions.
- Discovery of hazardous / contaminated substances during excavation.
- Incorrect orientation of modules.
- Insufficient cross-bracing on mounting structures.
- Incorrect use of torque wrenches.
- Damaging cables during construction / installation delayed grid connection.
- Access / construction constrained by weather.
- Insufficient clearance between rows for vehicle access.

While some of these issues appear minor, rectification of the problems they cause can be expensive. While close supervision of contractors during construction is important, using the services of a suitably experienced engineer should be considered if the required expertise is not available in-house.

IX. Commissioning

Commissioning should prove three main criteria:

- The power plant is structurally and electrically safe.
- The power plant is sufficiently robust (structurally and electrically) to operate for the specified project lifetime.
- The power plant operates as designed and performs as expected.

Commissioning tests are normally split into three groups:

- Visual acceptance tests. These tests take place before any systems are energised and consist of a detailed visual inspection of all significant aspects of the plant.
- Pre-connection acceptance tests. These include an open circuit voltage test and short circuit current test. These tests must take place before grid connection.
- Post-connection acceptance test. Once the plant is connected to the grid, a DC current test should be carried out. Thereafter, the performance ratio of the plant is measured and compared with the value stated in the contract. An availability test, usually over a period of 5 days, should also be carried out

X. Operation and Maintenance

Compared to most other power generating technologies, PV plants have low maintenance and servicing requirements. However, suitable maintenance of a PV plant is essential to optimise energy yield and maximise the life of the system.

Maintenance consists of:

- Scheduled or preventative maintenance – planned in advance and aimed to prevent faults from occurring, as well as to keep the plant operating at its optimum level.
- Unscheduled maintenance – carried out in response to failures. Scheduled maintenance typically includes:

- Module cleaning.
- Checking module connection integrity.
- Checking junction / string combiner boxes.
- Thermo graphic detection of faults.
- Inverter servicing.
- Inspecting mechanical integrity of
- Mounting structures.
- Vegetation control.
- Routine balance of plant servicing / inspection.
- Common unscheduled maintenance requirements include:
- Tightening cable connections that have loosened.
- Replacing blown fuses.
- Repairing lightning damage.
- Repairing equipment damaged by intruders or during module cleaning.
- Rectifying supervisory control and data acquisition (SCADA) faults.
- Repairing mounting structure faults.
- Rectifying tracking system faults.

Careful consideration should be given to selecting an operation and maintenance (O&M) contractor and drafting the O&M contract to ensure that the performance of the plant is optimised. After the project is commissioned, it is normal for the EPC contractor to guarantee the performance ratio and the O&M contractor to confirm the availability and, ideally, the performance ratio.

I. Economics and Financial Modelling

The development of solar PV projects can bring a range of economic costs and benefits at the local and national levels. Economic benefits can include:

- Job creation.
- Use of barren land.
- Avoidance of carbon dioxide emissions.
- Increased energy security.
- Reduction of dependence on imports.
- Increased tax revenue.

An awareness of the possible economic benefits and costs will aid developers and investors in making the case for developing solar energy projects to local communities and government bodies. India's Central Electricity regulatory Commission (CERC) has produced a benchmark capital cost of INR 169 million/MWp for solar PV power projects commissioned during fiscal years 2010/11 and 2011/12. The CERC benchmark ✓ also gives a breakdown of the various cost elements that can be used by developers for planning or comparison purposes. The financial benefits and drawbacks to the developer should be explored in detail through the development of a full financial model. This model should include the following inputs:

i. ***Capital costs*** – these should be broken down as far as possible. Initially, the CERC assumption can be used but quoted prices should be included when possible.

ii. ***Operations and maintenance costs*** – in addition to the predicted O&M contract price, operational expenditure will include comprehensive insurance, administration costs, salaries and labour wages.

iii. ***Annual energy yield*** – as accurate an estimate as is available at the time.

iv. ***Energy price*** – this can be fixed or variable and will depend on the location of the project as well as the tariff under which it has been developed.

v. ***Certified Emission Reductions*** – under the Clean Development Mechanism, qualifying Indian solar projects may generate Certified Emission reductions, which can then be sold. However, this revenue is difficult to predict.

vi. ***Financing assumptions*** – including proportion of debt and equity, interest rates and debt terms.

vii. ***Sensitivity analysis*** – sensitivity of the energy price to changes in the various input parameters should be assessed.

II. Financing PV Projects

Solar PV projects are generally financed on a project finance basis. As such, the equity partners and project finance partners typically conduct an evaluation of the project covering the legal aspects, permits, contracts (EPC and O&M), and specific technical issues prior to achieving financial closure. The project evaluations (due diligence) identify the risks and methods of mitigating them prior to investment. There are typically three main due diligence evaluations:

- Legal due diligence – assessing the permits and contracts (EPC and O&M).
- Insurance due diligence – assessing the adequacy of the insurance policies and gaps in cover.
- Technical due diligence – assessing technical aspects of the permits and contracts.

These include:

- Sizing of the PV plant.
- Layout of the PV modules, mounting and/or trackers, and inverters.
- Electrical design layout and sizing.
- Technology review of major components (modules/inverters/mounting or trackers).
- Energy yield assessments.
- Contract assessments (EPC, O&M, grid connection, power purchase and Feed-in Tariff (FIT) regulations).
- Financial model assumptions

According to the International Energy Agency's factsheet "Renewables in Global Energy Supply", the solar energy sector has grown by 32 % per annum since 1971. Solar applications can be broadly divided into grid connected applications and off grid applications. Worldwide, grid-connected solar PV continued to be the fastest growing power generation technology. It can be seen from the graph that worldwide, solar energy is being primarily used for grid connected generation and not merely for off-grid or rural energy applications.

India, due to its geo-physical location, receives solar energy equivalent to nearly 5,000 trillion kWh/year, which is equivalent to 600 GW. This is far more than the total energy consumption of the country today. But India produces a very negligible amount of solar energy - a mere 0.2 percent compared to other energy resources. Further, entire electricity generation is using Solar Photovoltaic (SPV) technology as power generation using solar thermal technology is still in the experimental stages. Currently, India has less than 3 MW of grid connected solar PV capacity.

While India receives solar radiation of 5 to 7 kWh/m2 for 300 to 330 days in a year, power generation potential using solar PV technology is estimated to be around 20MW/sq. km and using solar thermal generation is estimated to be around 35MW/sq. km

I. Policy Initiatives

Announcement of Generation based incentive (GBI) scheme for grid connected Solar Power Projects by Ministry of New and Renewable Energy and emphasis of National Action Plan on Climate Change (NAPCC) for increasing share of Solar Energy have provided impetus to the Solar Power market in India. National Solar Mission forming part of National Action Plan on Climate Change has envisaged significant increase in share of Solar Energy in total energy mix. The NAPCC aims to promote the development and use of Solar Energy for power generation and other uses with the ultimate objective of making solar competitive with fossil-based energy options. The plan includes:

- Specific goals for increasing use of solar energy in all urban areas, industries, and commercial establishments;
- A goal of increasing production of photovoltaic to 1000 MW/year; and
- A goal of deploying at least 1000 MW of solar thermal power generation.

Other objectives include the establishment of a solar research centre, increased international collaboration on technology development, strengthening of domestic manufacturing capacity, and increased government funding and international support.

II. Approaches for Development of Norms for Solar Power

In view of above developments, many developers have expressed keen interest in developing power plant based on solar energy. In order to encourage and facilitate expeditious development of gird connected solar based power generation, it is critical that regulatory clarity and certainty exists for solar power projects which are at nascent stage of development. Development of suitable norms for tariff determination would ensure conducive regulatory framework much needed for growth of solar based power generation in the country. However, development of such norms is challenging task in view of diverse range of technological options, complexities of project specific requirements and limited operational experience in the country.

III. Solar Photovoltaic Power Projects

i. Technology Aspect

Norms for Solar Photovoltaic (PV) power under these Regulations shall be applicable for grid connected PV systems that directly convert solar energy into electricity and are based on the technologies such as crystalline silicon or thin film as may be approved by MNRE.

ii. Norm for Capital Cost

In order to derive norm for capital cost for projects utilising solar photo voltaic technology the capital cost data from sources such as detailed project reports submitted to State Electricity Regulatory Commission, State Nodal Agencies and the tariff order announced by the various State Electricity Regulatory Commission for determination of tariff for Solar PV power plants has been analysed. Also, few internationally recognised literatures on the Solar Project development have been taken into consideration. Its has been observed that the capital cost for projects utilising same technology vary significantly from one project to another within a State.

It is recognised that capital cost of the Solar PV power project shall be greatly influenced by the cost of PV modules, balance of plant and power conditioning system costs, taxes and duties, inter-connection costs etc. whereas the performance of the PV project shall depend upon the insulation, ambient conditions, conversion efficiencies etc. Based on the submissions made by various project developers as part of detailed project report or petitions filed before SERCs, it is evident that the capital cost and capacity utilisation factor has varied over wide range. However, there exists a positive co-relation between capital cost and capacity utilisation factor over this range. Further, it is envisaged that with worldwide proliferation of the solar PV based installations, the economies of scale would ensure that the capital cost for Solar PV installations would decrease over the period.

IV. Capacity Utilisation Factor

For a Solar Photovoltaic (SPV) project, Capacity Utilisation Factor (CUF) is the ratio of actual energy generated by SPV project over the year to the equivalent energy output at its rated capacity over the yearly period. The energy generation for SPV project depends on solar radiation, measured in Wh/sq m/day and number of clear sunny days. The output of Solar Cell is measured in terms of Wp (Watt Peak) and refers to nominal power under Standard Test Conditions (STC) (1000 W/m2, 250C, .5AM).

According to the Solar Radiation Handbook (2008), published by Solar Energy Centre, MNRE the daily average global radiation incident over India is in the range of 4.3 kWh/Sq m to 5.8 kWh/Sq m.

Also, it is noted that around 290 to 320 clear sunny days are prevalent across most parts of India throughout the year. Hence, considering an average clear sunny days around 300 and daily average global solar radiation to be around 5.8 kWh/Sq m/day, project developers have proposed estimate of the capacity utilisation factors for various projects under consideration. The proposed capacity utilisation factors for various Solar PV based power project installations has varied from 15% to 25 % based on SPV (thin film or crystalline) and in one case up to 35% based on concentrated PV (CPV). Accordingly, the normative Capacity Utilisation factor of 19% has been proposed in case of grid connected Solar PV based power projects. In case a developer wishes to seek ‘project specific tariff’ for Solar PV power project, an enabling provision has been incorporated under the Draft Regulations to enable Commission to deviate from above mentioned norm upon filing of petition by such project developer for ‘project specific tariff’ determination in accordance with Regulation 7 and 8 of the Regulations along with relevant supporting information such as detailed project report, technical and operational details of the projects, site specific considerations, premise for capital cost assumption and proposed financing plan for the Project

V. Operation and Maintenance

There is very limited operating experience of MW scale solar PV Grid connected power plant till date in India. It is observed that none of the State Electricity Regulatory Commission has specified break up of operating expenses which comprises of employee expenses, A&G expenses, and maintenance expenses. The information available about few projects and assumptions contained in the Orders in few States indicate that O&M cost for Solar PV installations varies in the range of 0.2% to 0.8% of capital cost. In view of the limited availability of data a normative O&M expense of 0.5% of the capital cost, which amounts to Rs 9 Lakh/MW has been considered during the first year of operation which will be escalated at a rate of 5.72% per annum over tariff period.

Fig. A- Potential for Solar Power in India

I. Economic Benefits and Costs

As well as providing commercial benefits to renewable energy project developers, solar PV projects confer any economic advantages to local and national economic growth. Economic benefits and costs should be considered by policy makers, developers, investors and lenders to ensure that individual profitable projects develop within a framework of sustainable development. Lenders often require compliance with social and environmental standards. Multilateral agencies such as the IFC may have their own Social and Environmental Performance Standards. Other lenders may require compliance to standards as outlined in the Equator Principles before agreeing to finance a project. Government bodies may aim to mitigate the adverse impact of developments through permitting requirements. The Government of India has implemented an array of policies to enhance the growth of the solar market and support the National Action Plan for Climate Change (NAPCC). The major economic benefits and drawbacks for large scale solar PV projects are outlined in the following sections.

II. Local Economic Benefits and Costs

In general, a solar project is likely to usher in economic benefits for the local area. But the level of benefit may be region-specific, and may vary across the country. An awareness of these local economic benefits will help developers and investors in pushing solar projects as a development tool for local communities and government agencies. Local economic benefits may typically include the following:

1. Generation of direct and indirect employment.
2. Infrastructure developments such as roads, water and electricity.
3. Development of barren, unproductive or contaminated land.
4. Grid network upgrades providing power supply security.
5. Less polluting power generation.

However, these benefits must be weighed against:

- Resource impacts. Many projects are likely to be constructed in areas with a scarcity of water and electricity. So the use of these resources during construction and operation of the plant may have an impact on the local economy. Careful sitting and design of the projects should minimise this potential impact.
- Demand management. In urban India, peak demand normally occurs in the evening. Shortage of supply and inability to manage demand results in power cuts, which have a negative impact on the local economy and quality of life. While solar power is only generated during the day, there is no facility for trimming peak demand during the evening. Solar power development should, therefore, be part of a wider strategic plan to manage demand and supply.

III. National Economic Benefits and Costs

There are a number of national or macroeconomic benefits which are likely to accrue from the development of solar power generation within India. An awareness of these benefits will aid developers and investors when pitching the case for solar development to policy makers. National economic benefits may typically include the following:

- Increased energy security arising from diversification from coal-fired generation.
- Long term energy price pressures mitigated due to diversification of generation mix and technology development. The cost of installing solar power generation is currently more expensive than coal-fired generation in India. This gap would be expected to reduce as the solar market matures and coal prices rise. Energy price stability can lead to a wide range of social and economic benefits. These include improved global competitiveness of domestically produced goods and services, inflation reduction and social cohesion.
- Reduced dependence on imports resulting from long term solar project development targets and man datesset by the National Solar Mission for consumption of domestically produced project components.
- Technology development, which leads to are deployment of human resources from primary industrial activities to higher value-creating secondary industries.
- Climate change mitigation, in line with the NAPCC.
- Reduction in pollution externalities such as health and environmental consequences.
- Increased tax revenue.

These benefits must be weighed against the cost of upgrades to major transmission lines. Grid upgrades are likely if significant levels of solar power are installed in areas with a weak transmission network. Budget diversions may also be significant as higher government budget allocations for solar projects may divert resources from low income groups. Engagement of the developer with the local community (by supporting local employment, for example) would be one way to work out a mutually agreeable solution.

i. Benefits to Developers

Investment in solar projects offers a number of economic benefits to potential developers, the most important of which are outlined below:

- ***Preferential tariff and guaranteed returns*** – Solar projects in India receive a FIT for 25 years.
- ***Concessional duties and tax breaks*** – The Government of India has announced a concessional customs duty of 5% on imports, with an exemption on excise duty for some project components.
- ***Meeting the renewable energy obligation*** – Utilities and independent conventional power producers have been mandated by the State Electricity Regulatory Commissions (SERC) to purchase renewable energy under the Renewable Purchase Obligation (RPO). At present, the proportion of renewable energy to be purchased varies from 3% to 5% of the total generation across various SERCs. This is likely to increase to 15% by 2020.
- ***Renewable Energy Certificate (REC)*** – RECs are market-based instruments which give the developer the option to either sell power produced at the state specific average power pooled cost, or alternatively to trade RECs separately.
- ***Certified Emission Reduction (CER) Revenue*** - Improvement in corporate image– Investment in solar power projects allows developers to demonstrate their commitment to environmental concerns.
- ***Business diversification*** – Development of expertise and technical skills within the developer organisation, allowing diversification of income generation streams and access to a large emerging market.

ii. Cost Benchmarks By Central Electricity Regulatory Commission (CERC)

a. Capital Cost

In order to determine the level of the feed-in tariff, the Central Electricity Regulatory Commission (CERC) has produced a benchmark capital cost of INR 169 million/MWp for solar PV power projects commissioned during fiscal years 2010-11 and 2011-12. This capital cost is considered to be a reference cost in India as no large utility scale projects have yet been commissioned. Figure B.below gives the percentage breakdown of cost for a typical 1MWp size project. These costs are discussed in more detail in Table 15. It should be noted that the various elements of the capital cost will vary depending on the technology selected and other project specific parameters; as an example, while the CERC benchmark costs show modules accounting for approximately 60% of the overall capital cost, it is not unusual to see module costs ranging from 50% to 60% of the overall cost.

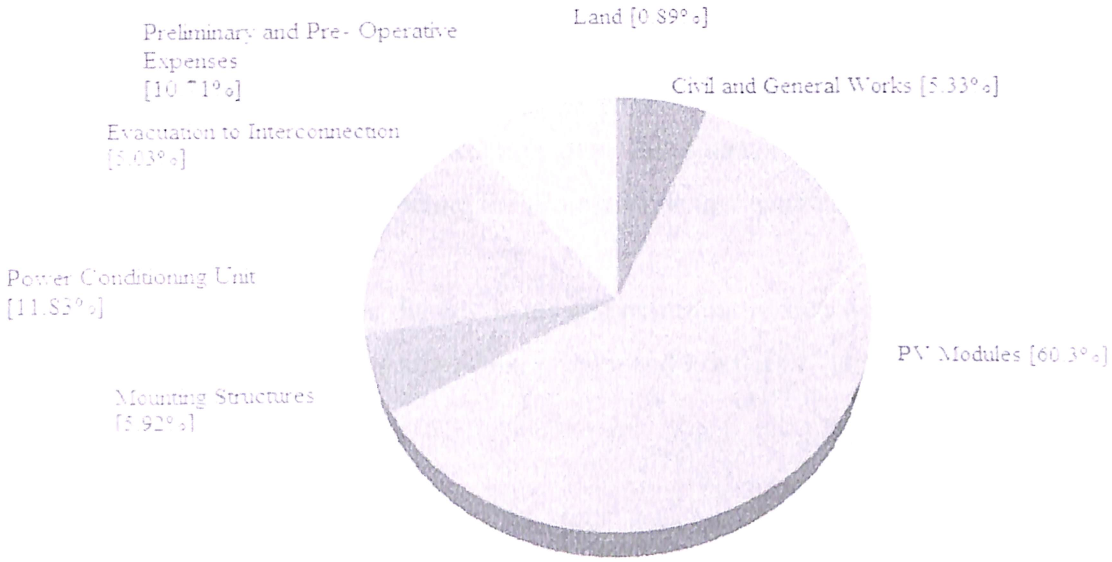

Fig. B Benchmark Solar PV Plant Cost Breakdown according to CERC

b. Tariff Structure

For projects commissioned in past years 2010-11 and 2011-12, the tariff has been structured (assuming a useful life of 25 years) at a levelised rate of INR 17.91/kWh. This tariff takes into account a reasonable return of equity, interest on loan capital, depreciation factor, interest on working capital and O&M costs.

c. Operations and Maintenance

O&M expenses comprising extended warranties, repairs, routine maintenance, employee and administrative costs have been assumed to be INR 0.951 million/MWp for projects commissioned in fiscal year 2010–11. There shall be an annual escalation of 5.72% over the tariff period. A more detailed discussion of the O&M costs associated with solar PV is provided in Sections below

IV. Financial Model

i. Introduction

It is clear from the discussion in the previous section that many of the economic benefits and costs of solar PV project development do not accrue directly to the developer Instead, these act as "externalities", which stem from investment choices made largely on the basis of financial benefits and drawbacks. The financial benefits and drawbacks to the developer are explored in detail through the construction of a full financial model. This facilitates the identification of key variables affecting the project value and enables financing decisions.

The following sections describe the key items and assumptions that would be included in the financial modelling of a typical Indian solar project and briefed in Table 7.1.

ii. Capital Costs

According to a CERC report, capital cost per MWp for solar PV plant in India is expected to vary between INR 150 million to INR 170 million. This total capital cost includes the cost of land, PV modules, mounting structure, inverters, balance of plant and support infrastructure, and start-up costs. The cost variation largely depends on the project location, the project design (such as the voltage level of power cables), the technology utilised and the grid connection cost. In addition to overall project cost, there can be significant variation in component costs depending on the type of PV technology used. A project with crystalline PV technology requires less surface area per kWp installed compared to thin film modules. As a result, the mounting structure and DC cabling costs are lower. However, there is not significant variation in the other cost components.

iii. Operations And Maintenance (O&M) Cost

O&M costs for solar PV are significantly lower than other renewable energy technologies. O&M costs depend on many factors, including the project location and the surrounding environment. For example, a site located in a dusty environment is likely to require frequent cleaning of modules. It is difficult to predict the O&M cost over the latter part of the 25 year design life as there are very few large scale solar projects that have been generating for sufficient time to have reached the end of their design life. The modules, which typically comprise over 60% of the total project cost, are generally supplied with performance guarantees for 25 years. However, other project components require routine maintenance and component replacement. Aside from O&M, operational expenditure will include comprehensive insurance, administration costs, salaries and labour wages.

iv. Annual Energy Yield

There are a number of factors which affect the annual energy yield of a solar PV. The confidence level of the yield forecast is important, as the annual energy yield directly affects the annual revenue.

v. Energy Price

Besides the power generated, the solar PV project revenue is dependent upon the power price. This may be fixed or variable according to the time of day or year, and must be clearly stipulated in the power purchase agreement.

Economic return has historically been the key limiting factor for development of large scale grid-connected solar PV projects. PV has a high initial capital cost. High energy prices are required for projects to be economic. Currently, grid-connected solar projects are highly dependent on policy support initiatives such as grants, feed-in tariffs, concessional project funding and mandatory purchase obligations.

In India, the power tariffs for solar PV projects are determined by the Ministry of New and Renewable Energy (MNRE). Incentive policies include the generation-based incentives (GBI) and the recently created Jawaharlal Nehru National Solar Mission (JNNSM).

Under these regulatory regimes and incentive schemes, there are five main tariff options for the sale of the renewable power that is generated:

i. Demonstration scheme GBI – tariffs aimed at supporting pilot projects.
ii. JNNSM scheme – tariffs to encourage both large and small scale projects.
iii. CERCs Levelised Tariff – generalised countrywide tariff.
iv. State Government Incentives – localised tariffs
v. Selling electricity and trading RECs separately. Under the GBI scheme, the project developer signs a PPA with the relevant state utility grid operator for a period of 10years, whereas under the JNNSM scheme, PPAs will be signed for 25 years.

Table- 7.1

Benchmark Costs		
Cost item	**Cost (INR million/ MWp)**	**Details**
Land	1.5	It is assumed that 5 acres/MW is required, at a cost of INR 0.3 million/ acre, although this estimate will vary according to the technology chosen.
PV Modules	101.9	Although in practice there is a cost difference between crystalline and thin film PV modules, the cost assumed for both of these technologies is US$ 2.2/Wp. An exchange rate of INR 46.33/US$ is assumed.
Mounting Structure	10.0	The cost assumed for the mounting structure is INR 10 million/MWp irrespective of the type of technology.
Power conditioning unit/inverters	20.0	The cost assumed for the power conditioning unit/inverters, including the required controls and instrumentation, is INR 20 million/MWp
Evacuation to grid connection	8.5	This cost includes supply, erection and commissioning of all cabling, transformers and evacuation infrastructure up to the grid connection point.
Preliminary and Operating expenses	18.1	This cost includes services related to design, project management, insurance and interest during construction, among others. Though it is expected to vary with project size, the cost assumed for generic tariff determination is INR 18.1 million/MWp.
Civil and general Works	9.0	This includes general infrastructure development, application for permits and approvals, and preparation of project reports
Total	**169.0**	

Under the GBI scheme, the project developer signs a PPA with the relevant state utility grid operator for a period of 10 years, whereas under the JNNSM scheme, PPAs will be signed for 25 years.

CERC has ruled that projects commissioned in financial year 2010-2011 and 2011-2012 shall have a tariff term of 25years. This term has been fixed on the basis of a reasonable deemed internal rate of return (IRR). Equity is assumed to comprise 20% of project cost, with a rate of return of 19%for the first 10 years of operation, and 24% for the rest of a plant's useful life.

Under the JNNSM scheme, large scale solar projects with an installed capacity of 5MWp and above connected to the grid at 33kV and above will sign a PPA with NVVN. This, in turn, shall bundle the power with conventional power and sell it to various utilities through the RPO. For projects with an installed capacity of less than 5MWp, connecting to the grid at less than 33kV, the project developer will sign a PPA with the state utilities.

Trading of RECs must be conducted through power exchanges within the price-range set by CERC. This range is subject to variation. Given the variability of the price of RECs, this policy involves a higher level of risk for developers than fixed rate tariffs. However, it has potential for better revenue than some of the other options.

All projects should carefully assess the current tariffs available to them to capitalise on the best rate. It is advisable to reassess the rate at any stage when the tariffs vary or new options (for which the plant would be eligible) become available.

vi. Certified Emission Reductions (CERs)

As India is a non-Annex 1 party under the UN Clean Development Mechanism (CDM), qualifying Indian solar projects could generate Certified Emission Reductions (CERs). These CERs can then be sold to Annex 1 parties and help them comply with their emission reduction targets. This effectively causes transference of wealth from Annex 1 parties such as the UK and Germany to Indian developers. Each CER is equivalent to the prevention of one tonne of carbon dioxide emissions. The income from CERs can be substantial. However, this revenue source cannot be predicted as it is uncertain whether the project will be accredited. Moreover, CER values fluctuate considerably. Therefore, sensitivity analysis around the CER price (and the period of time for which the project is accredited) is important. The National CDM Authority under the Ministry of Environment and Forests (MoEF) is the designated authority in India for approving CDM projects.

vii. Financing Assumptions

The project financing structure generally comprises of debt and equity. The general financial assumptions for a project in India are as follows:

- Financing structure – equity 20% and debt 80% as assumed in CERC tariff order.
- Debt repayment period – 10 years.

The aim of this project report is to estimate and calculate the approximate design of a 1MW solar PV power plant (utility scale). The total no. of solar panel required and the different parameters of the solar panel estimated. A site in West Bengal is taken virtually to estimate the solar intensity of the site which is most important for calculation of such type of report. A Single Line Diagram (SLD) has been introduced in this report. Also the brief details of the materials/equipments (solar panels, inverters, protective gears, transformer, SCADA etc.) used to set up a 1MW power plant have been highlighted. A financial overview with a possible income datasheet included in the project report

I. Aim of the Project

Aim of this paper is to give an overview of a 1MW solar PV power plant (utility scale).

II. How the project will work?

1. Using solar PV modules, solar power generates in DC which is converted into AC power and then using a power transformer the generated and modified AC power will be fed to the grid.
2. No battery storage introduced here because the plants will only functions in the daylight and here the generated power will be sold to the grid. For the minimal operation and maintenance of the plant, an off-grid/stand alone 5KW solar power can be introduced.

The benefits and the installation cost details are highlighted in the next article.

Table 8.1

Installation Cost	
Solar panels 1. German tech. 2. China tech.	 5.93 crore 4.10 crore
Central inverters(4)	1.00 crore
Combiner + junction boxes	30.0 lacs
Protective gears arrangement	10.0 lacs
SCADA & Data logger system	10.0 lacs
Land bank	5.00 lacs (approx.)
Erection of project	10.0 lacs
Total project cost i. For German Tech. ii. For China Tech	 7.58 crore 5.75 crore

Table 8.2

Maintenance Cost	
Human resource	20 lacs/ year
PV maintenance	1 lacs/ year
Site maintenance	1 lacs/ year
Total maintenance	22 lacs/ year

III. Income from the 1 MW Solar PV plant

- The site chosen in West Bengal where daily sun hours=5 hrs throughout the year.
- Maximum Solar intensity on the site= 6.18 KW-h/m2/day. Total sunny days available in west Bengal = 255 days

Table 8.3

Income from Plant	
Daily units generated	5000 units
Yearly units generated	5000x365=1,825,000 units
Govt. pays per unit (i.e. state electricity board's power purchase rate)	12.5 Rs./ unit (according to WBREDA 2011-12)
Total income over the year	2.28 crore
Net income over the year	2.28-0.22=2.06 crore

IV. Government Subsidiaries

- Central govt. or MNRE dept. will pay 30% of the total project cost or provide low bank loan interest (whichever is less)
- For this project, by taking the 30% govt. subsidy over the installation cost, investment will be:
  - 5.03 Cr. for German PV technology
  - 4.02 Cr for China PV technology

Table 8.4

Price Trends August 2 0 1 2			
Module Type, Origin	€ / Wp	Trend since 2012 - 07	Trend since 2012 - 01
Crystalline Germany	0.88	- 3.3 %	- 17.8 %
Crystalline China	0.61	- 4.7 %	- 22.8 %
Crystalline Japan	0.91	- 2.2 %	- 13.3 %
Thin film dS/CdTe	0.59	- 1.7 %	13.2 %
Thin film a-Si	0.50	-2.0%	-16.7%
Thin film a-Si/μ-Si	0.57	-3.4%	-25.0%

Price Trends July 2 0 1 2			
Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	091	- 2.2 %	- 15.0 %
Crystalline China	0.64	- 3.0 %	- 19.0 %
Crystalline Japan	0.93	- 1.1 %	- 11.4 %
Thin film dS/CdTe	0.6	-0.0 %	-11.8%
Thin film a-Si	0.51	-3.8%	-15.0%
Thin film a-Si/μ-Si	0.59	-4.8%	-22.4%

Price trends June 2 0 1 2			
Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	093	- 3.1 %	- 13.1 %
Crystalline China	0.66	- 4.3 %	- 16.5 %
Crystalline Japan	0.94	- 2.1 %	- 10.5 %
Thin film dS/CdTe	0.6	-1.6 %	-11.8 %
Thin film a-Si	0.53	-3.6%	-11.7 %
Thin film a-Si/μ-Si	0.62	-4.6%	-18.4 %

Price Trends May 2012

Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	096	- 2.9 %	- 13.1 %
Crystalline China	0.69	- 4.1 %	- 16.5 %
Crystalline Japan	0.96	- 2.0 %	- 10.5 %
Thin film dS/CdTe	0.61	-0.0 %	-11.8 %
Thin film a-Si	0.55	-1.8 %	-11.7 %
Thin film a-Si/μ-Si	0.65	-4.4 %	-18.4 %

Price Trends April 2012

Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	0.99	- 2.9 %	- 7.5 %
Crystalline China	0.71	- 4.1 %	- 10.1 %
Crystalline Japan	0.98	- 2.0 %	- 6.7 %
Thin film dS/CdTe	0.61	-0.0 %	-10.3 %
Thin film a-Si	0.56	-1.8 %	-6.7 %
Thin film a-Si/μ-Si	0.68	-4.2 %	-10.5 %

Price Trends March 2012

Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	1.02	- 1.0 %	- 4.7 %
Crystalline China	0.74	- 3.9 %	- 6.3 %
Crystalline Japan	1.00	- 2.0 %	- 4.8 %
Thin film dS/CdTe	0.61	-3.2 %	-10.3 %
Thin film a-Si	0.57	-0.0 %	-5.0 %
Thin film a-Si/μ-Si	0.71	-1.4 %	-6.6 %

Price Trends February 2012

Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	1.03	- 3.7 %	- 39.7 %
Crystalline China	0.77	- 2.5 %	- 47.6 %
Crystalline Japan	1.02	- 2.9 %	- 37.4 %
Thin film dS/CdTe	0.63	-7.4 %	-49.5 %
Thin film a-Si	0.55	-5.0 %	-47.0 %
Thin film a-Si/μ-Si	0.72	-5.3 %	-43.0 %

Price Trends January 2012

Module Type, Origin	€ / Wp	Trend since 2012 - 06	Trend since 2012 - 01
Crystalline Germany	1.07	- 4.5 %	- 37.3 %
Crystalline China	0.79	- 2.5 %	- 46.3 %
Crystalline Japan	1.05	- 4.5 %	- 35.6 %
Thin film dS/CdTe	0.68	-6.8 %	-45.5 %
Thin film a-Si	0.60	-6.3 %	-44.2 %
Thin film a-Si/μ-Si	0.76	-7.3 %	-39.8 %

1 EURO= 69.3609 INR

V. Worksheet for Determining Required Number of Panels

Table 8.5

Worksheet for Number of Panels	
Total capacity of the plant **	1MWp
Avg. sun hrs per day	5
Total power/day	5MWp
Total watt-hrs per day	5x1000x1000 W-h/day
Maximum solar insolation at the site	6.18 KW-h/m2/day
Divide total watt-hrs/day by solar insolation	809061.4887
Multiply this figure by 1.2(to cover system inefficiency) No. of solar panel=Divide this figure by the Wp(here 300Wp) of the chosen solar panel	809061.4887x1.2=970873.7864 3236.3 ~3236**

****For better efficiency and to utilize the inverter and other components better we should consider the no. of solar panel=3240.**

Solar PV arrangement & overall system rating

Table 8.6

Rating of Solar Panel	
Wattp (W)	300Wp
DC Voltage (Vmp(V))	36.72V
DC Current (Imp (A))	8.17A
Open Circuit Voltage (Voc (V))	45.50
Short Circuit Current (Isc (A))	8.65

VI. Setup of Panels as per Requirements

By calculation and the demand of the plant

- The total no. of solar PV panels to be used= 3236

- From 3236 panels, total 3240 panels are considered to generate the required energy-1MW.

Configuration details:

- 3240 panels are divided into 4 groups- each group containing 810 solar panels.
- In each group, 810 panels are further divided into 54 strings
- Each string contains 15 solar panels.

Table 8.7 (Electrical Power Calculations)

Electrical calculation	
Output voltage of each string	36.72x15=550.8 VDC
Output current of each string	8.17 ADC
Output voltage of each group	550.8 VDC
Output current of each group	8.17x54=441.18 ADC

NOTE: In each string, the solar panels are connected in series to increase the voltage. And in each group, the 54 strings are connected in parallel to increase the current.

DC output power calculation	
Output power of each string	550.8x8.17=4.5 KW
Output power of each group	243KW
Output power of 4 groups	972KW

The following table is a datasheet/spec of TITAN M6-72 Polycrystalline has been provided in this report.

Table 8.8

Model No.	265	270	275	280	285	290	295	300	305
ELECTRICAL DATA AT STC									
Maximum Power (Pmax)	265 Wp	270 Wp	275 Wp	280 Wp	285 Wp	290 Wp	295 Wp	300 Wp	305 Wp
Voltage at Maximum Power (Vmpp)	34.33 V	34.75 V	35.04 V	35.18 V	35.63 V	36.12 V	36.51 V	36.72 V	36.97 V
Current at Maximum Power (Impp)	7.72 A	7.77A	7.85 A	7.96 A	8:00 AM	8.03 A	8.08 A	8.17 A	8.25 A
Open Circuit Voltage (Voc)	43.27 V	43.7 V	43.99 V	44.28 V	44.42 V	44.78 V	45 V	45.5 V	45.58 V

Short Circuit Current (Isc)	8.3 A	8.34 A	8.39 A	8.46 A	8.49 A	8.53 A	8.56 A	8.65 A	8.68 A
Panel Efficiency	13.60%	13.80 %	14.10 %	14.30 %	14.60 %	14.90 %	15.10 %	15.40 %	15.60 %
Power Tolerance(Positive)	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
Power Tolerance(Negative)	-2.50%	-2.50 %	-2.50%	-2.50%	-2.50%	-2.50%	-2.50%	-2.50%	-2.50%
Standard Test Conditions (STC): air mass AM 1.5, irradiance 1000W/m2, cell temperature 25°C									
ELECTRICAL DATA AT NOCT									
Temperature	45±1 °C	45±1 °C	45±1 °C	45±1 °C	45±1 °C	45±1 °C	45±1 °C	45±1 °C	45±1 °C
Nominal Operating Cell Temperature (NOCT): 800W/m2, AM 1.5, windspeed 1 m/s,ambient temperature 20°C									
THERMAL RATINGS									
Operating Temperature Range	-40~85 °C								
Temperature Coefficient of Pmax	-0.41 %/°C								
Temperature Coefficient of Voc	-0.32 %/°C								
Temperature Coefficient of Isc	0.04 %/°C								
MAXIMUM RATINGS									
Maximum System Voltage	1000 V								
Series Fuse Rating	15 A								
MATERIAL DATA									
Panel Dimension (H/W/D)	1975x988x50 mm								
Weight	27 kg								
Cell Type	Polycrystalline								
Cell Size	156×156 mm								
Cell Number	72								
Glass Type	Tempered, Low Iron								
Glass Thickness	4 mm								
Junction Box Diodes	3								
Connector Type	MC4								

- CERC benchmarks can be used to make reasonable estimates of project costs at the feasibility stage.
- Costs need to be adjusted according to the specifics of the project, such as the distance to the grid connection point.
- Discrepancies with the CERC benchmarks were due to module cost, electrical connection costs and the total areaof land required for the project.

- Projects developed using EPC contracts are able to reduce the risk of cost overruns.
- Detailed financial models, including sensitivity analysis should be carried out.

VII. Inverter Details & Specification

Type of the Inverter: Central Inverter Considered

Recommended specification

Table 8.9 (Central Inverter Specification)

Input (DC)	
Maximum DC current (Imax (DC)) 600 A Voltage ripple < 3%	300 kWp
DC voltage range, mpp (UDC)	450 to 750 V (- 825 V)
Max input power Maximum DC voltage (Umax (DC))	900 V (1000 V)
Maximum DC current (Imax (DC)) Voltage ripple	600 A
Number of protected DC inputs (parallel)	2 (+/-) / 8

Input (DC)	
Nominal AC output power (PN (AC))	250 kW
Nominal AC current (IN (AC))	485 A
Nominal output voltage (UN (AC))	300 V
Output frequency	50 / 60 Hz
Output frequency	<3%
Power factor compensation (cos€)	Yes
Distribution network type	TN and IT

To meet the above stated criteria

- Central inverter manufactured by ABB is considered.
- PVS800-57-0250kW-A inverter manufactured by ABB considered.
- Total 4 inverters of PVS800-57-0250kW-A type required to generate the 1MWpower.

VIII. The Main Protections and Protective Gears are named here.

DC Side Protection

1. Fuses

- For string protection

- Fuses for array/inverter input protection

2. *Fuse holders*
    - For string protection
    - Panel mount fuse holder
    - In-line fuse holders
    - Array/inverter input protection
    - Dead front fuse covers
3. *Surge protection devices*
4. *DC switch*
    - Load break disconnect switches
    - High power switches
5. *Cooling devices*
    - Air and liquid cooled solutions
6. *Wire management solutions*
    - Finger-safe power distribution blocks
    - Finger-safe comb wiring bar
7. *Ground-fault protection*

AC Side Protection

- Circuit breaker
- Bar contractor
- Insulation monitoring device

For safety purpose and protection of the modules and plant equipments, protective gears from Schneider Electric have been considered for maximum benefits.

IX. Solar SCADA System

Data acquisition system for a solar plant is very important because it is important to monitor the overall system condition including input/output condition, temperature, solar insulation, weather condition, voltage/current fluctuation, output power condition, surge effect, load dispatch etc. So, in this point of view a compact system with well service provider need to be pointed out. ABB provides the monitoring facility/SCADA for solar (PV) power plants and the ABB inverter itself has an in-built SCADA system.

For monitoring and controlling of the overall power system of the plant, ABB SOLAR SCADA system has been suggested.

X. Yield Assessment of the Photovoltaic Power Plant

Table 8.10

Site Info	
Site name	Durgapur, Bardhaman, West Bengal, India
Coordinates	23° 32' 37.84" N, 87° 22' 44.67" E
Elevation a.s.l.	69 m
Slope inclination	1°
Slope azimuth	61° northeast
Annual global in-plane irradiation	1942 kWh/m2
Annual air temperature at 2 m	26.3 °C
PV system info	
Installed power	1000.0 kWp
Type of modules	crystalline silicon (c-Si)
Mounting system	Fixed mounting, free standing 2 angles
Azimuth/inclinations	180° (south) / 48° (winter), 17° (summer)
Inverter Euro eff.	97.50%
DC / AC losses	5.5% / 1.5%
Availability	99.00%
Annual average electricity production	1470.7 MWh
Average performance ratio	75.80%

Location on the map: http://solargis.info/imaps/#loc=23.543845,87.379074&tl=Google:Satellite&z=14

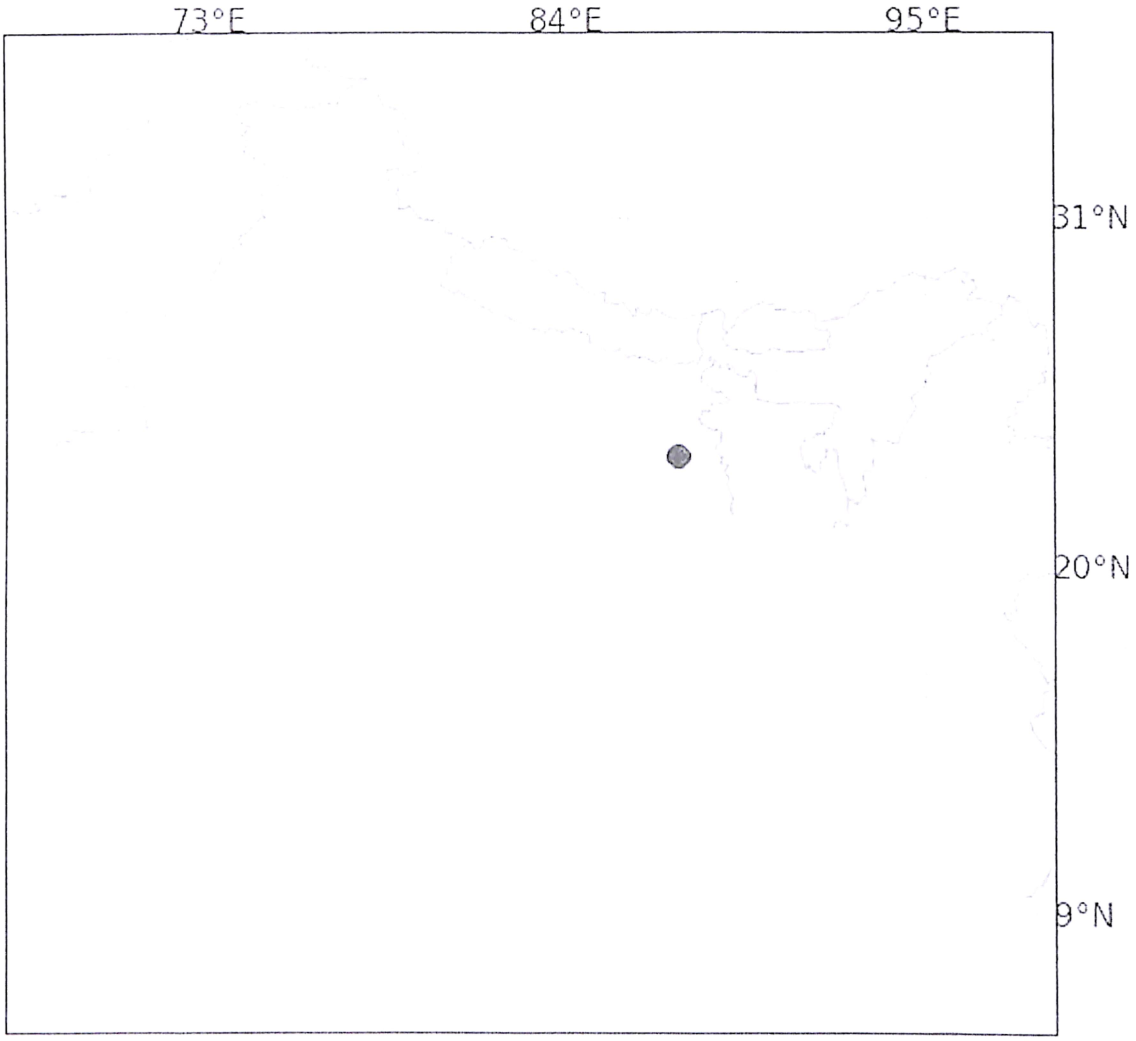

Fig. C-Geographical Position of the Plant

Fig. D- Geographical Position of the Plant using Google Map

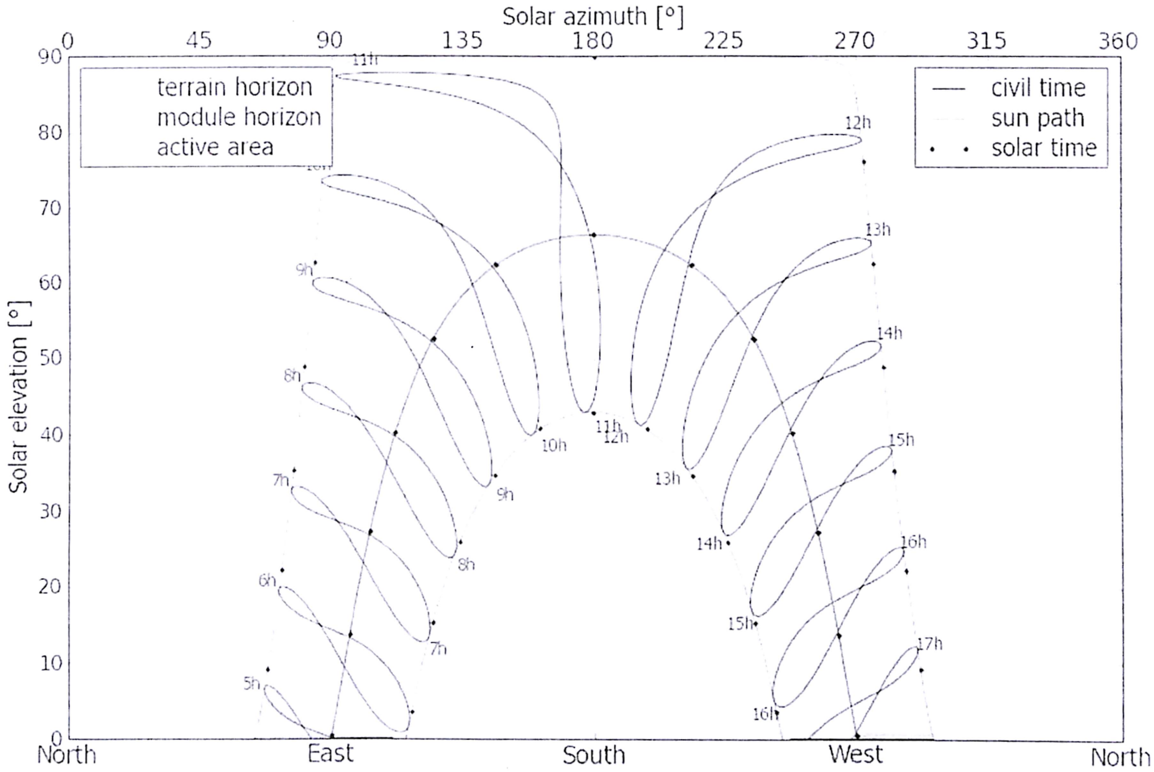

Fig. E- Terrain Horizon and Day Length

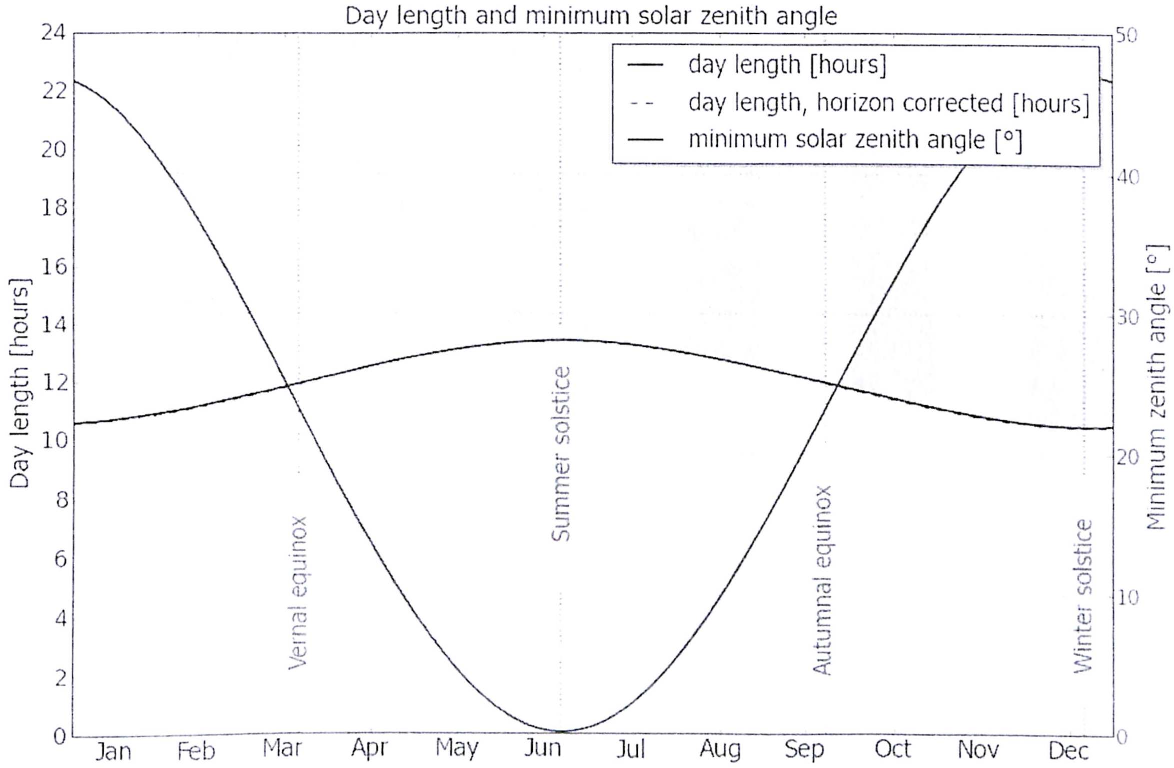

Fig. F- Day Length and Minimum Solar Zenith Angle

XI. Global Horizontal Irradiation and Air Temperature - Climate Reference

Table 8.11

Gh_m	Gh_d	Dh_d	T_{24}
126	4.05	2.1	18.1
139	4.96	2.23	22.1
184	5.93	2.56	27.1
192	6.42	2.93	31.8
190	6.12	3.28	33.7
152	5.08	3.17	32
140	4.51	2.98	29.3
140	4.51	2.92	28.4
132	4.4	2.66	27.4
141	4.56	2.34	25.2
127	4.25	2.13	21.8
119	3.83	2.04	18.7

Gh_m	Monthly sum of global irradiation [kWh/m2]
Gh_d	Daily sum of global irradiation [kWh/m2]
Dh_d	Daily sum of diffuse irradiation [kWh/m2]
T_{24}	Daily (diurnal) air temperature [°C]

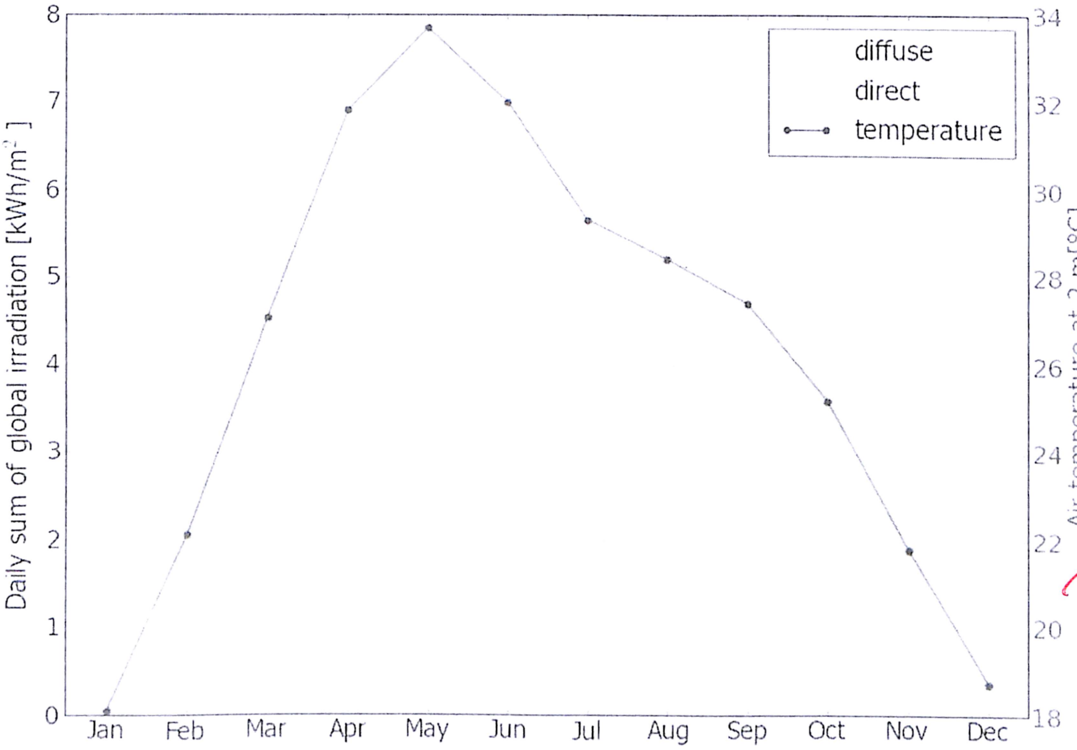

Fig. G- Global Horizontal Irradiation and Air Temperature - Climate Reference

XII. Global In-Plane Irradiation

Fixed surface, azimuth 180° (south), inclination.Winter 48°, Summer 17°

Table 8.12

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
January	166	5.35	2.33	0.08	0.0
February	168	5.99	2.39	0.10	0.0
March	189	6.09	2.51	0.12	0.0
April	196	6.54	2.98	0.02	0.0
May	185	5.96	3.23	0.02	0.0
June	146	4.87	3.08	0.01	0.0
July	135	4.35	2.90	0.01	0.0
August	139	4.48	2.89	0.01	0.0
September	137	4.57	2.71	0.01	0.0
October	157	5.06	2.35	0.09	0.0
November	163	5.44	2.32	0.09	0.0
December	161	5.18	2.28	0.08	0.0
Year	1942	5.32	2.67	0.05	0.0

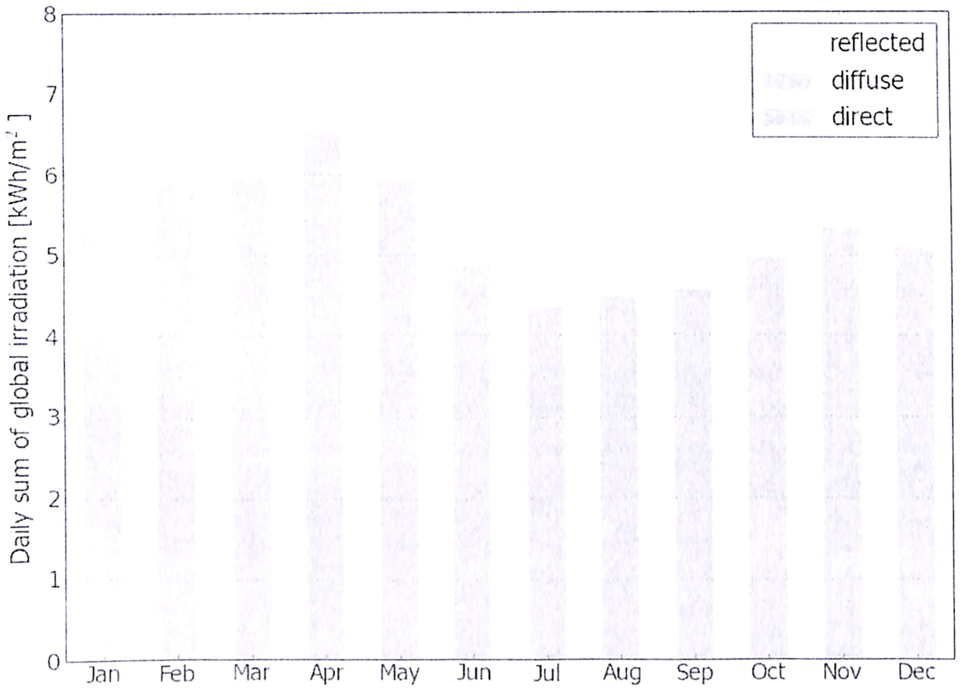

Fig.H- Global In-plane Irradiation

Long-term monthly averages:

G_{im}	Monthly sum of global irradiation [kWh/m2]
Sh_{loss}	Losses of global irradiation by terrain shading [%]
G_{id}	Daily sum of global irradiation [kWh/m2]
D_{id}	Daily sum of diffuse irradiation [kWh/m2]
R_{id}	Daily sum of reflected irradiation [kWh/m2]

Table 8.13

Average yearly sum of global irradiation for different types of surface:

	kWh/m2	Relative to optimally inclined
Horizontal	1782	93.50%
Optimally inclined (24°)	1905	100.00%
2-axis tracking	2256	118.40%
Your option	**1941**	**101.90%**

XIII. PV Electricity Production in the Start-Up

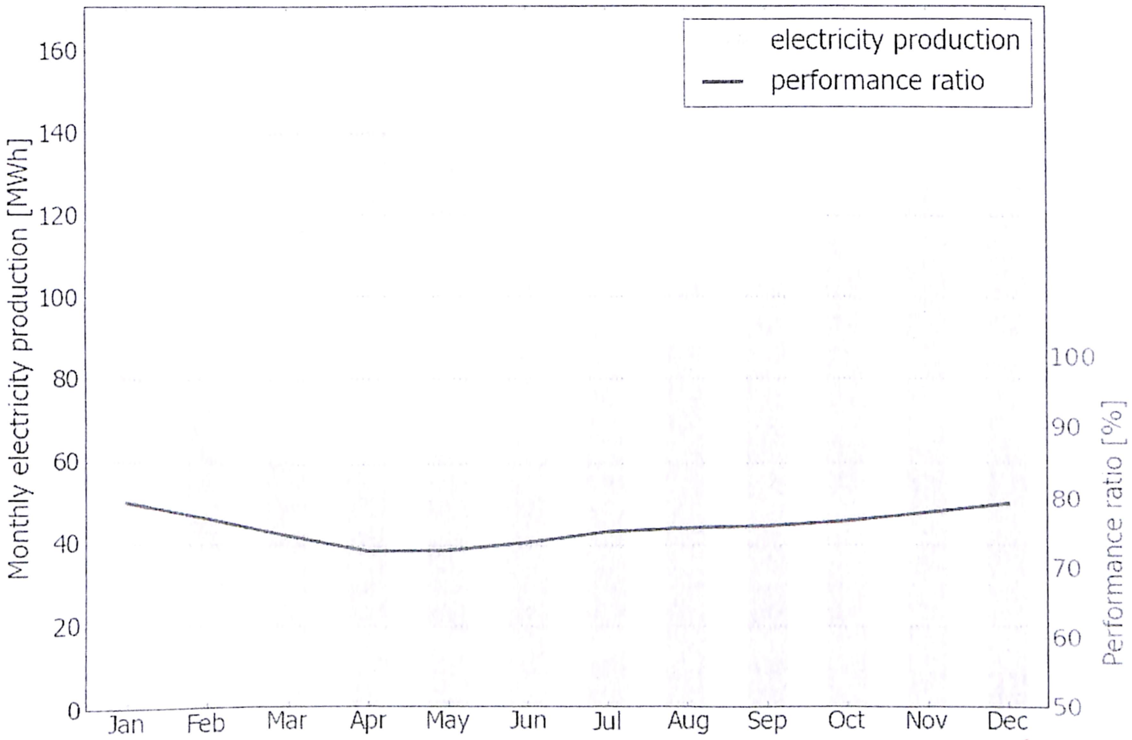

Fig. I- PV Electricity Production in the Start-Up

Table 8.14 **(PV Electricity Production)**

Month	Es_m	Es_d	Et_m	E_{share}	PR
January	131	4.24	131.3	8.9	79.2
February	129	4.61	129.1	8.8	77
March	141	4.55	141	9.6	74.6
April	142	4.74	142.1	9.7	72.5
May	134	4.32	134	9.1	72.6
June	107	3.59	107.7	7.3	73.7
July	101	3.27	101.5	6.9	75.2
August	105	3.39	105.1	7.1	75.7
September	104	3.47	104.1	7.1	76
October	120	3.88	120.3	8.2	76.7
November	127	4.24	127.3	8.7	77.9
December	127	4.1	127.2	8.6	79.2
Year	1470	4.03	1470.7	100	75.8

Long-term monthly averages:	
Esm	Monthly sum of specific electricity prod. [kWh/kWp]
Eshare	Perceptual share of monthly electricity prod. [%]
Esd	Daily sum of specific electricity prod. [kWh/kWp] PR Performance ratio [%]
Etm	Monthly sum of total electricity prod. [MWh]
PR	Performance ratio [%]

XIV. System Losses and Performance Ratio

Table 8.15

	Energy conversion step	**Energy Output [kWh/kWp]**	**Energy loss [kWh/kWp]**	**Energy Loss [%]**	**Performance Ratio [partial %]**	**Performance Ratio [cumul. %]**
1	Global in-plane irradiation (input)	1941	-	-	100	100
2	Global irradiation reduced by terrain shading	1941	0	0	100	100
3	Global irradiation reduced by reflectivity	1886	-55	-2.8	97.2	97.2
4	Conversion to DC in the modules	1637	-249	-13.2	86.8	84.3
5	Other DC losses	1547	-90	-5.5	94.5	79.7
6	Inverters (DC/AC conversion)	1508	-39	-2.5	97.5	77.7
7	Transformer and AC cabling losses	1486	-22	-1.5	98.5	76.6
8	Reduced availability	1471	-15	-1	99	75.8
	Total System Performance	1471	-470	-24.2	-	75.8

Energy conversion steps and losses:

- Initial production at Standard Test Conditions (STC) is assumed.
- Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass).
- Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC.
- DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses.
- due to dirt, snow, icing and soiling, and self-shading of PV modules.
- This step considers euro efficiency to approximate average losses in the inverter.
- Losses in AC section and transformer (where applicable) depend on the system architecture.

- Availability parameter assumes losses due to downtime caused by maintenance or failures.

XV. Solar GIS v1.8 - Description of the Database

Solar GIS is high-resolution climate database operated by Geo Model Solar s.r.o. with geographical extent covering Europe, Africa and Asia. Primary data layers include solar radiation, air temperature and terrain (elevation, horizon).

Air temperature at 2 m: Developed from CFSR data (© NOAA NCEP); years: 1991 - 2009; recalculated to 15-minute values. The data are spatially enhanced to 1 km resolution to reflect variability induced by high resolution terrain.

Solar radiation: Calculated from Meteosat satellite data; years: 1999 - 2011; 30-minute values - global horizontal and direct normal irradiance. This estimation assumes year having 365 days. Occasional deviations in calculations may occur as a result of mathematical rounding and cannot be considered as a defect of algorithms. More information about the applied data and algorithms can be found at:

http://solargis.info/doc/pvplanner/.

XVI. Service Provider

Geo Model Solar s.r.o., MilanaMarečka 3, 84107 Bratislava, Slovakia; Registration ID: 45 354 766, VAT Number: SK2022962766;Registration: Business register, District Court Bratislava I, Section Sro, File 62765/B

XVII. Mode of Use

This report shows solar power estimation in the start-up phase of a PV system. The estimates are accurate enough for small and medium-size PV systems. For large projects planning and financing, more information may be needed:

1. Statistical distribution and uncertainty of solar radiation.
2. Detailed specification of a PV system.
3. Inter annual variability and P90 uncertainty of PV production.
4. Lifetime energy production considering performance degradation of PV components.

BIBILOGRAPHY

I. Internet

- http://www.wbpdcl.co.in/
- http://www.wbreda.org/
- http://www.wbgedcl.in/
- http://en.wikipedia.org/wiki/Solar_power_in_India
- http://seci.gov.in/content/
- http://www.mnre.gov.in/
- http://www.iea.org/publications/freepublications/
- http://www.cercind.gov.in/
- http://www.titan-energy.com
- http://www.abb.com/solarinverters

II. Text Books

- Energy Security and Economic Development in India: a holistic approach By Bala Bhaskar
- Solar Electricity Handbook 2014 By Michael Boxwell
- Solar Photovoltaic Technology and Systems By Chetan Singh Solanki