DESIGN AND FEASIBILITY ANALYSIS OF 30 KW GCPV AND WIND-SOLAR HYBRID SYSTEM

Thesis

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By

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Pantnagar (Naveen Kumar)

July, 2017 **Author**

CERTIFICATE-I

This is to certify that the thesis entitled **"Design and Feasibility Analysis of 30 KW GCPV and Wind-Solar Hybrid System"** submitted in partial fulfilment of the requirements for the degree of **"Master of Technology"** in **ELECTRICAL ENGINEERING** with major in **"Electrical Energy System"** of the College of Post Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Naveen Kumar,** Id. No. **49419,** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

(S. K. Goel)
Chairman
Advisory Committee

Pantnagar
July, 2017

CERTIFICATE-II

We, the undersigned, members of the Advisory Committee of **Mr. Naveen Kumar,** Id. No. **49419,** a candidate for the degree of **Master of Technology** in **Electrical Engineering** with major in **Electrical Energy System,** agree that the thesis entitled **"Design and Feasibility Analysis of 30 KW GCPV and Wind-Solar Hybrid System"**, may be submitted in partial fulfilment of the requirements for the degree.

(S. K. Goel)
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LIST OF ABBREVIATIONS AND SYMBOLS

GCPV	:	Grid Connected Photovoltaic
SPV	:	Solar Photovoltaic
RE	:	Renewable Energy
AC	:	Alternating Current
DC	:	Direct Current
HAWT	:	Horizontal Axis Wind Turbine
VAWT	:	Vertical Axis Wind Turbine
MPPT	:	Maximum Power Point Tracker
STC	:	Standard Test Condition
NOCT	:	Nominal Operating Cell Temperature
CCC	:	Current Carrying Capacity
CAD	:	Computer Aided Design
Alt	:	Altitude
η	:	Efficiency

Introduction

India stands third in the ranking of power generation portfolio worldwide with generation capacity of 330.26 GW. Financial development, expanding richness, developing rate of urbanization and rising per capita energy utilization has increased demand for energy in the nation.

Renewable energy source is turning into a critical component of India's energy planning process. The significance of renewable energy sources in the change to a practical energy is currently recognized globally.

Sustainable power sources get their energy from existing streams of energy from progressing regular procedures, for example, streaming wind, sunshine, streaming water and geothermal warmth streams. A general meaning of renewable energy sources is that renewable energy is captured from an energy asset that is replaced rapidly by a natural process such as power generated from the sun or from the wind. At present the economically most attainable option vitality sources incorporate solar power, wind control, and hydroelectric power.

1.1 Solar Energy

One promising innovation, sun based arranged power merits considering for its supportable, sustainable and outflows diminishing qualities. Current sunlight based power frameworks utilize photovoltaic (PV) to gather the sun's vitality. "Photo" stands for "created by light" and "voltaic" is "power delivered by physical and chemical response".

Photovoltaic cells utilize solar energy to create chemical reaction that tends to electricity generation. Every cell comprises a semiconductor; mostly silicon in one of several structures such as mono-crystalline, poly-crystalline, or thin-layer, impurities as either boron or phosphorus diffused all through, and secured with a silk screen. Cells are associated together by a circuit and casing into a module. Semiconductors permit the electrons liberated from impurities by the sun's beams to move quickly and into the circuit, creating electric power.

Power range of commercial and residential solar modules varies from 10 watts to 300 watts in DC. A PV module must be connected with an inverter to convert the DC power into AC power so that the energy can be consumed, as the user end has appliances connected with ac grid. Photovoltaic modules can also be used all together to create megawatt scale power generating stations.

1.2 Wind Energy

Wind energy standout amongst the most encouraging sustainable power source of the future. All through late years, the measure of energy produced by wind turbines has expanded exponentially because of basic accomplishments in turbine advancements, making wind power economically perfect with ordinary source of energy.

Wind flow is caused by uneven heating of the earth surface by the sun, thus wind can be called as the byproduct of solar energy. Terrain of earth and other factors decide the amount and speed of wind. The kinetic energy of wind is converted into mechanical energy through wind turbines and then into electrical energy through generator. The wind turbines are of basically two types: The vertical axis wind turbine (VAWT) and the horizontal-axis wind turbine (HAWT). The most commonly used configuration is the horizontal-axis wind turbine.

Wind turbines mostly have either two or three blades, called as rotors, which are angled at a pitch to boost the rotation of the rotors.

The rating of utility scale wind turbines ranges from couple of kilowatts to several megawatts. Wind farms are formed in a windy zone by grouping these large wind turbines. It is easier to feed the generated electricity into the power grid by grouping wind turbines in a wind farm.

1.3 India's Energy Strategy

GOI has set an ambitious target of generation of 175 GW of renewable power by 2022, out of which 100 GW of power is to be generated by the means of solar power, 60 GW from wind power, 10 GW from biomass power and 5 GW from small hydro power. The government of India through Ministry of New and Renewable Energy (MNRE) is accepting a proactive part in advancing the determination of renewable energy resources by offering various incentives such as generation-based incentives (GBIs), capital and interest subsidies, viability gap funding (VGF), concessional finance, fiscal incentives etc.

Despite installed capacity exceeding power demand, some parts of the country face acute power shortages. The critical reasons are – coal supply deficiencies, high level of losses in transmission and distribution, and poor financial health of utilities. Further, unlike domestic coal, the cost of imported coal is unregulated its cost can be unpredictable. Imported coal in the recent past has been significantly more expensive than Indian coal. These are the key issues in the power sector which are hampering the economic utilization of the existing power system to even meet the grid-connected demand. Apart from this, more than 400 million individuals in India are still waiting for access to electricity. Extensive load-shedding and low-quality electricity supply strengths people to resort to private, local, expensive and messy arrangements such as diesel generators, which posture both health and environmental concerns. On top of this, estimates suggest that by 2021-22, India's electricity demand will be more than twofold the level in 2011- 12

Up until now, with her ever-growing electricity demand, India has been targeting to add large-scale traditional power capacities, with limited success on meeting these targets. The focus has always been on conventional power generation, as renewable were very costly. Now, however, with solar and wind power becoming commercially viable in comparison to marginal mainstream sources (especially imported coal, and nuclear based generation), there are additional choices accessible to policymakers concerned with the technical, economic, and environmental attributes of a future power system that can keep pace with the financial development.

In the immediate term, the high expenses related with renewables compared to domestic coal based power generation are considered to be obstacle. Due to advancement in technology and mass production resulted in lower installation cost of renewable power plants. Electricity through renewables is less expensive than other traditional energy sources such as gas, diesel, nuclear and also imported coal (in many cases), with the exception of domestic coal. In fact, prices of coal-based power are increasing while real power generation tariffs of renewables are decreasing. PV module costs have fallen 80% since 2008 and by 12% in 2012 alone. Wind turbine costs have fallen 29% since 2008. These falling costs can be attributed to decrease in the costs of system components (e.g., panels, inverters, racking, turbines, etc.), and dramatic improvements in efficiency, among other factors.

Table 1.1 Proposed targets of renewable energy for all states published by MNRE

State/UTs	Solar Power (MW)	Wind (MW)	SHP (MW)	Biomass Power (MW)
Delhi	2,762			
Haryana	4,142		25	209
Himachal Pradesh	776		1,500	
Jammu and Kashmir	1,155		150	
Punjab	4,772		50	244
Rajasthan	5,762	8,600		
Uttar Pradesh	10,697		25	3,499
Uttarakhand	900		700	197
Chandigarh	153			
Northern Region	**31,120**	**8,600**	**2,450**	**4,149**
Goa	358			
Gujarat	8,020	8,800	25	288
Chhattisgarh	1,783		25	
Madhya Pradesh	5,675	6,200	25	118
Maharashtra	11,926	7,600	50	2,469
Daman & Diu	199			
Western Region	**28,410**	**22,600**	**125**	**2,875**
Andhra Pradesh	9,834	8,100		543
Karnataka	5,697	6,200	1,500	1,420
Kerala	1,870		100	
Tamil Nadu	8,884	11,900	75	649
Puducherry	246			
Southern Region	**26,531**	**28,200**	**1,675**	**2,612**
Bihar	2,493		25	244
Jharkhand	1,995		10	
Orissa	2,377			
Sikkim	36		50	
Eastern region	**12,237**		**135**	**244**
Assam	663		25	
Manipur	105			
Meghalaya	161		50	
Nagaland	61		15	
Tripura	105			
Arunachal Pradesh	39		500	
Mizoram	72		25	
North Eastern Region	**1,205**		**615**	
Andaman & Nicobar Islands	27			
Lakshadweep	4			
Other (New States)		600		120
All India	**99,533**	**60,000**	**5,000**	**10,000**

1.4 Upcoming Trends in Renewable Energy Sector

Renewable energy based electricity access through Mini-Grids: The Government of India has also rolled out "Power for All" programme to address India's energy security challenge. This programme seeks to provide round the clock power to each household by 2019. However, the programme appears ambitious when approximately 400 million people do not have access to electricity today. A transition solution could be to provide immediate access to basic electricity needs by renewable energy based tail-end generation with or without the need to create new distribution infrastructure (mini-grids).

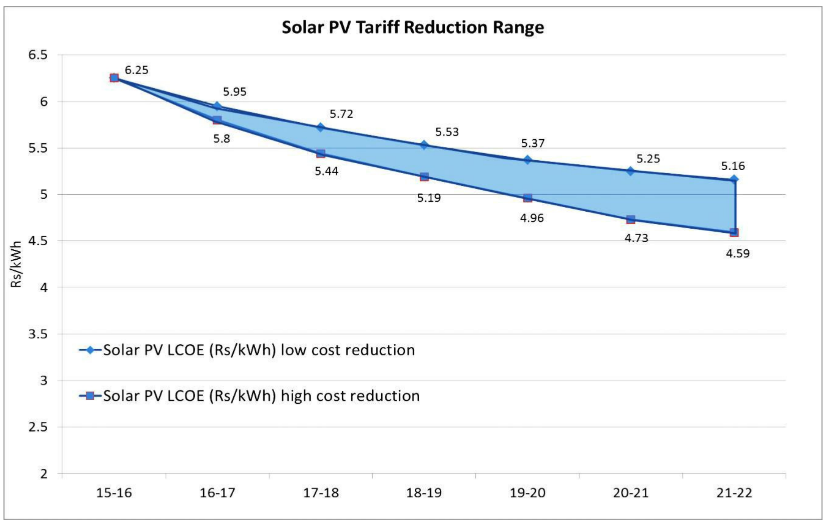


Fig. 1.1 Year wise expected change in solar PV tariffs

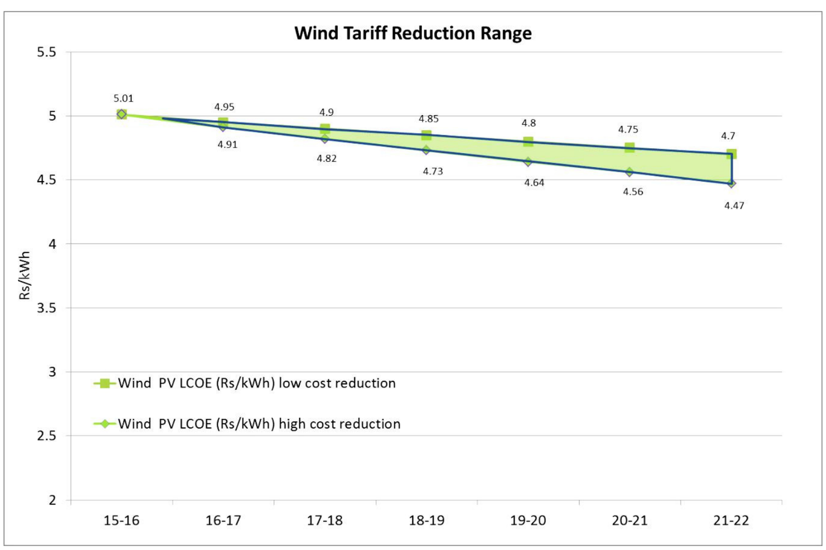


Fig. 1.2 Year wise expected change in wind tariffs

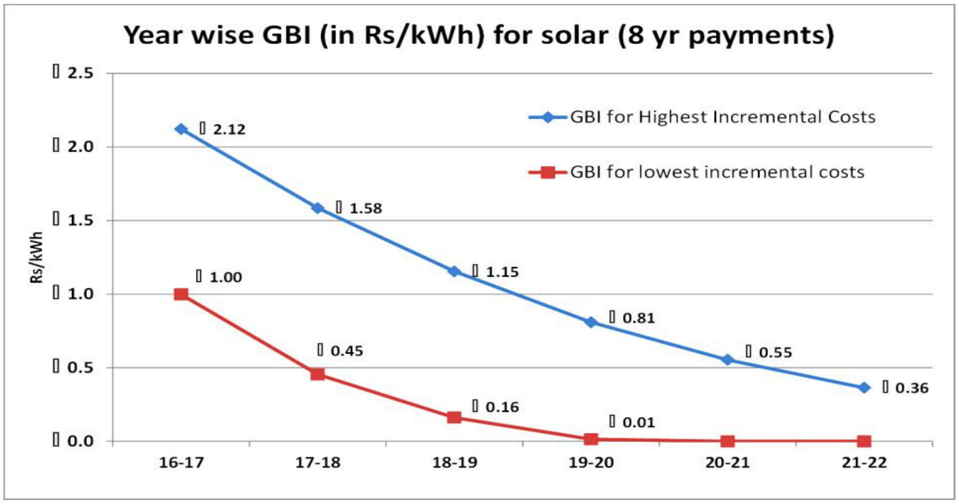


Fig. 1.3 Year wise solar GBI estimates for highest and lowest incremental cost scenarios

If one were to consider the worst case from the point of view of the budgetary exposure to the GOI (highest incremental cost from low coal prices (Rs 4/kWh in 2015-16 escalating at 2% p.a.) and low cost reduction in RE, then the following picture emerges in terms of GBI. Year wise GBI per kWh reduces from Rs 2.12/kWh to 0.36/kWh from 2015-16 to 2021-22 in case of solar PV, while for wind power it starts with Rs 0.81/kWh and practically gets eliminated (Rs 0.05/kWh) in 2021-22.

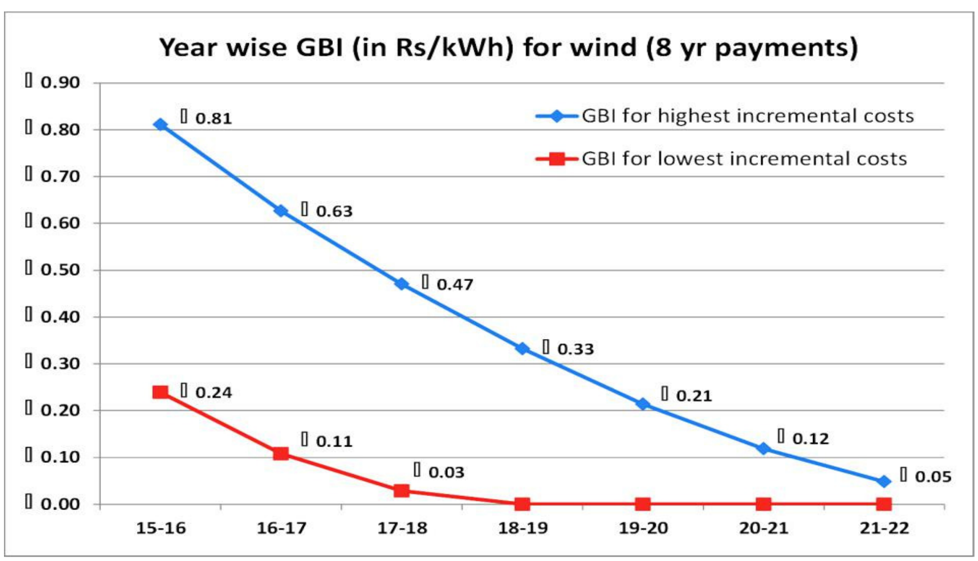


Fig. 1.4 Year wise wind GBI estimates for highest and lowest incremental cost scenarios

1.5 Targets and Achievements in RE Sector

Make in India campaign, in renewable energy sector, is intended to create 5 GW of photovoltaic manufacturing capacity from 2019 and build 20 GW of projects in the country by 2026. This will cause further drops in the overall cost of solar PV modules consequence to further lower tariffs.

The UN Environment Program's (UNEP) 'Global Trends in Renewable Energy Investment 2016' report positions India among the top 10 countries in the world investing in renewable energy. The Government is also dedicated to Clean Energy and is driving efforts to achieve 40% power installed capacity from renewable energy resources and reducing emissions by 33- 35% of its GDP by 2030.

Some key achievements are:

- The world's largest 648-MW solar power plant was commissioned in Tamil Nadu on September 21, 2016.
- A 157% increase in solar power capacity addition (4132 MW) during the last two years (FY2014-15 & FY 2015-16).
- Highest ever wind power capacity addition of 3300 MW in 2015-16.
- 500 MW grid connected solar rooftop projects have been installed in the country.

1.6 Grid Connected Small Solar Photovoltaic

In grid connected small solar photovoltaic system, the DC power generated from SPV panel is converted to AC power using power conditioning unit and is fed to the grid either of 33 kV/11 kV three phase lines or of 440/220 V three/single phase line depending on the capacity of the system installed. In grid interactive systems, it has, however to be ensured that in case the grid fails, the solar power has to be stopped immediately feeding to the grid so as to safe-guard any grid person/technician from getting shock (electrocuted) while working on the grid for maintenance etc. This feature is termed as 'Islanding Protection'.

According to guidelines of MNRE the maximum capacity of small solar photovoltaic power generation plant is 500 KW per project/system.

1.6.1 Classification of small solar projects based on grid connectivity

System up to 10 KW will be connected to 230 V 1-phase supply. Plant capacity ranging between 10 KW and 100 kW will be connected to LT 400/415/440 V 3-phase supply. Plant capacity above 100 KW and up to 500 KW will be connected to 11/33 KV line depending upon the site location.

1.7 Small Wind-Solar Hybrid System

An ideal wind-solar hybrid system is generates electrical energy by using an optimum utilization of solar-PV and wind-turbines with an efficiently shared infrastructure allowing for greater economic and social utilization of all resources.

Small wind–solar hybrid system is restricted to a maximum capacity of 50kW (system capacity) by MNRE. The minimum share of wind component in the hybrid system has to be at least 60% of the total capacity.

1.8 Problem Identification

As due to the depletion of fossil fuels and environmental concerns the renewable power sector of India is getting pace. To set up a small solar, wind or wind-solar hybrid plant, either grid connected or stand alone, technical and basic financial knowledge related to these plants is must. As the energy output of solar/wind power plants vary according to geographical location, it is necessary to choose the location which yields optimum output. Again, the difference in tariffs and subsidies from state to state requires brainstorming to find the suitable location. Land cost, availability of land and availability of grid are also some important points to be taken into account before installation of small solar/ wind/ hybrid system. On the other hand, finance and economics related to small power plant plays important role at the time of project consideration. Initial amount, loan amount, interests, payback period, depreciation rate of money and income tax etc. are the issues which come under the category finance and economics.

The above stated problem motivated us to do techno-economic analysis of grid connected small solar power plant and wind-solar hybrid plant each of rating 30 KW at three different locations in India.

1.9 Thesis Objectives

The main objectives of this thesis work are as follows-

a) Designing of grid connected solar power plant of rating 30 KW at Pantnagar (Uttarakhand), Porbandar (Gujarat) and Visakhapatnam (Andhra Pradesh).

b) To analyze the investment, energy output, payback period of each solar power plant.

c) Economic comparing of the solar power plant with wind-solar hybrid power plant of rating 30 KW (19.8 KW wind + 10.2 KW solar) at the above mentioned location.

d) Finding out which type of plant is more economically efficient at mentioned location.

1.10 Organization of thesis

Thesis on "Financial Analysis of 30 KW Grid Connected Solar and Wind-Solar Hybrid Power Plant" include following chapters:

Chapter 1: introduces the solar energy, wind energy, hybrid system, government's vision and policies, problem identification and objectives of thesis.

Chapter 2: gives overview of literature regarding financial analysis of solar and wind solar hybrid system.

Chapter 3: presents materials and methodology adopted for the designing, analysis of energy output, investment, running cost and payback period of solar and wind-solar hybrid plant.

Chapter 4: discusses result obtained and comparison is made regarding financial analysis.

Chapter 5: concludes and summarize the entire work.

Review of Literature

The improvement process of harnessing the renewable energy using PV cell and wind generator is done by the many researchers around the world. Obviously there is no doubt about the health and environmental benefits of such solar and wind energy. As the solar and wind projects require huge investment in terms of money, so it is required to find out which type of RE plant (solar or wind-solar hybrid) is commercially feasible for a particular location. Hence the related literature has been studied and presented below.

2.1 General

Ajao, K.R. and Oladosu, O.A. (2011) have done cost benefit analysis of wind solar hybrid power generation using HOMER power optimization software. They used a 400 W FD series wind turbine and a 100 W solar module and installed the system on rooftop. 80 W was peak load, base load was 10 W and total daily load average was 903 watts-hours per day. Wind and solar irradiance data was taken from NASA surface metrology and solar energy website. For economic analysis, interest rate was considered as 6% and the project life was considered as 20 years. For PV system capital and investment costs were calculated as $7.50/W while for wind system, the capital and investment costs of $ 2.50/W were specified. Total Capital cost was found as $ 3455 while operating cost was $ 69 per year. Cost of energy was specified as 1.74$/KWh. On comparing the hybrid system net cost with utility tariff bill, it was found that the system had payback period of about thirty-three (33) years. Thus they found that wind-solar hybrid system as compared to utility tariff, hybrid system was economically costlier and had a system payback time which is thirty-three years is greater than the system life cycle. The system might be cost effective if there was reduction in component cost by installation of numbers of such wind-solar hybrid system in a farm thereby lowering the per kilowatts investment cost.

Maheshwari, P. and Gupta, S. (2012) wrote when a number of renewable energy resources are linked to form a power system, the system behavior is unstable, some complexity encountered, including dealing with under voltage and over voltage, phase switch and frequency and power quality problems. In this way, separate the numerical model of the association and gain an appropriate control techniques become necessary for exploring the micro level grid. Simulating the operational parts of such a micro-grid power system can help outline, the control system for the power system. To manage the regular load demand also can accomplish better harmony between power demand and supply. These works are principally focused along the hybrid generation (wind and solar energy) system displaying with distribution-grid, as simply as the dynamic synchronization and resynchronization with the distribution network when it is vital, which are the one of the characters of such a micro-grid power system.

Shankar, S. and Sharma, B. S. (2012) published a paper about the optimization of solar and wind hybrid system. They considered the project location at Jodhpur in Rajsathan. They considered the three cases, 50 KW solar alone, 50 KW wind alone and hybrid system of combination of solar and wind system both comprising 50 KW each. They calculated the per unit generation cost of electricity for all the three types of system. Result was obtained as wind system had highest per unit electricity generation cost while hybrid system had lowest per unit cost of electricity photoelectric. Solar system had the cost in between the two types of system.

Meena, R.S. and Rathore, J.S. (2014) have analyzed grid connected solar system. According to the literature India can possibly rise as one of the pioneers in sun based power era having land zone with most part accepting 4-7 kWh per sq. m every day. Grid tied systems are fundamentally intended to supply the produced energy to the grid and also power the load. These systems will not generate energy during a power failure as the inverter close down the system to quit sending power into the grid. Estimation is done for 100 KWp system in Rajsthan state. Cost estimated Rs. 80-90 lakhs. Expected electricity generation forecasted 140000-160000 units, Payback period at grid electricity cost founded 5-6 years. Plant life is expected for 25 years.

Katyal, R. (2014) Sr. Scientist at Centre for Wind Energy Technology (C-WET), wrote a paper about small wind turbine and solar hybrid system in which he calculated the system sizing parameters. He writes as the small or micro wind turbines and solar photo voltaic find application in isolated or remain solitary systems, mostly rural electrification, business applications (communication towers) etc. The majority of the current systems come under this class i.e. stand alone systems. Hybrid systems compose a major part of these separated systems, as they constitute at least two sources of renewable energy to guarantee the supply continuity. Grid connected small wind turbines are getting accepted in the countries like USA, Canada and European countries, the grid interactive device feeds power to the grid via a system that is called as net metering and the consumer is permitted to export or import energy. Small scale wind farms comprising of extensive number of such wind turbines in huge open spaces in urban communities have additionally turned into a reality and can fill as miniature power plants. Conventional ‘mega-power’ generation of power is insufficient today in light of exponential modern development and higher expectations for everyday comforts. Small scale power generation, which incorporates advance small wind turbines, biomass gasifiers, solar photovoltaic power, miniature scale hydro, is both a genuine type of clean energy generation and a social development, which is gathering momentum around the world. Hence there is a need to concentrate on a program to extend the market for small wind turbines and hybrid systems in India by industry adjustment through large scale manufacturing, expanded megawatt scale annual market (both stand alone and grid interactive systems), different item portfolio, institutionalization of items, item testing, and item accreditation, enhanced O&M benefit arrange, plan of action rebuilding, imaginative approach and administrative system and limit building.

Singh, J.P. and Bhaskaran A.H. (2014) Scientist, Ministry of New and Renewable Energy, New Delhi, published a literature named small wind energy and hybrid systems in which they discussed need of grid interactive hybrid system in India. They also analyze the economic and cost-benefit. They write as Small Wind Turbines (SWTs) and Small Wind Energy–Solar Hybrid Systems (SWES) are ending up plainly more mainstream worldwide as the innovation develops. These systems can assume a noteworthy part in decentralized energy generation and its utilization and can potentially reduce the pressures on centralized generation systems, transmission and distribution networks. Most provincial areas in India have a feeble network portrayed by substantial voltage variances and low accessibility and dependability of electric power. Power generation from wind using small wind turbines is a set up innovation today. The requirement for reliable energy to support the developing business and household power requirements of consumers from remote area as well as establishments at remote locations requires expansive scale sending and interconnection of small wind farms to the nearby network. Grid interconnection maintains a strategic distance from the misfortunes required in transmission of power from the source to the client point. A kilowatt aero-generator system should produce about 3 to 4 kWh at wind speeds of 4–5 m/sec. Similarly, a kilowatt solar energy system generates about 4 to 5 kWh per day. However, as a thumb rule, 60%–70% wind and 40%– 30% solar is the ideal combination for most locations in the country, which can generate about 3.5 to 6 kWh a day depending on available resources. In high wind areas, higher wind component is preferred. Grid-tied wind–solar hybrid systems are valuable in adapting to the broadening gap amongst demand and supply of power. It is imperative to investigate the application ranges of grid-tied and stand-alone small wind turbine systems in India. The application areas for grid-tied small wind turbine systems may be different enterprises and business foundations utilizing diesel generators for move down power or residences with abundant rooftop space accessible relying on upon economic feasibility. However, before promoting grid-tied SWT systems in India, the research group strongly feels that the SWT innovation should first be altered to Indian conditions and afterward institutionalized. Interconnectivity issues, sorts of metering, and tariff philosophies should be broke down before advancing such systems.

Manoharan, K. (2014) Business Development, ReGen Powertech Pvt Ltd. wrote a literature about MW scale wind solar-hybrid in which he proposed single inverter concept for hybrid system. Reason was given as it avoids the need to store separate for the solar and wind inverter, diminishing a considerable measure of stock administration cost and hybrid inverter works at higher effectiveness as the pooled control is constantly nearer to the appraised energy of the inverter. This enhances the general yield by 2% to 5%. He also provided an idea of metering for hybrid system as the tariffs for solar and wind energy are different. He proposed that two dc meters would be installed, one at the output of solar and other at the output of wind. An Ac energy meter would be installed at the AC side after the inverter and the share of solar and wind generation could be found.

Maniknandan, P.; Saravanan, J. and Ayyadurai, M. (2014) published a case study of 50 KW wind solar hybrid system. The system is located at Aruppukottai in Tamilnadu district of India. Out of 50 KW, 30 KW is generated by wind and 20 KW from solar photovoltaic. 10 numbers of permanent magnet type wind turbines each rating 30 KW is installed. Number of solar panels is 100 with rating 200 W, 30 V. Also the have used batteries of 120 Ah, 20 numbers. Fixed type structure is used for solar system. Inverter rating is 20 KVA.

Ingole, S. and S. Rakhonde, S. (2015)) published a paper in which they described the hybrid power generation system using wind energy and solar energy. They have written that the only initial investment is needed in case of solar-wind hybrid energy systems as the operating and maintenance cost is much less. It contends well in era with the traditional energy sources. At the point when represented a lifetime of diminished or evaded utility expenses. The system cost relies on the system picked, wind resource on the site, electricity tariff in the area. For minimize the cost of such system there is have to build the utilization of non customary energy sources. This will increase the production of solar photovoltaic and wind turbines. That will decrease the entire system cost. Hybrid power generation system is great and successful answer for energy production than traditional energy sources. It has more prominent productivity. It can be given to remote spots where government can't reach. So that the power can be use where it is created so it will lessen the transmission losses and cost. Further, it is possible to reduce the cost by mass production of equipment. It tends to cost effective option for electricity production. It only needs capital investment. It has likewise long life expectancy. General it is great, solid and moderate answer for power.

Udaykanthi, G. (2015) has done her thesis on design of wind-solar hybrid in Sri Lanka. Work is started with site selection and data collection. Hambantota is selected for project installation. 6 numbers of Gamesa G 58 850 KW rating wind turbines are selected for wind power generation at 55 m height. 300 W polycrystalline solar modules is selected. Total solar capacity is selected as 3000 KW. Total plant capacity is found as 8100 KW. Power plant life is assumed 25 years. Capacity factor of solar part is found around 19% while it is 34% in case of wind part. Payback period was found as 3.4 years.

2.2 Summary

Interest in wind-solar hybrid is being developed by various authors as the reliability of the system is higher than any other renewable hybrid system. Energy cost generated from the hybrid system is higher than the solar energy. Wind solar hybrid is not feasible at all geographical location. While solar alone system can be installed almost every location. Also the maintenance cost of wind solar hybrid system is higher but there is higher probability of energy generation in night time and rainy/ foggy season form hybrid system, which is almost nil in case of solar alone system.

Materials

&

Methods

This chapter contains various techniques and tools for the proposed work. For 30 KW solar power plant PV*SOL Premium test version is used to implement the proposed work. While for analysis of 30 KW wind-solar hybrid power plant, data is collected from site of NASA for particular locations and energy generation is forecasted.

This chapter is divided into sections. The first section describes the materials that have been used for the analysis such as PV*SOL which is used as a software tool. The second section describes the methodology of the work done which is followed by designing of solar and hybrid plants at various locations.

3.1 Materials

This section deals with the software tools that have been used in our proposed work. PV*SOL is the basic software which has been used in simulation.

3.1.1 Software used

PV SOL is professional simulator developed by Valentin Software used for designing, estimation financial analysis of solar power plant. It is a high-level simulation tool that allows quick, easy and reliable estimation and calculations related to design of solar plant.

Basic features of this simulator are:

- Climate data selection using zip code or map, or own climate data
- Solar panel manufacturer and panel rating selection
- Inverter manufacturer list with products
- String suggestion for optimum efficiency of system
- Calculation of AC losses DC losses and string losses
- Calculation of feed- in energy to the local grid
- Detailed economic forecast including main parameters like yield payback time
- Hourly and minute-by-minute yield simulation of grid-connected PV systems

AutoCAD is a commercial computer-aided design (CAD) and drafting software application. AutoCAD is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and many other professionals.

AutoCAD is used to draw the layouts of solar and hybrid power plant. Layouts helped in determining the area required for each type of plant at different location also the length of cables and wires required for solar power plant for different locations determined with the help of layouts.

3.2 Methodology

In this section, the methodology for the proposed work has been introduced and discussed. First section deals with designing of solar power plant while second section deals with design of wind-solar hybrid power plant with separate design procedure of wind and solar part.

3.2.1 Site selection for solar power plant

- **Weather conditions:** location must have better solar irradiance and sunshine hours. Out of 365 days, 300 days of sunshine is assumed good. Average energy generation from solar system is 4 to 5 KWh per KW per day. Temperature variation must be within the permissible limit according to solar modules.
- **Terrain and counters of land:** Selected area must be shadow free. Area nearby buildings and trees must be avoided for solar modules installation. Plain land is preferred.
- **Soil quality:** Soil should be not dusty, moderate level of moisture in soil is preferred.
- **Grid availability:** Generated electricity will be sold to the local distribution companies; hence grid availability near to the land is a positive factor for site selection.

3.2.2 Site selection for wind power plant

- **Weather conditions:** A KW aero-generator generates 3 to 4 KWh at wind speed of 4-5 m/s in a day. Average wind speed in the region must be above to cut-in speed of wind turbine. Duration of wind flow must be higher throughout the year.

- **Terrain and counters of land:** Land must be free from wind obstacles i.e. large buildings or structures, forests or mountains. Coastal area is preferred for wind power plants. Soil should be harder but not rocky.
- **Grid availability:** Generated electricity will be sold to the local distribution companies; hence grid availability near to the land is a positive factor for site selection.

3.3 Solar Power Plant Design

For Solar alone system, PV*SOL simulator is used. Before working on simulator, following calculation is done related to 30 KW GCPV.

A. **Project Site 1: Pantnagar (Uttarakhand)**

Latitude-29.021° Longitude -79.49°

Module selection

Table 3.1 Solar module specification

Zytech 300P: specification			
Max. power	300 W	NOCT	47±2°C
Open circuit voltage	45.5 V	Temperature coefficient of Voc	- (120 ± 5) mV / °C
Max. power point voltage	36.72 V	Temperature coefficient of Isc	+0.04 % / °C
Short circuit current	8.65 A	Temperature coefficient of power	-0.35 % / °C
Max. power point current	8.17 A	Dimensions of module	1965 x 1000 x 50

3.3.1 Optimum tilt angle of the module

Altitude on the basis of sun position:

- Altitude at Equinox = 90 – 29.02 = 60.98º S
- Altitude at Tropic of Cancer = 90 – 29.02 + 23.45 = 84.43º S
- Altitude at Tropic of Capricorn = 90 – 29.02 – 23.45 = 37.53º S

The tilt angle for different altitudes:

- Tilt angle at Equinox = 180 – 90 – 60.98 = 29.02º S
- Tilt angle at Tropic of Cancer = 180 – 90 – 84.43 = 5.57º S
- Tilt angle at Tropic of Capricorn = 180 – 90 – 37.53 = 52.47º S

We choose 30° S as the optimum angle for the whole year.

3.3.2 Array row spacing

We have calculated the optimum tilt angle at 30º S. The spacing between two strings /sub-arrays is chosen by calculating the length of the shadow as shown in Fig.

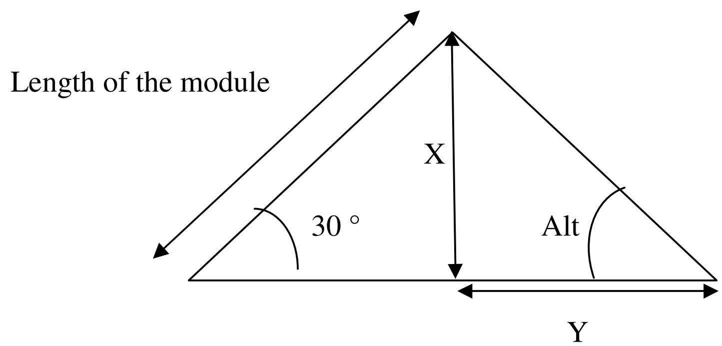


Fig. 3.1 Array row spacing

Where

X: height of the module

Y: length of the shadow

In winter solstice, morning time 11:30 AM – azimuth = 168.48° and altitude = 36.68°

X= Sin tilt X length of the module

$$Y = X \frac{\cos(\text{azimuth angle})}{\tan(\text{altitude angle})}$$

$$X = sin\ (30)\ X\ 1.965$$

$$= 0.9825 \text{ m}$$

$$Y = 0.9825\ X\ \frac{cos\ (168.48)}{\tan(36.68)}$$

$$=1.29 \text{ m}$$

Hence, total length of the array row spacing = 1.288 m. Modules are mounted vertically.

3.3.2 Inverter selection

Delta M 30 A

Table.3.2 Solar inverter specification

Input Side Data		**Output Side Data**	
Max. PV input power	38000W	Nominal AC output power	30000W
Max. PV input voltage	1100V	Max. AC output apparent power	33000VA
MPP operating voltage range	200-1000V	Max. AC output current	43.5 A
V/g range for nominal power	520~800V	Nominal AC voltage	230/400V
Max. PV input current	60A (30A/30A)	Nominal grid frequency	50Hz/60Hz

3.3.3 Array and inverter matching

$T_{cell\text{-}min} = 2^{o}$ C $T_{average\text{-}ambient} = 25^{o}$ C $T_{cell\text{-}max} = 70^{o}$ C

- Minimum number of modules in a string (Maximum Cell Temperature):

i. Difference between the maximum cell temperature and STC temperature-

$$70 – 25 = 45^{o} \text{ C or } 318 \text{ K}$$

ii. Multiply this difference by the Vmpp coefficient (V/ºC)-

$$45 \times 0.0035 \times 36.72$$

$$= 5.78 \text{ V}$$

iii. Take this away from the rated Vmpp –

$$36.72 – 5.78 = 30.94 \text{ V}$$

iv. Multiply this by 0.98 to account for 2% voltage drop-

$$30.94 \times 0.98= 30.32 \text{ V}$$

v. Multiply the inverter minimum voltage by 1.1 to account for 10% safety margin-

$$250 \times 1.1 = 275 \text{ V}$$

vi. Divide the inverter voltage (v) by the module voltage (iv)-

$$\frac{275}{30.32} = 9.07$$

vii. Round this number to 9

- Maximum number of modules in a string (Minimum Cell Temperature):

i. Difference between minimum cell temperature and STC temperature-

2 – 25 = -23º C

ii. Multiply this difference by the Voc coefficient (V/ºC)-

-.125 X -23 = 2.875 V

iii. Add this to the rated Voc-

45.5+2.875 = 48.375 V

iv. No voltage drop to be considered as we are using Voc and hence, no current.

v. Multiply the inverter maximum voltage by 0.95 to account for 5% safety margin-

1100 X .95 = 1045

vi. Divide the inverter voltage (v) by the module voltage (iii)-

$$\frac{1045}{48.375} = 21.60$$

Round this number DOWN- **21**

- Maximum number of strings-

Divide the maximum input current of the inverter by the maximum short circuit current of the module.

Maximum input current of the inverter (per MPPT) - 30 A

To find out the maximum short circuit current of the module, calculate

i. Difference between cell temperature and STC temperature-

70 – 25 = 45º C

ii. Multiply this difference by the Isc coefficient (A/ºC)-

.0004 X 45 = 0.018 A

iii. Add this to the rated Isc-

8.65 + 0.018 = 8.668 A

iv. Divide the max. current per MPPT by string current-

$$\frac{30}{8.668} = 3.46$$

Round this number DOWN- 3

- Total maximum number of modules per MPPT-

  Divide the maximum PV input (Wp) per MPPT by the module rated power

$$\frac{19000}{300} = 63.33 \text{ Modules}$$

Since the recommended max. PV output of the inverter is 19,000Wp per MPPT I have chosen to install 60 modules (300W) at first MPPT and 40 modules at second MPPT. The chosen configuration is 20 modules in string and 3 parallel strings for first MPPT and 20 modules in a string and 2 parallel strings for second MPPT.

3.3.4 Cable sizing

Minimum current carrying capacity of string cable-

$$\text{CCC} \geq 1.25 \times \text{I}_{\text{sc-mod}}$$

$$\text{CCC} \geq 1.25 \times 8.668$$

$$\text{CCC} \geq 10.835 \text{ A}$$

3.3.5 Voltage drop calculation in DC and AC cables

$$\text{V}_{\text{DC-Drop}} = \frac{\text{length of the DC cable} \times \text{string current} \times \text{resistivity of the cable}}{\text{cross} - \text{sectional area of DC cable}}$$

$$\text{V}_{\text{DC-Drop}} = \frac{54 \times 8.17 \times .0183}{4}$$

$$\text{V}_{\text{DC-Drop}} = 2.02 \text{ V}$$

$$\% \text{ Voltage drop in DC cable} = \frac{2.02}{20 \times 45.5} \times 100 = 0.22\%$$

$$\text{V}_{\text{AC-Drop}} = \frac{\text{length of the AC cable} \times \text{nominal current} \times \text{resistivity of the cable}}{\text{cross} - \text{sectional area of AC cable}}$$

$$\text{Nominal Current of the inverter} = \frac{\text{nominal power}}{\text{nominal voltage}} = \frac{30000}{\sqrt{3} \times 400} = 43.30 \text{ A}$$

$$\text{V}_{\text{AC-Drop}} = \frac{5 \times 43.30 \times .0183}{10}$$

$$= 0.396 \text{ V}$$

$$\% \text{ Voltage drop in AC cable} = \frac{0.396}{400} \times 100 = 0.1\%$$

3.3.5 System yield

Losses assumptions: Loss due to deviation from standard spectrum- 1%, Power loss due to drop in voltage at the bypass diodes- 1%, Power loss from mismatch in string-2%, Soiling loss-5% and Shading- 4%.

B. Project Site 2: Porbandar (Gujarat)

Latitude-21.73°   Longitude -69.631°

Altitude on the basis of sun position:

- Altitude at Equinox = 90 – 21.73 = 68.27º S
- Altitude at Tropic of Cancer = 90 – 21.73 + 23.45 = 1.72º N
- Altitude at Tropic of Capricorn = 90 – 21.73 – 23.45 = 44.82º S

The tilt angle for different altitudes:

- Tilt angle at Equinox = 180 – 90 – 68.27 = 21.73º S
- Tilt angle at Tropic of Cancer = 180 – 90 – 91.72 = 1.72º N
- Tilt angle at Tropic of Capricorn = 180 – 90 – 44.82 = 45.18º S

We choose 22° S as the optimum angle for the whole year since it's the angle calculated at equinox.

I. Array row spacing

X: height of the module

Y: length of the shadow

In winter solstice, morning time 11:30 AM – azimuth = 155.59° and altitude = 40.87°

X= Sin tilt X length of the module

$$Y = X\ \frac{\cos(\text{azimuth angle})}{\tan(\text{altitude angle})}$$

$$X = sin\ (22)\ X\ 1.965$$

$$= 0.736 \text{ m}$$

$$Y = 0.736\ X\ \frac{cos\ (155.59)}{\tan(40.87)}$$

$$= 0.774 \text{ m}$$

Min. spacing between consecutive rows is chosen 1.0 m.

C. Project Site 3: Visakhapatnam (Andhra Pradesh)

Latitude-17.738° Longitude -82.982°

Altitude on the basis of sun position:

- Altitude at Equinox = 90 – 17.738 = 72.26º S
- Altitude at Tropic of Cancer = 90 – 17.738 + 23.45 = 5.712º N
- Altitude at Tropic of Capricorn = 90 – 17.738 – 23.45 = 48.812º S

The tilt angle for different altitudes:

- Tilt angle at Equinox = 180 – 90 – 72.26 = 17.74º S
- Tilt angle at Tropic of Cancer = 180 – 90 – 95.712 = 5.712º N
- Tilt angle at Tropic of Capricorn = 180 – 90 – 48.812 = 41.20º S

We choose 18° S as the optimum angle for the whole year since it's the angle calculated at equinox.

I. Array Row Spacing

X: height of the module

Y: length of the shadow

In winter solstice, morning time 11:30 AM – azimuth = 170.92° and altitude = 48.35°

X= Sin tilt X length of the module

$$Y = X\ \frac{\cos(\text{azimuth angle})}{\tan(\text{altitude angle})}$$

$$X = sin\ (18)\ X\ 1.965$$

$$= 0.607 \text{ m}$$

$$Y = 0.607\ X\ \frac{cos\ (170.92)}{\tan(48.35)}$$

$$= 0.533 \text{ m}$$

Min. spacing between consecutive rows is chosen 1.0 m.

3.4 PV*SOL Environment

3.4.1 Location/site selection

i. Selected type of system as grid connected PV system.

ii. India selected as country and Pantnagar as location.

iii. Grid v/g level- 3-Phase 400V

iv. Max grid feed-in- 80%

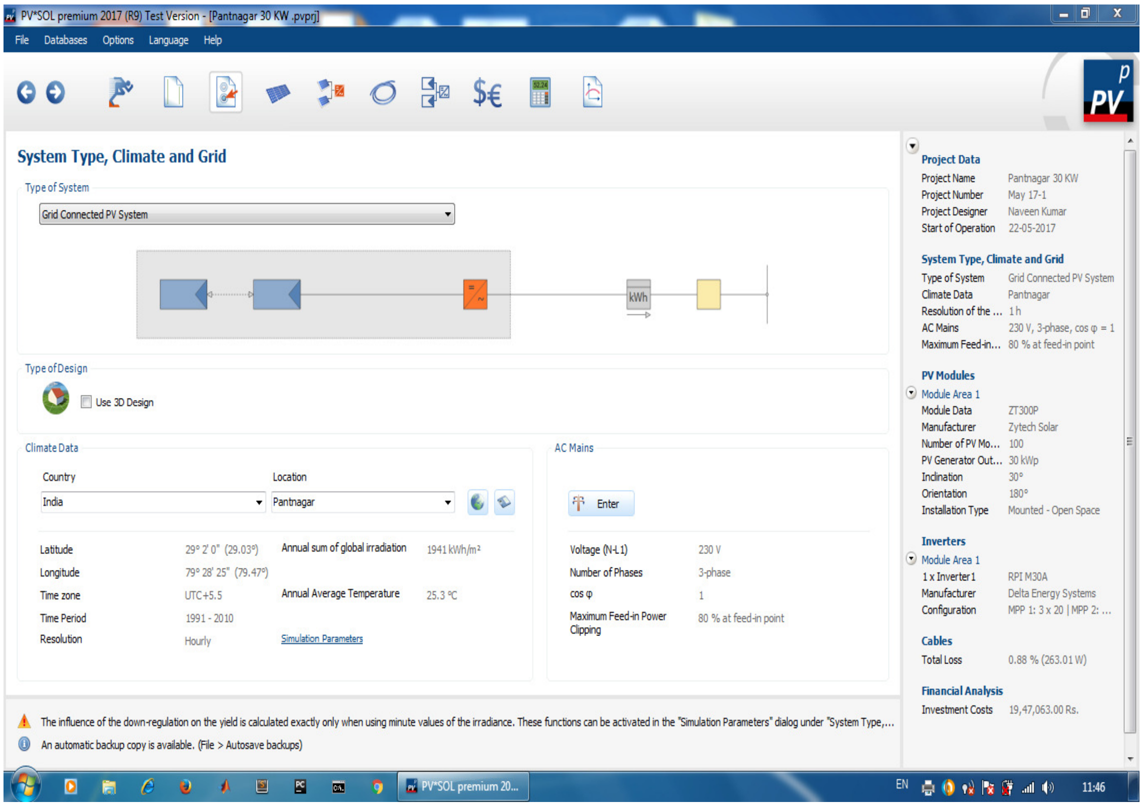


Fig. 3.2 System type selection

3.4.2 Solar modules selection: manufacturer and rating of panels

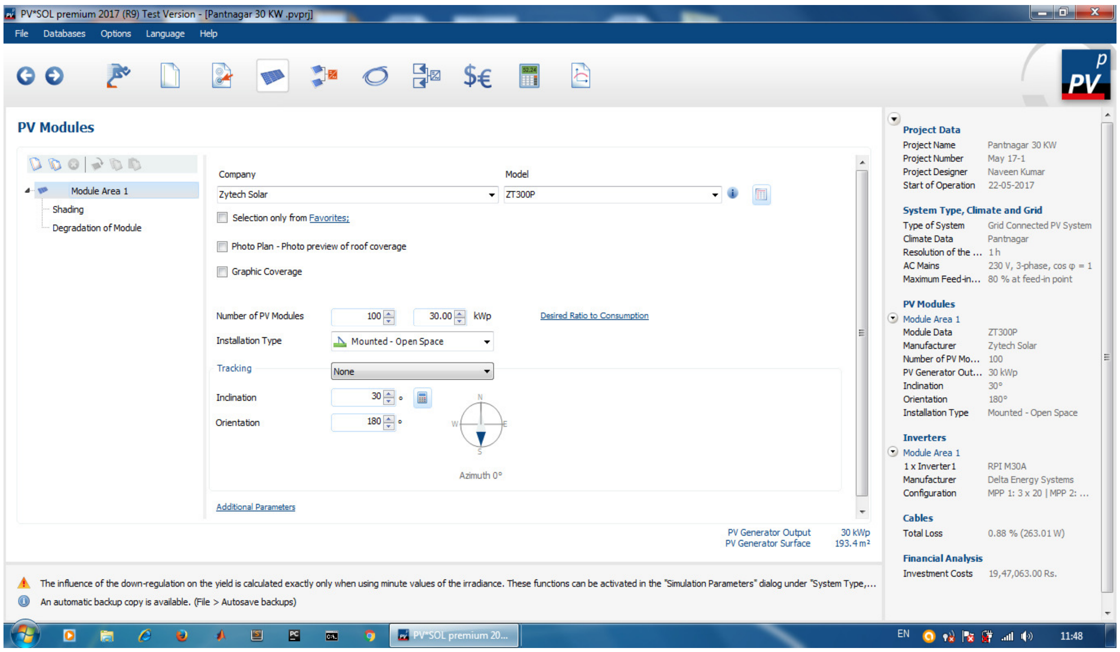
i. Zytech Solar as company and ZT 300P as Model.

ii. No. of PV modules entered as 100. Installation type is mounted open space.

iii. Inclination automatically calculated according to the location, found 30 deg.

iv. Orientation (facing of modules) is 180 deg.

v. Degradation of modules with time- 0.7% per year (given by manufacturer).



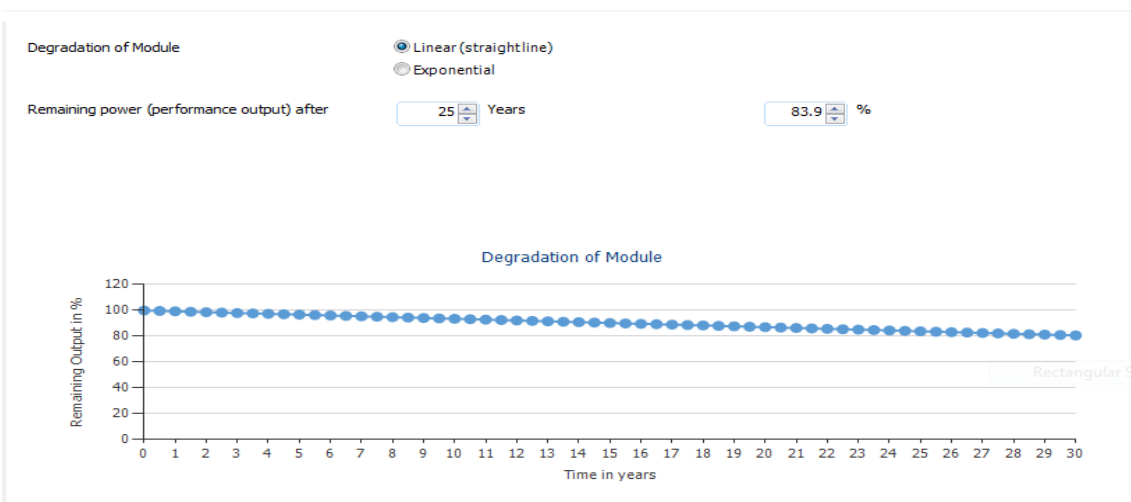


Fig. 3.3 Module and degradation selection

3.4.3 Inverter selection: string configuration

i. Manufacturer of inverter is selected as Delta Energy Systems.

ii. Model as RPI M30A. This model has two nos. of MPPT.

iii. Module configuration suggested automatically for max efficiency at each MPPT.

iv. First MPPT has three strings of 20 modules in series.

v. Second MPPT has two strings of 20 modules in series.

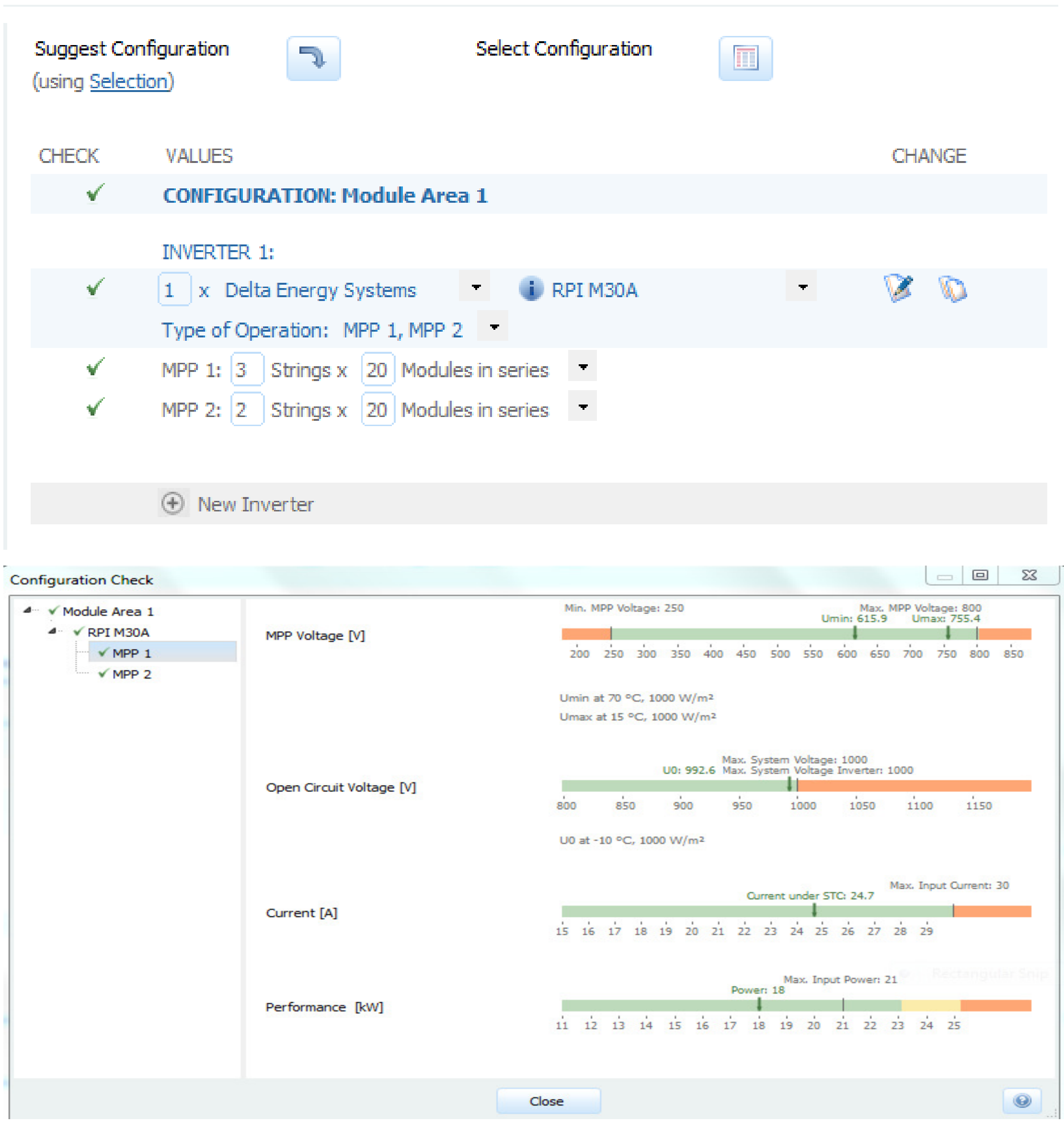


Fig. 3.4 Inverter and array matching

3.4.4 String losses calculation

i. Wire length is calculated from the plant layout designed on Auto CAD.

ii. Wire length for MPPT- 1 is 120 m of 1C X 4mm^2.

iii. For MPPT-2, it is 110 m of 1C X 4mm^2.

iv. At AC side it is 20 m (4 X 5 m, 3P+1 PE) of 1C X 10mm^2.

v. Copper wire is used.

3.4.5 Financial analysis result overview

i. Return on assets, total repayment from utility in first year, accrued cash flow (total cash flow during assessment period) is estimated.

ii. Energy generated throughout the year, energy generated per KW is forecasted.

iii. Energy taken from grid by inverter during non generation period and grid feed in energy is computed.

iv. Payback curve is plotted.

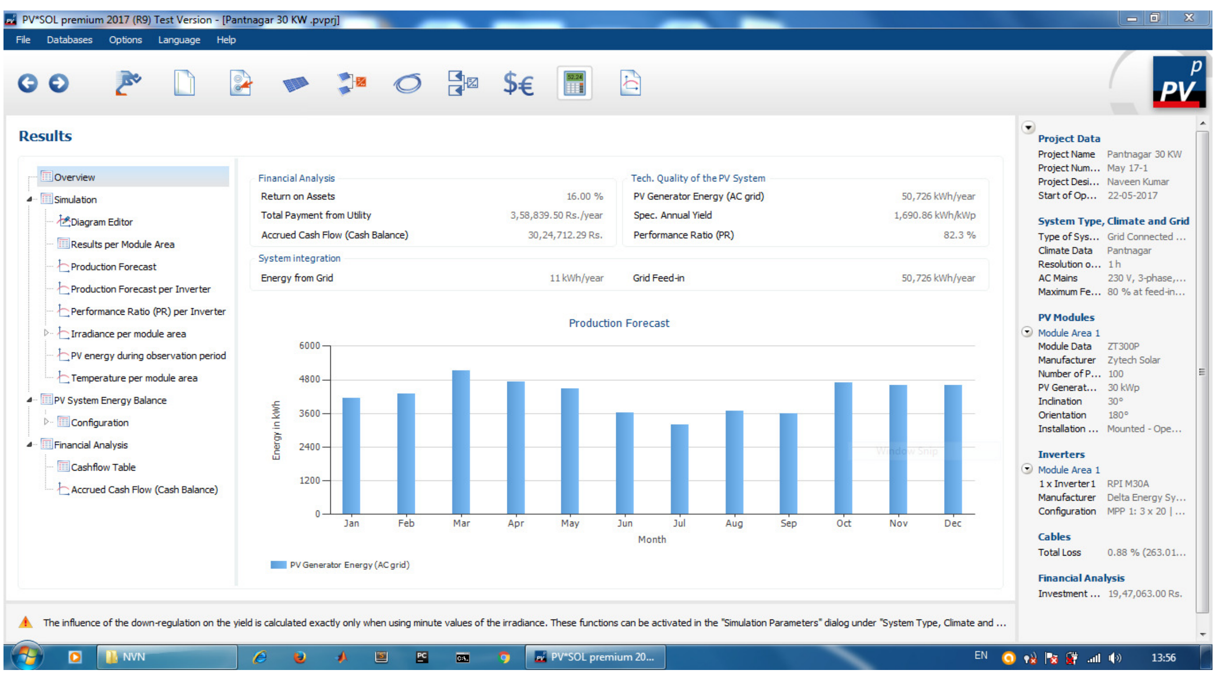


Fig. 3.5 Financial calculation

3.5 Wind-Solar Hybrid System Design

3.5.1 Design of 19.8 KW wind power system

Wind turbine selection: Unitron Energy make UE 33 (3.3 KW)

Table 3.3 Wind turbine specification

Unitron UE-33: specification			
Rated output power	3300 W	Rotor Dia.	4.65 m
Rated wind speed	10.5 m/s	No. of blades	3
Cut in speed	2.7 m/s	Swept area	16.4 sq. m.
Generator	PM 3 Ph alternator	Tip speed ratio	8.5
Poles	16	Output voltage	240 V

6 nos. of such turbines is taken for analysis of 19.8 KW wind power system.

3.5.1.1 Turbine placement

Let D_r is the rotor diameter, then spacing is four rotor diameters between turbines in a row and six rotor diameters between rows.

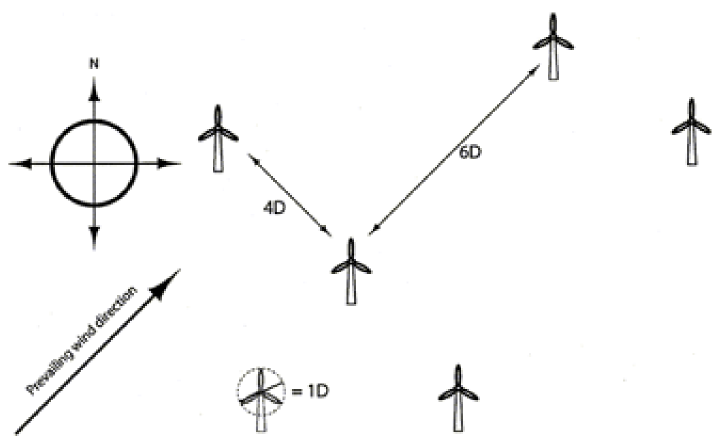


Figure 3.6 Turbine spacing

Tower height is selected as 15 meters (provided by manufacturer).

3.5.1.5 Electrical network

As the turbine output is 3 phase ac with variable frequency. There are six such turbines, generated power is variable AC therefore there is requirement of wind turbine interface to connected all wind turbine in parallel.

ABB 4000 wind interface is taken for analysis. This wind interface rectifies and filters AC and converts into DC.

Table 3.4 Wind interface specification

ABB 4000 wind-interface: specification			
Input Side Data (AC)		**Output Side Data (DC)**	
AC i/p voltage range	0-400 V	Max. output power	4000 W
Operating AC i/p voltage range	35-400 V	Output voltage range	0-600 V
Operating frequency range	0-600 Hz	Max. output current	6A
Max. Ac i/p current	16.6 A	Peak efficiency	99.40%

One wind interface is used for one wind turbine; hence six nos. of wind interface is required. Output of each wind interface is connected in junction box to make parallel connection. Combined DC output from junction box is connected to wind inverter.

For grid connection of wind turbines, ABB make TRIO-20.0 grid interactive wind inverter is used. It is a transformerless inverter.

Table 3.5 Wind inverter specification

ABB TRIO-20.0 Wind inverter: specification			
Input Side Data (DC)		**Output Side Data (AC)**	
Max. input voltage	1000 V	Rated AC power	20000 W
Operating voltage range	190-950V	Max. AC output current	33 A
Rated DC voltage at rated power	440-800 V	AC voltage range	320-480 V
Rated DC i.p voltage	620 V	Rated AC voltage	3W+PE, 400V
Max. i/p current	50 A	Nominal grid frequency	50Hz/60Hz

3 Phase output of inverter is connected to the 63 A MCB. Energy meter is connected between 3 phase LV grid and MCB.

3.5.1.6 Cable sizing

$$\text{Wind generator max current} = \frac{3650}{\sqrt{3}\times 240}$$

$$= \frac{3650}{\sqrt{3}\times 240}$$

$$= 8.78\ A$$

Minimum current carrying capacity of wire from generator to wind interface-

$$\text{CCC} \geq 1.25 \times \text{I}_{\text{max}}$$

$$\text{CCC} \geq 1.25 \times 8.78$$

$$\text{CCC} \geq 11\ \text{A}$$

Maximum output current of wind interface = 6 A

Minimum current carrying capacity of wire from wind interface to junction box-

$$CCC \geq 1.25 \times I_{max}$$

$$CCC \geq 1.25 \times 6$$

$$CCC \geq 7.5\ A$$

Minimum current carrying capacity of wire from junction box to inverter-

$$CCC \geq 6 \times 7.5$$

$$CCC \geq 45\ A$$

3.5.1.7 Voltage drop calculation in AC & DC cables

From wind generator to wind-interface-

$$V_{AC-Drop} = \frac{\text{length of the AC cable} \times \text{nominal current} \times \text{resistivity of the cable}}{\text{cross} - \text{sectional area of AC cable}}$$

$$\text{Max. current} = 8.78\ A$$

$$V_{AC-Drop} = \frac{18 \times 8.78 \times .0183}{4}$$

$$= 0.723\ V$$

$$\%\ \text{Voltage drop in AC cable} = \frac{0.723}{240} \times 100 = 0.3\%$$

From wind interface to junction box-

$$V_{DC-Drop} = \frac{\text{length of the DC cable} \times \text{string current} \times \text{resistivity of the cable}}{\text{cross} - \text{sectional area of DC cable}}$$

$$V_{DC-Drop} = \frac{160 \times 6 \times .0183}{4}$$

$$V_{DC-Drop} = 4.392\ V$$

$$\%\ \text{Voltage drop in DC cable} = \frac{4.392}{550} \times 100 = 0.8\%$$

From inverter to low voltage grid-

$$\text{Nominal Current of the inverter} = \frac{\text{nominal power}}{\text{nominal voltage}} = \frac{20000}{\sqrt{3} \times 400} = 28.90\ A$$

$$V_{AC-Drop} = \frac{5 \times 28.90 \times .0183}{10}$$

$$= 0.264\ V$$

$$\%\ \text{Voltage drop in AC cable} = \frac{0.264}{400} \times 100 = 0.07\%$$

3.5.2 Design of 10.2 KW solar power system

3.5.2.1 Module selection

Table 3.6 Solar module specification

Zytech 300P: specification			
Max. power	300 W	NOCT	47±2°C
Open circuit voltage	45.5 V	Temperature coefficient of Voc	- (120 ± 5) mV / °C
Max. power point voltage	36.72 V	Temperature coefficient of Isc	+0.04 % / °C
Short circuit current	8.65 A	Temperature coefficient of power	-0.35 % / °C
Max. power point current	8.17 A	Dimensions of module	1965 x 1000 x 50

3.5.2.2 Inverter selection

Table 3.7 Solar inverter specification

Delta M 10 : Specification			
Input Side Data (DC)		**Output Side Data (AC)**	
Max. PV input power	11000 W	Nominal AC O/P power	10000 VA
Max. PV input voltage	1000 V	Max. AC output VA	10500 VA
Startup voltage	250 V	Max. AC output current	16 A
MPP V/g range for rated power	350~850V	Nominal AC voltage	3/N/PE, 400V
Max. PV input current	30A (15A/15A)	Nominal grid frequency	50Hz/60Hz

3.5.2.3 Array and inverter matching

$T_{cell\text{-}min} = 2^o$ C $T_{average\text{-}ambient} = 25^o$ C $T_{cell\text{-}max} = 70^o$ C

- Minimum number of modules in a string (Maximum Cell Temperature):

i. Difference between the maximum cell temperature and STC temperature-

$$70 – 25 = 45^o \text{ C or } 318 \text{ K}$$

ii. Multiply this difference by the Vmpp coefficient (V/ºC)-

$$46 \text{ X } 0.0035 \text{ X } 36.72$$
$$5.78 \text{ V}$$

iii. Take this away from the rated Vmpp –

$$36.72 – 5.78 = 30.94 \text{ V}$$

iv. Multiply this by 0.98 to account for 2% voltage drop-

$$30.94 \text{ X } 0.98= 30.32 \text{ V}$$

v. Multiply the inverter minimum voltage by 1.1 to account for 10% safety margin-

$$250 \text{ X } 1.1 = 275 \text{ V}$$

vi. Divide the inverter voltage (v) by the module voltage (iv)-

$$\frac{275}{30.32} = 9.07$$

vii. Round this number to 9

- Maximum number of modules in a string (Minimum Cell Temperature):

i. Difference between minimum cell temperature and STC temperature-

2 – 25 = -23º C

ii. Multiply this difference by the Voc coefficient (V/ºC)-

-.125 X -23 = 2.875 V

iii. Add this to the rated Voc-

45.5+2.875 = 48.375 V

iv. No voltage drop to be considered as we are using Voc and hence, no current.

v. Multiply the inverter maximum voltage by 0.95 to account for 5% safety margin-

1000 X .95 = 950

vi. Divide the inverter voltage (v) by the module voltage (iii)-

$$\frac{950}{48.375} = 19.63$$

Round this number DOWN- **19**

- Maximum number of strings-

Divide the maximum input current of the inverter by the maximum short circuit current of the module.

Maximum input current of the inverter (per MPPT) - 15 A

To find out the maximum short circuit current of the module, calculate

v. Difference between cell temperature and STC temperature-

70 – 25 = 45º C

vi. Multiply this difference by the Isc coefficient (A/ºC)-

.0004 X 45 = 0.018 A

vii. Add this to the rated Isc-

8.65 + 0.018 = 8.668 A

$$\frac{15}{8.668} = 1.73$$

Round this number DOWN- **1**

- Total maximum number of modules in a string-

  Divide the maximum PV output (Wp) per MPPT by the module rated power

$$\frac{5500}{300} = 18.33 \text{ Modules}$$

Since the recommended max. PV input to the inverter is 5500Wp per MPPT, we have chosen to install single string having 17 modules (300W) in each string at each MPPT. Two strings of 17 modules make total power rating of the system equal to 10.2 KW. Cable sizing selected as 4sq. mm for dc voltage and 10 sq. mm for AC voltage.

3.6 Calculation of Energy Generation for Hybrid Plant

In Case of Wind- solar hybrid system, following steps are taken to estimate the output.

Step 1

- Data collected from Atmospheric Science Data Center of NASA. For Solar system monthly average irradiance (on 3 hourly basis) and monthly average daylight hours is obtained.
- For wind system monthly average wind speed (on 3 hourly basis) at 50 m above the surface of the earth is obtained.

Step 2

- As the radiation intensity varies, efficiency of solar cell varies too logarithmically. Change in efficiency is given by

$$\frac{\Delta\eta}{\eta} \cong .04 \ln n$$

Where η is efficiency at n=1, $\Delta\eta$ = change in efficiency

- n is the factor accounting for radiation intensity (where n=1 for one sun, n=0.5 for half sun or half radiation intensity).
- Let the radiation intensity is 0.54 Kw/m^2 the change in efficiency will be 2.47 %. For 30 KW system new rating will be 29.26 KW (=30-30x.0247). Similarly for other values of n.

Step 3

- Formula for KWh generated (for solar plant)

$$\text{KWh generated} = \frac{\text{Solar system rating} \times \text{insolation (KW/m}^2\text{)} \times \text{hours}}{1\ \text{KW/m}^2}$$

- Monthly and annually KWh generated calculated.

Step 4

- As the wind speed is available at 50 meters above the ground, the speed is obtained at 15 meters height by the power law, expressed as

$$\frac{u(z_2)}{u(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha}$$

Where α is an exponent given by the expression

$$\alpha = a - b \log_{10} u(z_1)$$

Typical values of coefficient a and b are 0.11 and 0.061 in the daytime and 0.38 and 0.209 at night.

- Unitron UE-33 wind turbine is chosen for analysis of wind side energy generation.

Step 5

- Formula for KWh generated (for Wind plant)

$$KWh\ generated = Wind\ Turbine\ rating \times \left[\frac{wind\ speed}{10.5}\right]^3 \times hours$$

- Monthly and annually KWh generated calculated.

Step 6

Table 3.8 Tariffs in selected states

State	Tariff for Wind Energy (Rs./KWh)	Tariff for Solar Energy (Rs. /KWh)
Andhra Pradesh	4.84	5.25
Gujarat	4.19	11.33
Uttarakhand	4.95	7.10

- Generated KWh is calculated on the basis of tariffs.
- Financial analysis, Payback period, total energy generated throughout the assessment period is estimated.

Results & Discussion

This chapter presents the results that have been produced by simulating/analyzing our project. First section contains analysis of results obtained of both type of plant while second section contains comparison with each other.

4.1 Project Site 1: Pantnagar (Uttarakhand)

4.1.1 30 KW GCPV

Initial investment-

Table 4.1 Costing of GCPV for Pantnagar

S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
1	Land	399	sq. m.	600	239400
2	Solar Panels	100	nos.	8400	840000
3	Mounting structures	1800	nos.	77.22	138996
4	Earthing and Protection	3	nos.	3240	9720
5	Accessories	1	nos.	6676	6676
6	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
7	Wire 1Cx 4 Sq.mm	230	mtrs.	49.28	11334
8	Inverter	1	no.	343035	343035
9	3 phase meter	1	no.	8500	8500
10	CB B 80 A	1	no.	4502	4502
11	MCB 1 pole 16 A	5	no.	1760	8800
12	Civil works			283500	283500
13	Documentation charges			50000	50000
				Total investment	1947063

Annual operation and maintenance cost (estimation) for fixed -tilt solar module plant-

Table 4.2 Operating cost of GCPV for Pantnagar

S. No.	Operation	Rs./KW/Annum	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total annual cost	22500

4.1.2 Wire plan for 30 KW GCPV

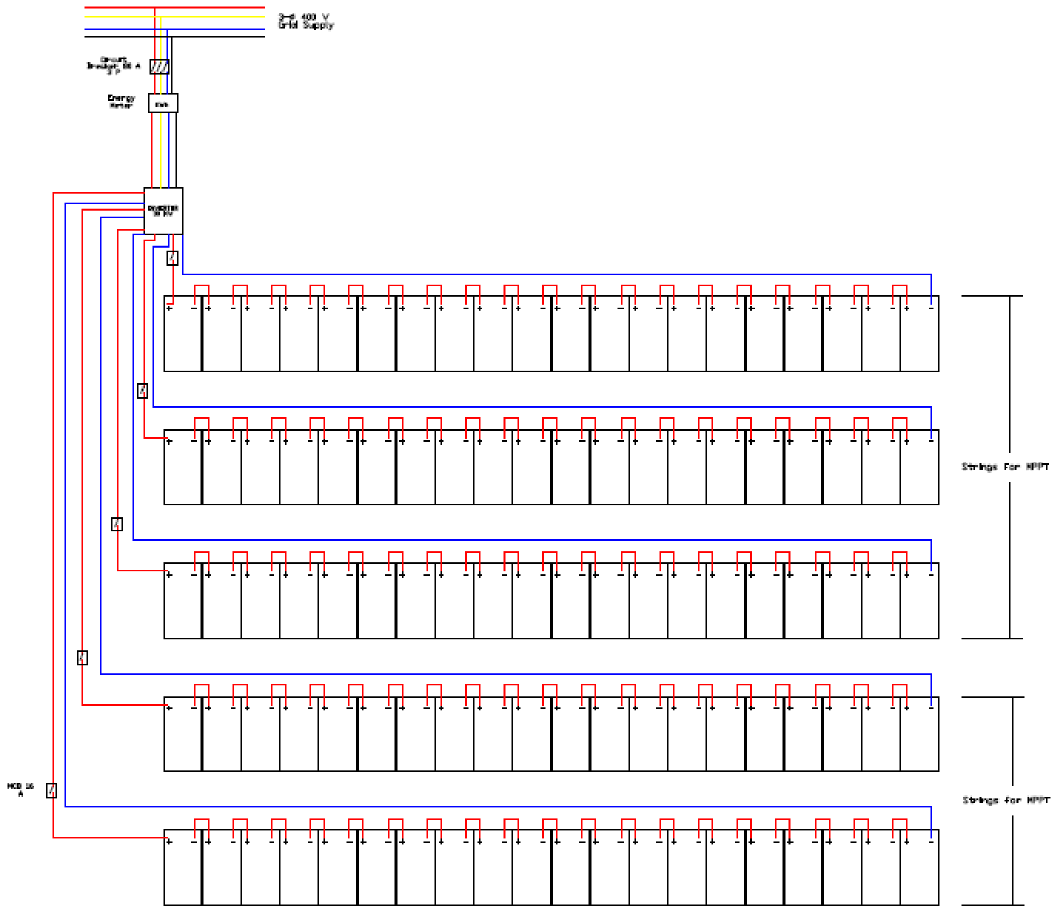
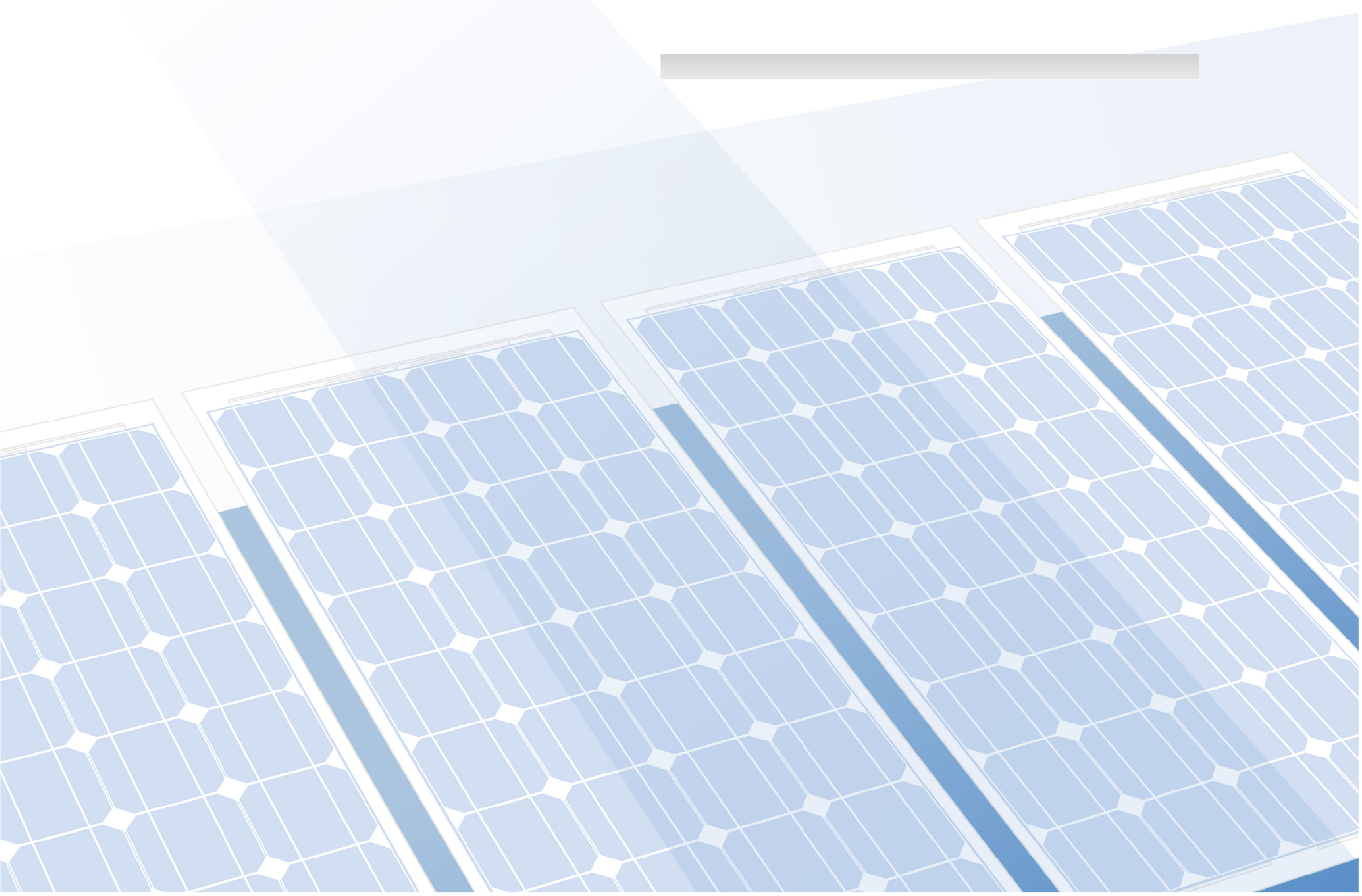


Fig. 4.1 Wire plan for 30 KW GCPV (for all location)

Pantnagar 30 KW



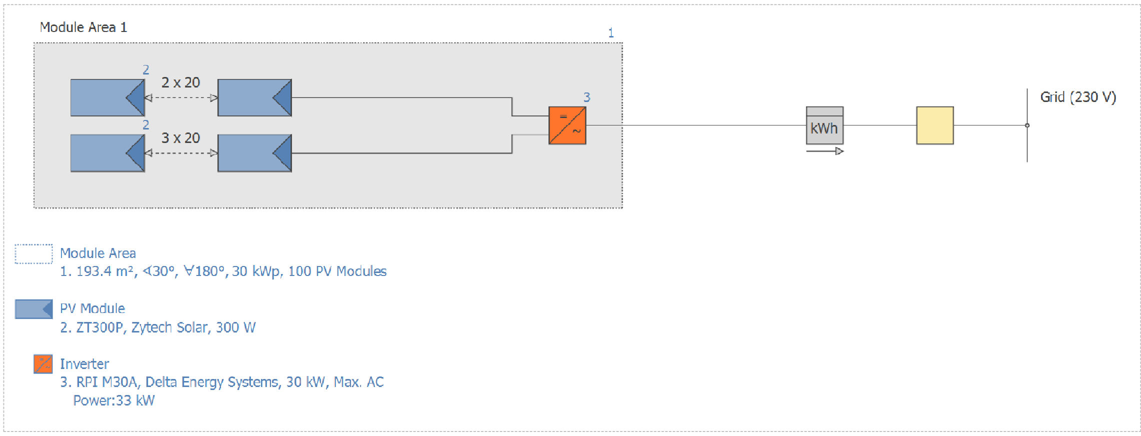
Project Number: May 17-1
Date of Offer: 25-05-2017

Project Designer: Naveen Kumar
Company: Please enter in Options > User data.

Pantnagar 30 KW

Grid Connected PV System

Climate Data	Pantnagar (1991 - 2010)	
PV Generator Output	30	kWp
PV Generator Surface	193.4	m²
Number of PV Modules	100	
Number of Inverters	1	



The yield

PV Generator Energy (AC grid)	50,726	kWh
Spec. Annual Yield	1,690.86	kWh/kWp
Performance Ratio (PR)	82.3	%
CO_2 Emissions avoided	43,624	kg / year

Your Gain

Total investment costs	19,47,063.00	Rs.
Return on Assets	16.00	%
Amortization Period	7.0	Years
Electricity Production Costs	2.85	Rs./kWh

The results have been calculated with a mathematical model calculation from Valentin Software GmbH (PV*SOL algorithms). The actual yields from the solar power system may differ as a result of weather variations, the efficiency of the modules and inverter, and other factors.

Set-up of the system

Climate Data	Pantnagar
Type of System	Grid Connected PV System

PV Generator Module Area

PV Modules*	100 x ZT300P
Manufacturer	Zytech Solar
Inclination	30 °
Orientation	South 180 °
Installation Type	Mounted - Open Space
PV Generator Surface	193.4 m²
Shading	4 %

Inverter

Inverter 1*	1 x RPI M30A
Manufacturer	Delta Energy Systems
Configuration	MPP 1: 3 x 20 | MPP 2: 2 x 20

AC Mains

Number of Phases	3
Mains Voltage (1-phase)	230 V
Displacement Power Factor (cos phi)	+/- 1
Power Feed-in Limit as a Percentage of the DC Power	80 %

* The guarantee provisions of the respective manufacturer apply

Simulation Results

PV System

PV Generator Output	30	kWp
Spec. Annual Yield	1,690.86	kWh/kWp
Performance Ratio (PR)	82.3	%
Grid Feed-in	50,726	kWh/year
Grid Feed-in in the first year (incl. module degradation)	50,541	kWh/year
Stand-by Consumption	11	kWh/year
CO_2 Emissions avoided	43,624	kg / year

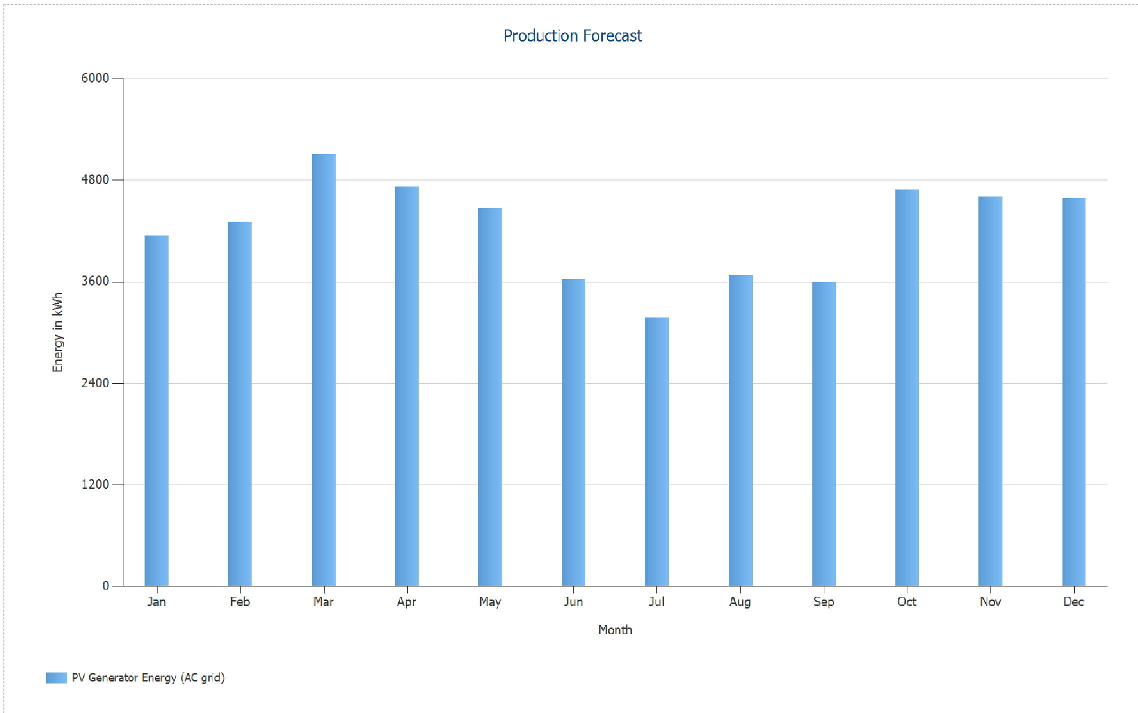


Figure: Production Forecast

Results per Module Area

PV Generator Output	30	kWp
PV Generator Surface	193.4	m²
Global Radiation at the Module	2053.9	kWh/m²
PV Generator Energy (AC grid)	50725.7	kWh/year
Spec. Annual Yield	1690.9	kWh/kWp
Performance Ratio (PR)	82.3	%

PV System Energy Balance

Global radiation - horizontal	**1,940.7**	**kWh/m²**	
Deviation from standard spectrum	-19.41	kWh/m²	-1.00 %
Ground Reflection (Albedo)	12.87	kWh/m²	0.67 %
Orientation and inclination of the module surface	205.31	kWh/m²	10.61 %
Shading	-85.58	kWh/m²	-4.00 %
Reflection on the Module Interface	-15.62	kWh/m²	-0.76 %
Global Radiation at the Module	**2,038.3**	**kWh/m²**	
	2,038.3	kWh/m²	
	x 193.44	m²	
	= 394,287.3	kWh	
Global PV Radiation	**394,287.3**	**kWh**	
Soiling	-19,714.36	kWh	-5.00 %
STC Conversion (Rated Efficiency of Module 15.51 %)	-316,475.79	kWh	-84.49 %
Rated PV Energy	**58,097.1**	**kWh**	
Low-light performance	-206.54	kWh	-0.36 %
Deviation from the nominal module temperature	-4,158.86	kWh	-7.18 %
Diodes	-537.32	kWh	-1.00 %
Mismatch (Manufacturer Information)	-1,063.89	kWh	-2.00 %
Mismatch (Configuration/Shading)	0.00	kWh	0.00 %
String Cable	-77.80	kWh	-0.15 %
PV Energy (DC) without inverter regulation	**52,052.7**	**kWh**	
Regulation on account of the MPP Voltage Range	0.00	kWh	0.00 %
Regulation on account of the max. DC Current	0.00	kWh	0.00 %
Regulation on account of the max. DC Power	0.00	kWh	0.00 %
Regulation on account of the max. AC Power/cos phi	-3.82	kWh	-0.01 %
MPP Matching	-132.84	kWh	-0.26 %
PV energy (DC)	**51,916.1**	**kWh**	

Energy at the Inverter Input	**51,916.1**	**kWh**	
Input voltage deviates from rated voltage	-72.78	kWh	-0.14 %
DC/AC Conversion	-936.98	kWh	-1.81 %
Stand-by Consumption	-11.25	kWh	-0.02 %
AC Cable	-180.63	kWh	-0.35 %
PV energy (AC) minus standby use	**50,714.4**	**kWh**	
Grid Feed-in	**50,725.7**	**kWh**	

Financial Analysis

System Data

Grid Feed-in in the first year (incl. module degradation)	50,541	kWh/year
PV Generator Output	30	kWp
Start of Operation of the System	22-05-2017	
Assessment Period	25	Years

Economic Parameters

Return on Assets	16.00	%
Accrued Cash Flow (Cash Balance)	30,24,712.30	Rs.
Amortization Period	7.0	Years
Electricity Production Costs	2.85	Rs./kWh

Payment Overview

Specific Investment Costs	64,902.10	Rs./kWp
Investment Costs	19,47,063.00	Rs.
One-off Payments	0.00	Rs.
Incoming Subsidies	0.00	Rs.
Annual Costs	22,500.00	Rs./year
Other Revenue or Savings	0.00	Rs./year

Remuneration and Savings

Total Payment from Utility in First Year	3,58,839.50	Rs./year
Remuneration of Electricity sold to Third Party		
Price of Electricity sold to Third Party	7.10	Rs./kWh
Remuneration of Electricity sold to Third Party	3,58,839.50	Rs./year

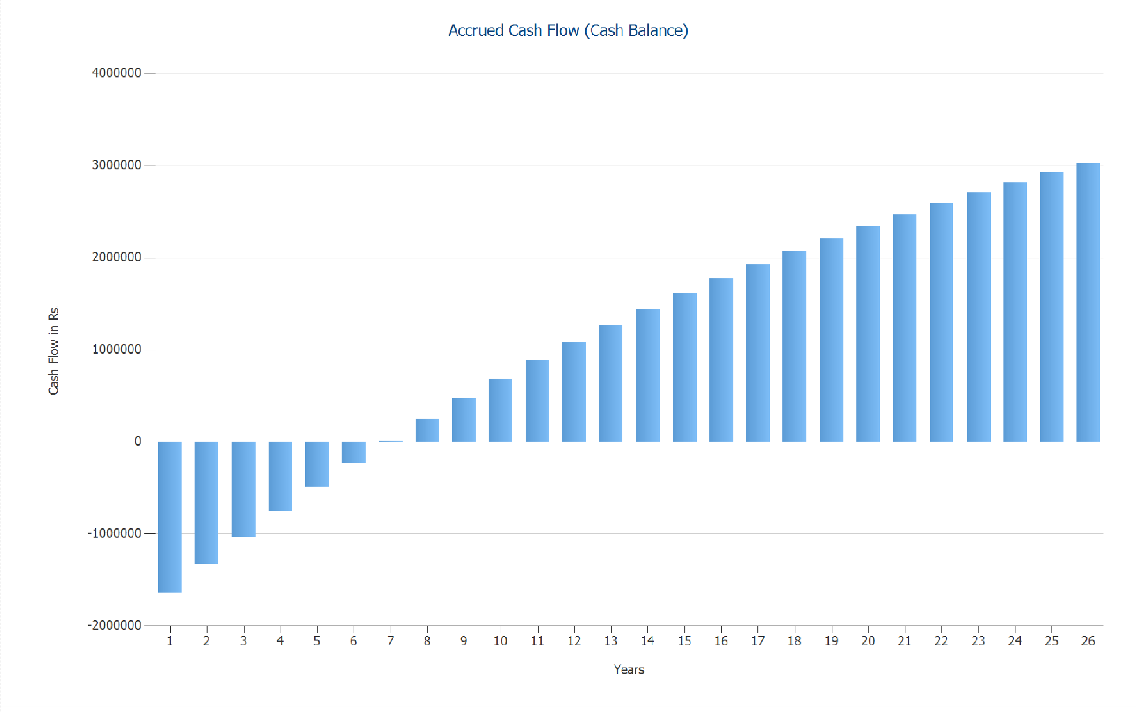


Figure: Accrued Cash Flow (Cash Balance)

Cashflow Table

	year 1	year 2	year 3	year 4	year 5
Investments	Rs. -19,47,063.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -21,634.62	Rs. -20,802.51	Rs. -20,002.42	Rs. -19,233.09	Rs. -18,493.36
Feed-in / Export Tariff	Rs. 3,24,393.68	Rs. 3,29,621.56	Rs. 3,14,880.60	Rs. 3,00,785.96	Rs. 2,87,309.73
Annual Cash Flow	**Rs. -16,44,303.94**	**Rs. 3,08,819.04**	**Rs. 2,94,878.19**	**Rs. 2,81,552.87**	**Rs. 2,68,816.37**
Accrued Cash Flow (Cash Balance)	Rs. -16,44,303.94	Rs. -13,35,484.89	Rs. -10,40,606.71	Rs. -7,59,053.84	Rs. -4,90,237.47

	year 6	year 7	year 8	year 9	year 10
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -17,782.08	Rs. -17,098.15	Rs. -16,440.53	Rs. -15,808.20	Rs. -15,200.19
Feed-in / Export Tariff	Rs. 2,74,425.17	Rs. 2,62,106.72	Rs. 2,50,329.89	Rs. 2,39,071.24	Rs. 2,28,308.33
Annual Cash Flow	**Rs. 2,56,643.10**	**Rs. 2,45,008.57**	**Rs. 2,33,889.36**	**Rs. 2,23,263.04**	**Rs. 2,13,108.14**
Accrued Cash Flow (Cash Balance)	Rs. -2,33,594.38	Rs. 11,414.20	Rs. 2,45,303.56	Rs. 4,68,566.60	Rs. 6,81,674.74

	year 11	year 12	year 13	year 14	year 15
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -14,615.57	Rs. -14,053.43	Rs. -13,512.92	Rs. -12,993.19	Rs. -12,493.45
Feed-in / Export Tariff	Rs. 2,18,019.68	Rs. 2,08,184.73	Rs. 1,98,783.80	Rs. 1,89,798.05	Rs. 1,81,209.46
Annual Cash Flow	**Rs. 2,03,404.11**	**Rs. 1,94,131.29**	**Rs. 1,85,270.88**	**Rs. 1,76,804.86**	**Rs. 1,68,716.00**
Accrued Cash Flow (Cash Balance)	Rs. 8,85,078.85	Rs. 10,79,210.14	Rs. 12,64,481.02	Rs. 14,41,285.89	Rs. 16,10,001.89

	year 16	year 17	year 18	year 19	year 20
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -12,012.93	Rs. -11,550.90	Rs. -11,106.63	Rs. -10,679.45	Rs. -10,268.71
Feed-in / Export Tariff	Rs. 1,73,000.75	Rs. 1,65,155.43	Rs. 1,57,657.68	Rs. 1,50,492.36	Rs. 1,43,645.00
Annual Cash Flow	**Rs. 1,60,987.82**	**Rs. 1,53,604.53**	**Rs. 1,46,551.04**	**Rs. 1,39,812.90**	**Rs. 1,33,376.29**
Accrued Cash Flow (Cash Balance)	Rs. 17,70,989.71	Rs. 19,24,594.24	Rs. 20,71,145.29	Rs. 22,10,958.19	Rs. 23,44,334.48

	year 21	year 22	year 23	year 24	year 25
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -9,873.76	Rs. -9,494.00	Rs. -9,128.84	Rs. -8,777.73	Rs. -8,440.13
Feed-in / Export Tariff	Rs. 1,37,101.74	Rs. 1,30,849.31	Rs. 1,24,875.02	Rs. 1,19,166.74	Rs. 1,13,712.82
Annual Cash Flow	**Rs. 1,27,227.98**	**Rs. 1,21,355.31**	**Rs. 1,15,746.18**	**Rs. 1,10,389.00**	**Rs. 1,05,272.69**
Accrued Cash Flow (Cash Balance)	Rs. 24,71,562.46	Rs. 25,92,917.78	Rs. 27,08,663.96	Rs. 28,19,052.96	Rs. 29,24,325.66

	year 26
Investments	Rs. 0.00
Operating costs	Rs. -8,115.51
Feed-in / Export Tariff	Rs. 1,08,502.16
Annual Cash Flow	**Rs. 1,00,386.65**
Accrued Cash Flow (Cash Balance)	Rs. 30,24,712.30

Degradation and inflation rates are applied on a monthly basis over the entire observation period.
This is done in the first year.

PV Module: ZT300P

Manufacturer	Zytech Solar
Available	Yes

Electrical Data

Cell Type	Si polycrystalline
Only Transformer Inverters suitable	No
Number of Cells	72
Number of Bypass Diodes	3

Mechanical Data

Width	1000 mm
Height	1965 mm
Depth	50 mm
Frame Width	35 mm
Weight	26 kg
Framed	No

I/V Characteristics at STC

MPP Voltage	36.72 V
MPP Current	8.17 A
Nominal output	300 W
Open Circuit Voltage	45.5 V
Short-Circuit Current	8.65 A

I/V Part Load Characteristics

Values source	Manufacturer/user-created
Irradiance	200 W/m²
Voltage in MPP at Part Load	36.719 V
Current in MPP at Part Load	1.6078 A
Open Circuit Voltage (Part Load)	43.374 V
Short Circuit Current at Part Load	1.6746 A

Further

Voltage Coefficient	-120 ±5 mV/°C
Electricity Coefficient	0.04 %/°C
Output Coefficient	-0.35 %/°C
Incident Angle Modifier	99 %
Maximum System Voltage	1000 V
Spec. Heat Capacity	920 J/(kg*K)
Absorption Coefficient	70 %
Emissions Coefficient	85 %

Inverter: RPI M30A

Manufacturer	Delta Energy Systems
Available	Yes

Electrical Data

DC Power Rating	38 kW
AC Power Rating	30 kW
Max. DC Power	35 kW
Max. AC Power	33 kW
Stand-by Consumption	2.5 W
Night Consumption	2.5 W
Feed-in from	40 W
Max. Input Current	60 A
Max. Input Voltage	1100 V
Nom. DC Voltage	600 V
Number of Feed-in Phases	3
Number of DC Inlets	6
With Transformer	No
Change in Efficiency when Input Voltage deviates from Rated Voltage	0.2 %/100V

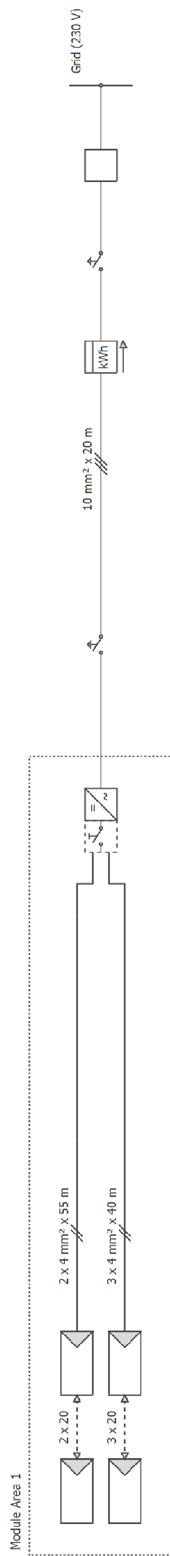
MPP Tracker

Output Range < 20% of Power Rating	98.5 %
Output Range > 20% of Power Rating	99.8 %
No. of MPP Trackers	2
Max. Input Current per MPP Tracker	30 A
Max. Input Power per MPP Tracker	19 kW
Min. MPP Voltage	250 V
Max. MPP Voltage	800 V

Project Number: May 17-3
Date of Offer: 25-05-2017

Project Designer: Naveen Kumar
Company: Please enter in Options > User data.

Pantnagar 30 KW



4.1.3 Grid connected 30 KW wind-solar hybrid system

Initial investment-

Table 4.3 Costing of hybrid system for Pantnagar

S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
	19.8 KW wind				
1	Land	1836	sq. m.	600	1101600
2	Wind turbines	6	nos.	330000	1980000
3	Wind interface	6	nos.	38366	230196
4	Wind inverter	1	no.	483556	483556
5	Earthing and Protection	2	nos.	3240	6480
6	Accessories	1	nos.	5000	5000
7	Wire 1Cx 10 Sq.mm	30	mtrs.	130	3900
8	Wire 1Cx 4 Sq.mm	540	mtrs.	49.28	26611
9	3 phase meter	1	no.	8500	8500
10	MCB 63 A	1	no.	1388	1388
11	MCB 1 pole 16 A	6	nos.	1760	10560
12	Civil works	1	no.	215820	215820
	10.2 KW Solar				
13	Solar Modules	34	nos.	8400	285600
14	Mounting structures	600	nos.	77.22	46332
15	Earthing and Protection	1	no.	3240	3240
16	Accessories	1	nos.	2288	2288
17	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
18	Wire 1Cx 4 Sq.mm	70	mtrs.	49.28	3449.6
19	Solar inverter	1	no.	151250	151250
20	3 phase meter	1	no.	8500	8500
21	MCB 32 A	1	no.	925	925
22	MCB 1 pole 16 A	2	no.	1760	3520
23	Civil works			96390	96390
	Others				
24	Documentation charges			50000	50000
				Total investment	**4727706**

Annual operation and maintenance cost (estimation) for hybrid plant-

Table 4.4 Operating cost of hybrid for Pantnagar

S. No.	Operation	Rs./KW/Month	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total annual cost	22500

Grid feed-in-

Table 4.5 KWh calculation of hybrid system for Pantnagar

19.8 KW Wind	
Wind energy generated	6625 KWh
Losses accounted	10%
Grid feed-in	6625 X 0.9 = 5962 KWh
Feed- in tariff (Rs.)	5962 X 4.95 = 26511
10.2 KW Solar	
Solar energy generated	18296 KWh
Losses accounted	10%
Grid feed- in	18296 X 0.9 = 16466 KWh
Feed- in tariff (Rs.)	16466 X 7.1 = 116911
Total Feed in tariff for 30 KW (Rs.)	143422
Capital cost (Rs.)	4727706
Annual operating and maintenance cost (Rs.)	22500
Rupee depreciation rate	4%
Working life of plant	25 years
Total cash generated through energy export (Rs.)	2201596

Table 4.6 Calculation of annual cash flow: Pantnagar

Years	Investment (Rs.)	Operating and maint. cost (Rs.)	Feed -in/Export tariff (Rs.)	Annual cash flow (Rs.)	Cash Balance (Rs.)
Year 1	-4727706	21600.00	137685.12	-4611620.88	-4611620.88
Year 2	0	20736.00	132177.72	111441.72	-4500179.16
Year 3	0	19906.56	126890.61	106984.05	-4393195.12
Year 4	0	19110.30	121814.98	102704.68	-4290490.43
Year 5	0	18345.89	116942.38	98596.50	-4191893.94
Year 6	0	17612.05	112264.69	94652.64	-4097241.30
Year 7	0	16907.57	107774.10	90866.53	-4006374.77
Year 8	0	16231.27	103463.14	87231.87	-3919142.90
Year 9	0	15582.01	99324.61	83742.60	-3835400.30
Year 10	0	14958.73	95351.63	80392.89	-3755007.41
Year 11	0	14360.38	91537.56	77177.18	-3677830.23
Year 12	0	13785.97	87876.06	74090.09	-3603740.14
Year 13	0	13234.53	84361.02	71126.49	-3532613.66
Year 14	0	12705.15	80986.58	68281.43	-3464332.23
Year 15	0	12196.94	77747.11	65550.17	-3398782.06
Year 16	0	11709.07	74637.23	62928.16	-3335853.90
Year 17	0	11240.70	71651.74	60411.04	-3275442.86
Year 18	0	10791.08	68785.67	57994.59	-3217448.27
Year 19	0	10359.43	66034.24	55674.81	-3161773.46
Year 20	0	9945.05	63392.87	53447.82	-3108325.64
Year 21	0	9547.25	60857.16	51309.91	-3057015.73
Year 22	0	9165.36	58422.87	49257.51	-3007758.22
Year 23	0	8798.75	56085.96	47287.21	-2960471.02
Year 24	0	8446.80	53842.52	45395.72	-2915075.29
Year 25	0	8108.93	51688.82	43579.89	-2871495.40

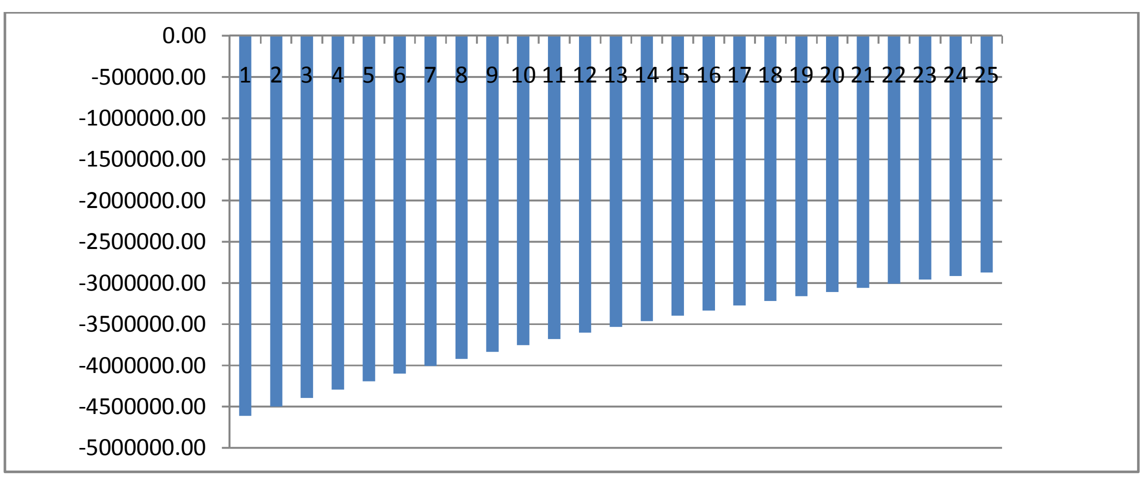


Fig. 4.2 Payback curve

4.2 Project Site 2: Porbandar (Gujarat)

4.2.1 30 KW GCPV

Initial investment-

Table 4.7 Costing of GCPV for Porbandar

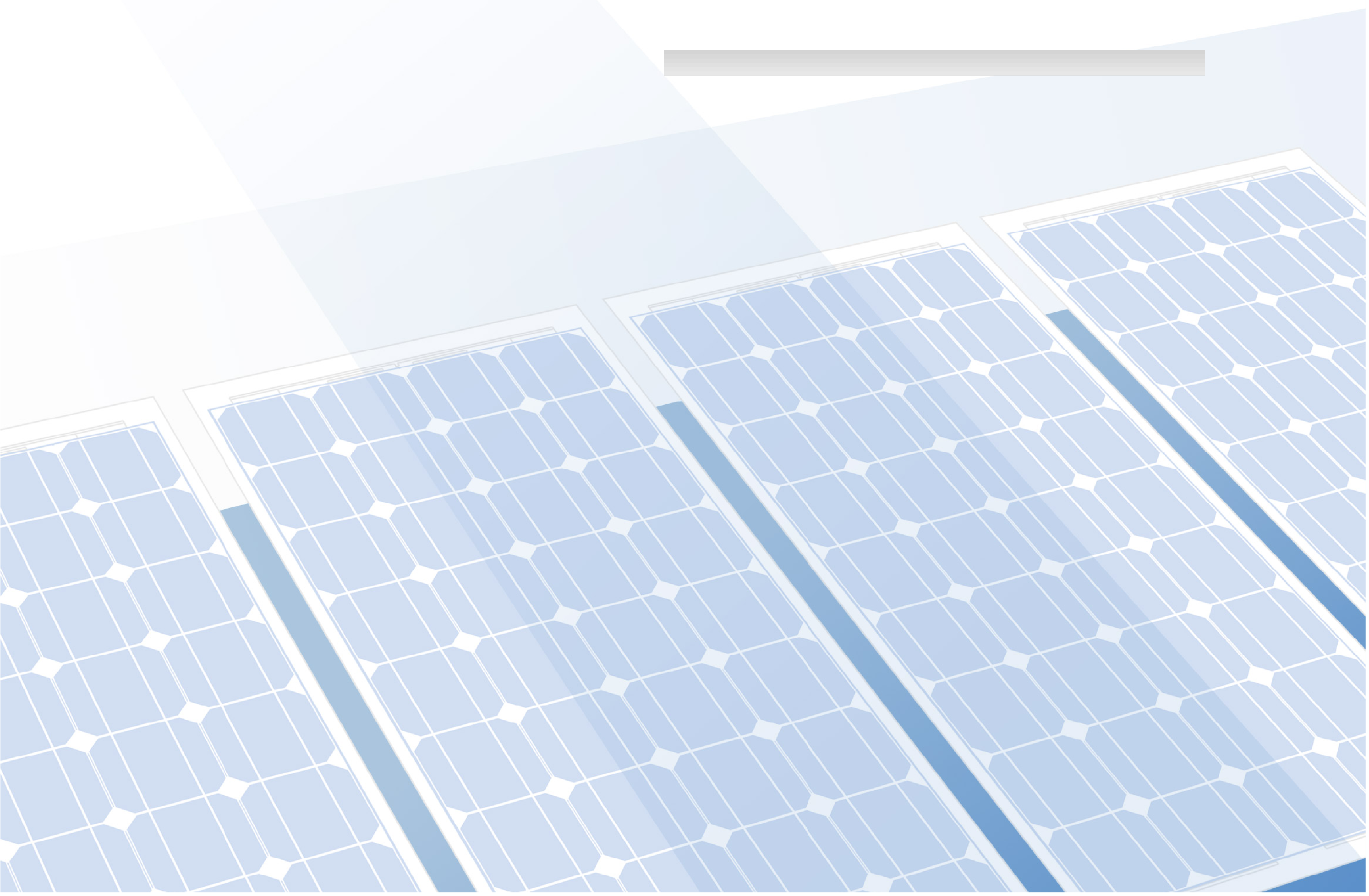
S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
1	Land	378	sq. m.	580	219240
2	Solar Panels	100	nos.	8400	840000
3	Mounting structures	1800	nos.	77.22	138996
4	Earthing and Protection	3	nos.	3240	9720
5	Accessories	1	nos.	6676	6676
6	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
7	Wire 1Cx 4 Sq.mm	230	mtrs.	49.28	11334
8	Inverter	1	no.	343035	343035
9	3 phase meter	1	no.	8500	8500
10	CB B 80 A	1	no.	4502	4502
11	MCB 1 pole 16 A	5	no.	1760	8800
12	Civil works			283500	283500
13	Documentation charges			50000	50000
				Total investment	1926903

Annual operation and maintenance cost (estimation) for fixed -tilt solar module plant-

Table 4.8 Operating cost of GCPV for Porbandar

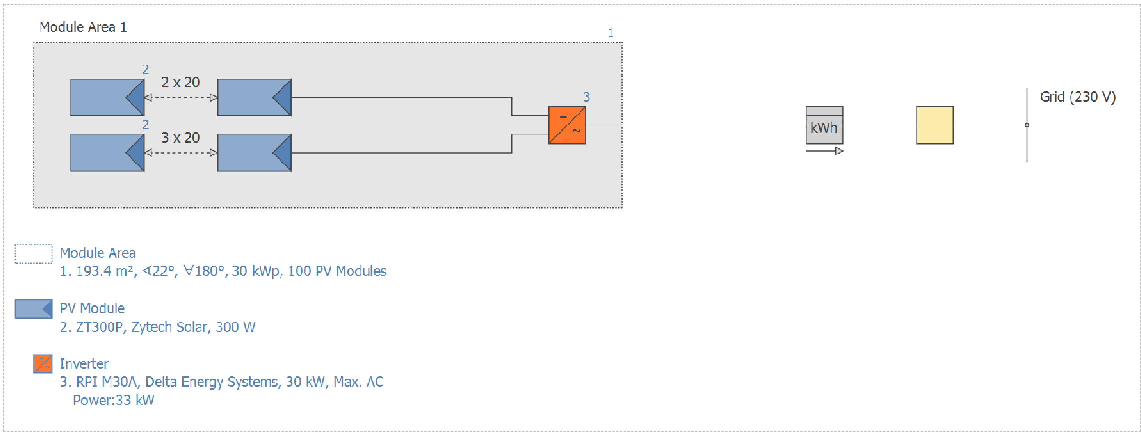
S. No.	Operation	Rs./KW/Annum	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total annual cost	22500

Porbandar 30 KW



Grid Connected PV System

Climate Data	Porbandar (1991 - 2010)
PV Generator Output	30 kWp
PV Generator Surface	193.4 m²
Number of PV Modules	100
Number of Inverters	1



The yield

PV Generator Energy (AC grid)	52,108 kWh
Spec. Annual Yield	1,736.92 kWh/kWp
Performance Ratio (PR)	81.6 %
CO_2 Emissions avoided	44,813 kg / year

Your Gain

Total investment costs	19,26,903.00 Rs.
Return on Assets	28.06 %
Amortization Period	3.9 Years
Electricity Production Costs	2.75 Rs./kWh

The results have been calculated with a mathematical model calculation from Valentin Software GmbH (PV*SOL algorithms). The actual yields from the solar power system may differ as a result of weather variations, the efficiency of the modules and inverter, and other factors.

Set-up of the system

Climate Data	Porbandar
Type of System	Grid Connected PV System

PV Generator Module Area

PV Modules*	100 x ZT300P	
Manufacturer	Zytech Solar	
Inclination	22	°
Orientation	South 180	°
Installation Type	Mounted - Open Space	
PV Generator Surface	193.4	m²
Shading	4	%

Inverter

Inverter 1*	1 x RPI M30A
Manufacturer	Delta Energy Systems
Configuration	MPP 1: 3 x 20 | MPP 2: 2 x 20

AC Mains

Number of Phases	3	
Mains Voltage (1-phase)	230	V
Displacement Power Factor (cos phi)	+/- 1	
Power Feed-in Limit as a Percentage of the DC Power	80	%

* The guarantee provisions of the respective manufacturer apply

Simulation Results

PV System

PV Generator Output	30	kWp
Spec. Annual Yield	1,736.92	kWh/kWp
Performance Ratio (PR)	81.6	%
Grid Feed-in	52,108	kWh/year
Grid Feed-in in the first year (incl. module degradation)	51,916	kWh/year
Stand-by Consumption	11	kWh/year
CO_2 Emissions avoided	44,813	kg / year

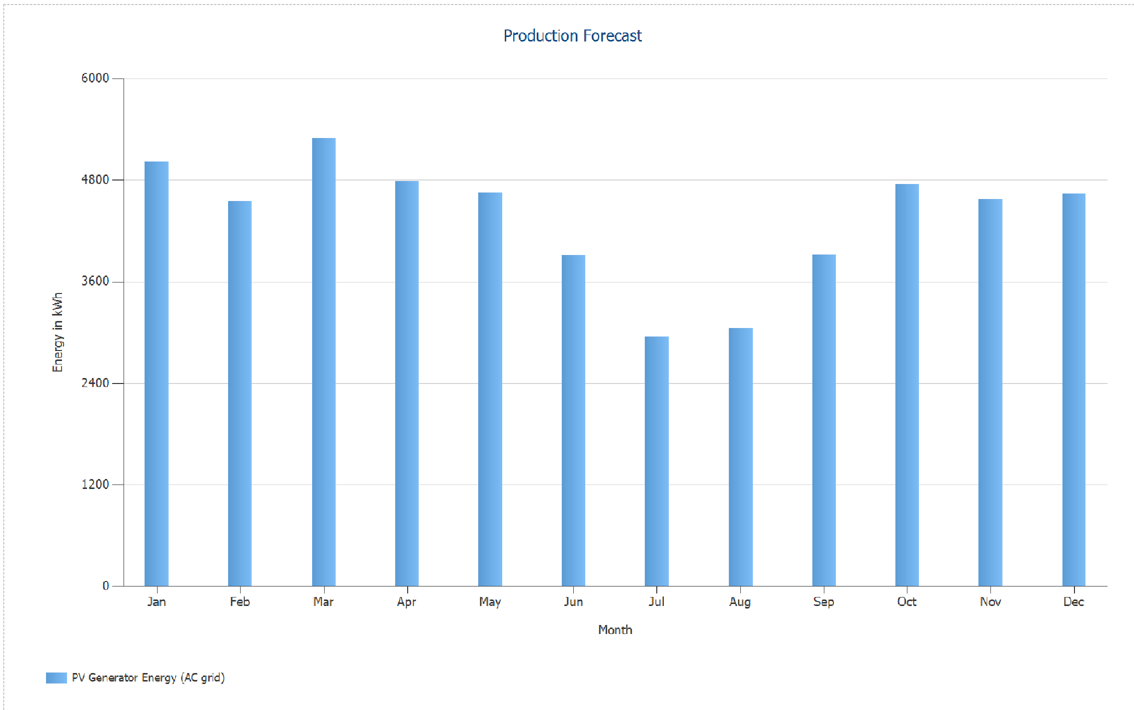


Figure: Production Forecast

Results per Module Area

PV Generator Output	30	kWp
PV Generator Surface	193.4	m²
Global Radiation at the Module	2129.5	kWh/m²
PV Generator Energy (AC grid)	52107.6	kWh/year
Spec. Annual Yield	1736.9	kWh/kWp
Performance Ratio (PR)	81.6	%

PV System Energy Balance

Global radiation - horizontal	**2,082.2**	**kWh/m²**	
Deviation from standard spectrum	-20.82	kWh/m²	-1.00 %
Ground Reflection (Albedo)	7.51	kWh/m²	0.36 %
Orientation and inclination of the module surface	149.39	kWh/m²	7.22 %
Shading	-88.73	kWh/m²	-4.00 %
Reflection on the Module Interface	-16.19	kWh/m²	-0.76 %
Global Radiation at the Module	**2,113.4**	**kWh/m²**	
	2,113.4	kWh/m²	
	x 193.44	m²	
	= 408,807.5	kWh	
Global PV Radiation	**408,807.5**	**kWh**	
Soiling	-20,440.37	kWh	-5.00 %
STC Conversion (Rated Efficiency of Module 15.51 %)	-328,130.44	kWh	-84.49 %
Rated PV Energy	**60,236.7**	**kWh**	
Low-light performance	-335.84	kWh	-0.56 %
Deviation from the nominal module temperature	-4,733.71	kWh	-7.90 %
Diodes	-551.67	kWh	-1.00 %
Mismatch (Manufacturer Information)	-1,092.31	kWh	-2.00 %
Mismatch (Configuration/Shading)	0.00	kWh	0.00 %
String Cable	-82.82	kWh	-0.15 %
PV Energy (DC) without inverter regulation	**53,440.3**	**kWh**	
Regulation on account of the MPP Voltage Range	0.00	kWh	0.00 %
Regulation on account of the max. DC Current	0.00	kWh	0.00 %
Regulation on account of the max. DC Power	0.00	kWh	0.00 %
Regulation on account of the max. AC Power/cos phi	-1.35	kWh	0.00 %
MPP Matching	-136.31	kWh	-0.26 %
PV energy (DC)	**53,302.6**	**kWh**	

Energy at the Inverter Input	**53,302.6**	**kWh**	
Input voltage deviates from rated voltage	-69.32	kWh	-0.13 %
DC/AC Conversion	-936.83	kWh	-1.76 %
Stand-by Consumption	-11.26	kWh	-0.02 %
AC Cable	-188.90	kWh	-0.36 %
PV energy (AC) minus standby use	**52,096.3**	**kWh**	
Grid Feed-in	**52,107.6**	**kWh**	

Financial Analysis

System Data

Grid Feed-in in the first year (incl. module degradation)	51,916	kWh/year
PV Generator Output	30	kWp
Start of Operation of the System	25-05-2017	
Assessment Period	25	Years

Economic Parameters

Return on Assets	28.06	%
Accrued Cash Flow (Cash Balance)	64,47,249.05	Rs.
Amortization Period	3.9	Years
Electricity Production Costs	2.75	Rs./kWh

Payment Overview

Specific Investment Costs	64,230.10	Rs./kWp
Investment Costs	19,26,903.00	Rs.
One-off Payments	0.00	Rs.
Incoming Subsidies	0.00	Rs.
Annual Costs	22,500.00	Rs./year
Other Revenue or Savings	0.00	Rs./year

Remuneration and Savings

Total Payment from Utility in First Year	5,88,205.61	Rs./year
Remuneration of Electricity sold to Third Party		
Price of Electricity sold to Third Party	11.33	Rs./kWh
Remuneration of Electricity sold to Third Party	5,88,205.61	Rs./year

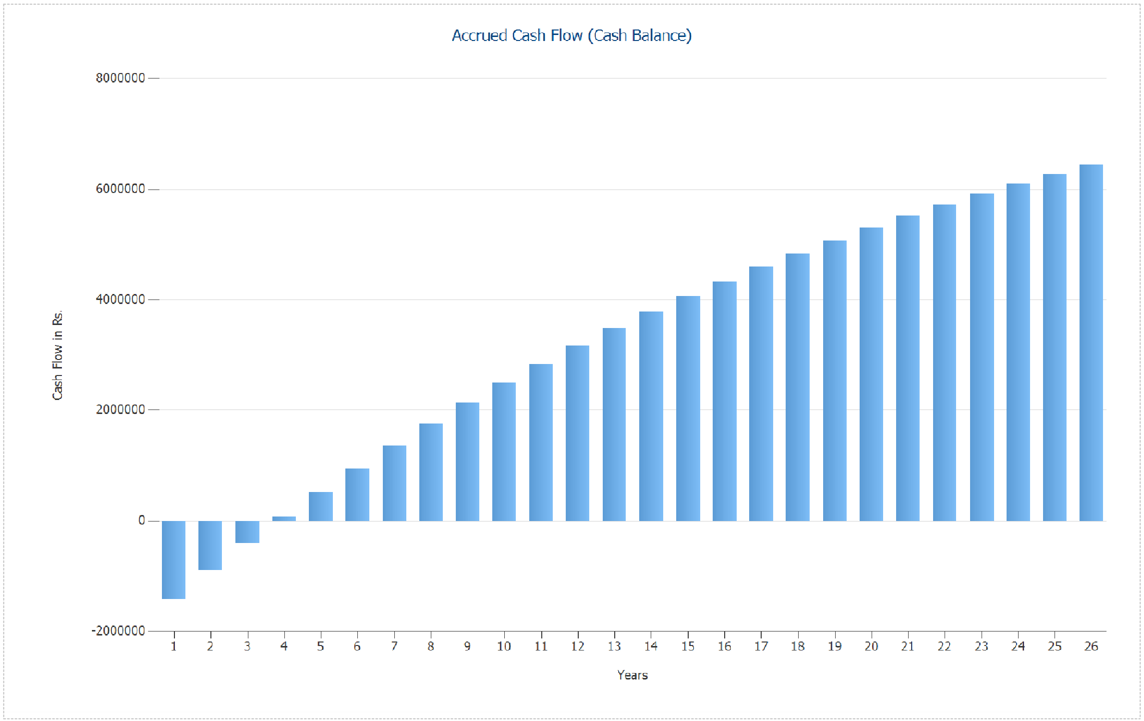


Figure: Accrued Cash Flow (Cash Balance)

Cashflow Table

	year 1	year 2	year 3	year 4	year 5
Investments	Rs. -19,26,903.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -21,634.62	Rs. -20,802.51	Rs. -20,002.42	Rs. -19,233.09	Rs. -18,493.36
Feed-in / Export Tariff	Rs. 5,26,379.95	Rs. 5,40,311.76	Rs. 5,16,148.44	Rs. 4,93,044.56	Rs. 4,70,954.36
Annual Cash Flow	**Rs. -14,22,157.66**	**Rs. 5,19,509.25**	**Rs. 4,96,146.02**	**Rs. 4,73,811.46**	**Rs. 4,52,461.00**
Accrued Cash Flow (Cash Balance)	Rs. -14,22,157.66	Rs. -9,02,648.41	Rs. -4,06,502.39	Rs. 67,309.07	Rs. 5,19,770.08

	year 6	year 7	year 8	year 9	year 10
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -17,782.08	Rs. -17,098.15	Rs. -16,440.53	Rs. -15,808.20	Rs. -15,200.19
Feed-in / Export Tariff	Rs. 4,49,834.06	Rs. 4,29,641.72	Rs. 4,10,337.19	Rs. 3,91,882.07	Rs. 3,74,239.57
Annual Cash Flow	**Rs. 4,32,051.98**	**Rs. 4,12,543.57**	**Rs. 3,93,896.66**	**Rs. 3,76,073.87**	**Rs. 3,59,039.37**
Accrued Cash Flow (Cash Balance)	Rs. 9,51,822.06	Rs. 13,64,365.63	Rs. 17,58,262.29	Rs. 21,34,336.16	Rs. 24,93,375.53

	year 11	year 12	year 13	year 14	year 15
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -14,615.57	Rs. -14,053.43	Rs. -13,512.92	Rs. -12,993.19	Rs. -12,493.45
Feed-in / Export Tariff	Rs. 3,57,374.47	Rs. 3,41,253.08	Rs. 3,25,843.13	Rs. 3,11,113.76	Rs. 2,97,035.39
Annual Cash Flow	**Rs. 3,42,758.90**	**Rs. 3,27,199.64**	**Rs. 3,12,330.22**	**Rs. 2,98,120.57**	**Rs. 2,84,541.94**
Accrued Cash Flow (Cash Balance)	Rs. 28,36,134.43	Rs. 31,63,334.07	Rs. 34,75,664.29	Rs. 37,73,784.86	Rs. 40,58,326.80

	year 16	year 17	year 18	year 19	year 20
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -12,012.93	Rs. -11,550.90	Rs. -11,106.63	Rs. -10,679.45	Rs. -10,268.71
Feed-in / Export Tariff	Rs. 2,83,579.75	Rs. 2,70,719.76	Rs. 2,58,429.50	Rs. 2,46,684.17	Rs. 2,35,460.04
Annual Cash Flow	**Rs. 2,71,566.82**	**Rs. 2,59,168.86**	**Rs. 2,47,322.87**	**Rs. 2,36,004.72**	**Rs. 2,25,191.34**
Accrued Cash Flow (Cash Balance)	Rs. 43,29,893.62	Rs. 45,89,062.48	Rs. 48,36,385.35	Rs. 50,72,390.07	Rs. 52,97,581.41

	year 21	year 22	year 23	year 24	year 25
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -9,873.76	Rs. -9,494.00	Rs. -9,128.84	Rs. -8,777.73	Rs. -8,440.13
Feed-in / Export Tariff	Rs. 2,24,734.39	Rs. 2,14,485.47	Rs. 2,04,692.48	Rs. 1,95,335.51	Rs. 1,86,395.51
Annual Cash Flow	**Rs. 2,14,860.63**	**Rs. 2,04,991.47**	**Rs. 1,95,563.64**	**Rs. 1,86,557.78**	**Rs. 1,77,955.39**
Accrued Cash Flow (Cash Balance)	Rs. 55,12,442.04	Rs. 57,17,433.51	Rs. 59,12,997.15	Rs. 60,99,554.92	Rs. 62,77,510.31

	year 26
Investments	Rs. 0.00
Operating costs	Rs. -8,115.51
Feed-in / Export Tariff	Rs. 1,77,854.25
Annual Cash Flow	**Rs. 1,69,738.74**
Accrued Cash Flow (Cash Balance)	Rs. 64,47,249.05

Degradation and inflation rates are applied on a monthly basis over the entire observation period.
This is done in the first year.

PV Module: ZT300P

Manufacturer	Zytech Solar
Available	Yes

Electrical Data

Cell Type	Si polycrystalline
Only Transformer Inverters suitable	No
Number of Cells	72
Number of Bypass Diodes	3

Mechanical Data

Width	1000	mm
Height	1965	mm
Depth	50	mm
Frame Width	35	mm
Weight	26	kg
Framed	No	

I/V Characteristics at STC

MPP Voltage	36.72	V
MPP Current	8.17	A
Nominal output	300	W
Open Circuit Voltage	45.5	V
Short-Circuit Current	8.65	A

I/V Part Load Characteristics

Values source	Manufacturer/user-created	
Irradiance	200	W/m²
Voltage in MPP at Part Load	36.719	V
Current in MPP at Part Load	1.6078	A
Open Circuit Voltage (Part Load)	43.374	V
Short Circuit Current at Part Load	1.6746	A

Further

Voltage Coefficient	-120 ±5	mV/°C
Electricity Coefficient	0.04	%/°C
Output Coefficient	-0.35	%/°C
Incident Angle Modifier	99	%
Maximum System Voltage	1000	V
Spec. Heat Capacity	920	J/(kg*K)
Absorption Coefficient	70	%
Emissions Coefficient	85	%

Inverter: RPI M30A

Manufacturer	Delta Energy Systems
Available	Yes

Electrical Data

DC Power Rating	38	kW
AC Power Rating	30	kW
Max. DC Power	35	kW
Max. AC Power	33	kW
Stand-by Consumption	2.5	W
Night Consumption	2.5	W
Feed-in from	40	W
Max. Input Current	60	A
Max. Input Voltage	1100	V
Nom. DC Voltage	600	V
Number of Feed-in Phases	3	
Number of DC Inlets	6	
With Transformer	No	
Change in Efficiency when Input Voltage deviates from Rated Voltage	0.2	%/100V

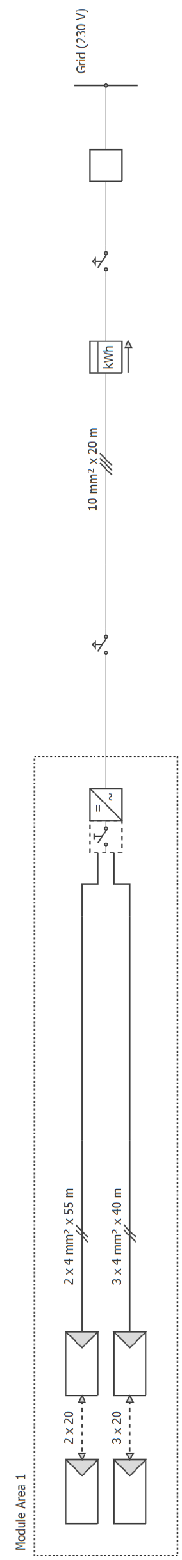
MPP Tracker

Output Range < 20% of Power Rating	98.5	%
Output Range > 20% of Power Rating	99.8	%
No. of MPP Trackers	2	
Max. Input Current per MPP Tracker	30	A
Max. Input Power per MPP Tracker	19	kW
Min. MPP Voltage	250	V
Max. MPP Voltage	800	V

Project Number: May 17-3
Date of Offer: 25-05-2017

Project Designer: Naveen Kumar
Company: Please enter in Options > User data.

Porbandar 30 KW



4.2.2 Grid connected 30 KW wind-solar hybrid system

Initial investment-

Table 4.9 Costing of hybrid system for Porbandar

S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
	19.8 KW wind				
1	Land	1836	sq. m.	580	1064880
2	Wind turbines	6	nos.	330000	1980000
3	Wind interface	6	nos.	38366	230196
4	Wind inverter	1	no.	483556	483556
5	Earthing and Protection	2	nos.	3240	6480
6	Accessories	1	nos.	5000	5000
7	Wire 1Cx 10 Sq.mm	30	mtrs.	130	3900
8	Wire 1Cx 4 Sq.mm	540	mtrs.	49.28	26611
9	3 phase meter	1	no.	8500	8500
10	MCB 63 A	1	no.	1388	1388
11	MCB 1 pole 16 A	6	nos.	1760	10560
12	Civil works	1	no.	215820	215820
	10.2 KW Solar				
13	Solar Modules	34	nos.	8400	285600
14	Mounting structures	600	nos.	77.22	46332
15	Earthing and Protection	1	no.	3240	3240
16	Accessories	1	nos.	2288	2288
17	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
18	Wire 1Cx 4 Sq.mm	70	mtrs.	49.28	3449.6
19	Solar inverter	1	no.	151250	151250
20	3 phase meter	1	no.	8500	8500
21	MCB 32 A	1	no.	925	925
22	MCB 1 pole 16 A	2	no.	1760	3520
23	Civil works	1	no.	96390	96390
	Others				
24	Documentation charges	1	no.	50000	50000
				Total investment	**4690986**

Annual operation and maintenance cost (estimation) for hybrid plant-

Table 4.10 Operating cost of hybrid for Porbandar

S. No.	Operation	Rs./KW/Month	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total annual cost	22500

Grid feed-in-

Table 4.11 KWh calculation of hybrid system for Porbandar

19.8 KW Wind	
Wind energy generated	7605 KWh
Losses accounted	10%
Grid feed-in	7605 X 0.9 = 6844 KWh
Feed- in tariff (Rs.)	6844 X 4.19= 28676
10.2 KW Solar	
Solar energy generated	20294 KWh
Losses accounted	10%
Grid feed- in	20294 X 0.9 = 18264KWh
Feed- in tariff (Rs.)	18264 X 11.33 = 206931
Total Feed in tariff for 30 KW (Rs.)	235607
Capital cost (Rs.)	4690986
Annual operating and maintenance cost (Rs.)	22500
Rupee depreciation rate	4%
Working life of plant	25 years
Total cash generated through energy export (Rs.)	3616680

Table 4.12 Calculation of annual cash flow: Porbandar

Years	Investment (Rs.)	Operating and maint. cost (Rs.)	Feed –in /Export tariff (Rs.)	Annual cash flow (Rs.)	Cash balance (Rs.)
Year 1	-4690986	21600.00	226182.72	-4486403.28	-4486403.28
Year 2	0	20736.00	217135.41	196399.41	-4290003.87
Year 3	0	19906.56	208449.99	188543.43	-4101460.43
Year 4	0	19110.30	200111.99	181001.70	-3920458.74
Year 5	0	18345.89	192107.52	173761.63	-3746697.11
Year 6	0	17612.05	184423.21	166811.16	-3579885.94
Year 7	0	16907.57	177046.29	160138.72	-3419747.23
Year 8	0	16231.27	169964.43	153733.17	-3266014.06
Year 9	0	15582.01	163165.86	147583.84	-3118430.21
Year 10	0	14958.73	156639.22	141680.49	-2976749.73
Year 11	0	14360.38	150373.65	136013.27	-2840736.46
Year 12	0	13785.97	144358.71	130572.74	-2710163.72
Year 13	0	13234.53	138584.36	125349.83	-2584813.89
Year 14	0	12705.15	133040.99	120335.84	-2464478.05
Year 15	0	12196.94	127719.35	115522.40	-2348955.65
Year 16	0	11709.07	122610.57	110901.51	-2238054.15
Year 17	0	11240.70	117706.15	106465.45	-2131588.70
Year 18	0	10791.08	112997.90	102206.83	-2029381.87
Year 19	0	10359.43	108477.99	98118.55	-1931263.32
Year 20	0	9945.05	104138.87	94193.81	-1837069.50
Year 21	0	9547.25	99973.31	90426.06	-1746643.44
Year 22	0	9165.36	95974.38	86809.02	-1659834.43
Year 23	0	8798.75	92135.41	83336.66	-1576497.77
Year 24	0	8446.80	88449.99	80003.19	-1496494.58
Year 25	0	8108.93	84911.99	76803.06	-1419691.52

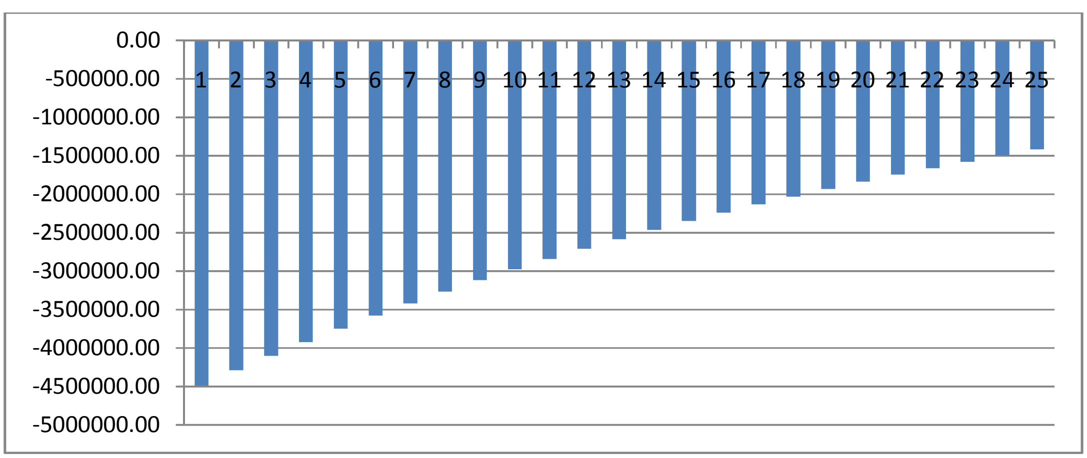


Fig. 4.3 Payback curve

4.3 Project Site 3: Visakhapatnam (Andhra Pradesh)

4.3.1 30 KW GCPV

Initial investment-

Table 4.13 Costing of GCPV for Visakhapatnam

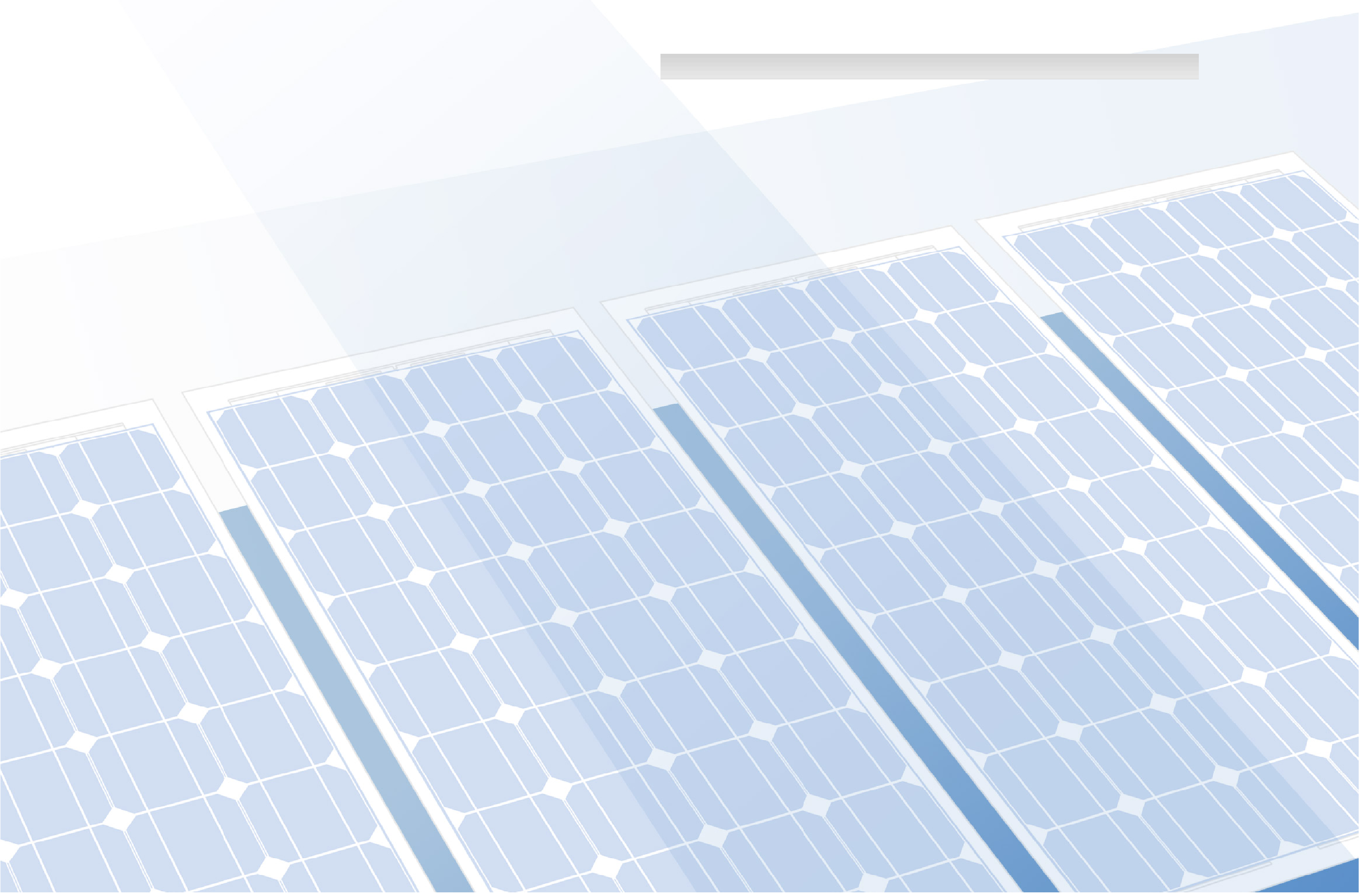
S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
1	Land	399	sq. m.	480	191520
2	Solar Panels	100	nos.	8400	840000
3	Mounting structures	1800	nos.	77.22	138996
4	Earthing and Protection	3	nos.	3240	9720
5	Accessories	1	nos.	6676	6676
6	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
7	Wire 1Cx 4 Sq.mm	230	mtrs.	49.28	11334
8	Inverter	1	no.	343035	343035
9	3 phase meter	1	no.	8500	8500
10	CB B 80 A	1	no.	4502	4502
11	MCB 1 pole 10 A Sch.	5	no.	1760	8800
12	Civil works			283500	283500
13	Documentation charges			50000	50000
				Total investment	1899183

Annual operation and maintenance cost (estimation) for fixed -tilt solar module plant-

Table 4.14 Operating cost of GCPV for Visakhapatnam

S. No.	Operation	Rs./KW/Annum	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total annual cost	22500

Visakhapatnam 30 KW

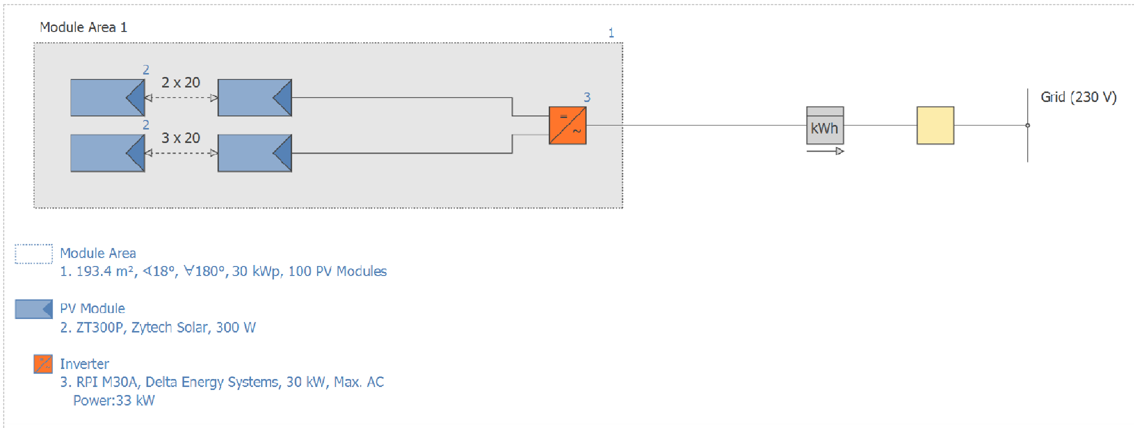


Project Number: May 17-3
Date of Offer: 25-05-2017

Project Designer: Naveen Kumar
Company: Please enter in Options > User data.

Visakhapatnam 30 KW

Grid Connected PV System		
Climate Data	Vishakhapatnam (1981 - 2010)	
PV Generator Output	30	kWp
PV Generator Surface	193.4	m²
Number of PV Modules	100	
Number of Inverters	1	



The yield		
PV Generator Energy (AC grid)	45,533	kWh
Spec. Annual Yield	1,517.75	kWh/kWp
Performance Ratio (PR)	82.4	%
CO_2 Emissions avoided	39,158	kg / year

Your Gain		
Total investment costs	18,99,183.00	Rs.
Return on Assets	9.58	%
Amortization Period	11.7	Years
Electricity Production Costs	3.1	Rs./kWh

The results have been calculated with a mathematical model calculation from Valentin Software GmbH (PV*SOL algorithms). The actual yields from the solar power system may differ as a result of weather variations, the efficiency of the modules and inverter, and other factors.

Set-up of the system

Climate Data	Vishakhapatnam	
Type of System	Grid Connected PV System	

PV Generator Module Area

PV Modules*	100 x ZT300P	
Manufacturer	Zytech Solar	
Inclination	18	°
Orientation	South 180	°
Installation Type	Mounted - Open Space	
PV Generator Surface	193.4	m²
Shading	4	%

Inverter

Inverter 1*	1 x RPI M30A
Manufacturer	Delta Energy Systems
Configuration	MPP 1: 3 x 20 | MPP 2: 2 x 20

AC Mains

Number of Phases	3	
Mains Voltage (1-phase)	230	V
Displacement Power Factor (cos phi)	+/- 1	
Power Feed-in Limit as a Percentage of the DC Power	80	%

* The guarantee provisions of the respective manufacturer apply

Simulation Results

PV System

PV Generator Output	30 kWp
Spec. Annual Yield	1,517.75 kWh/kWp
Performance Ratio (PR)	82.4 %
Grid Feed-in	45,533 kWh/year
Grid Feed-in in the first year (incl. module degradation)	45,366 kWh/year
Stand-by Consumption	11 kWh/year
CO_2 Emissions avoided	39,158 kg / year

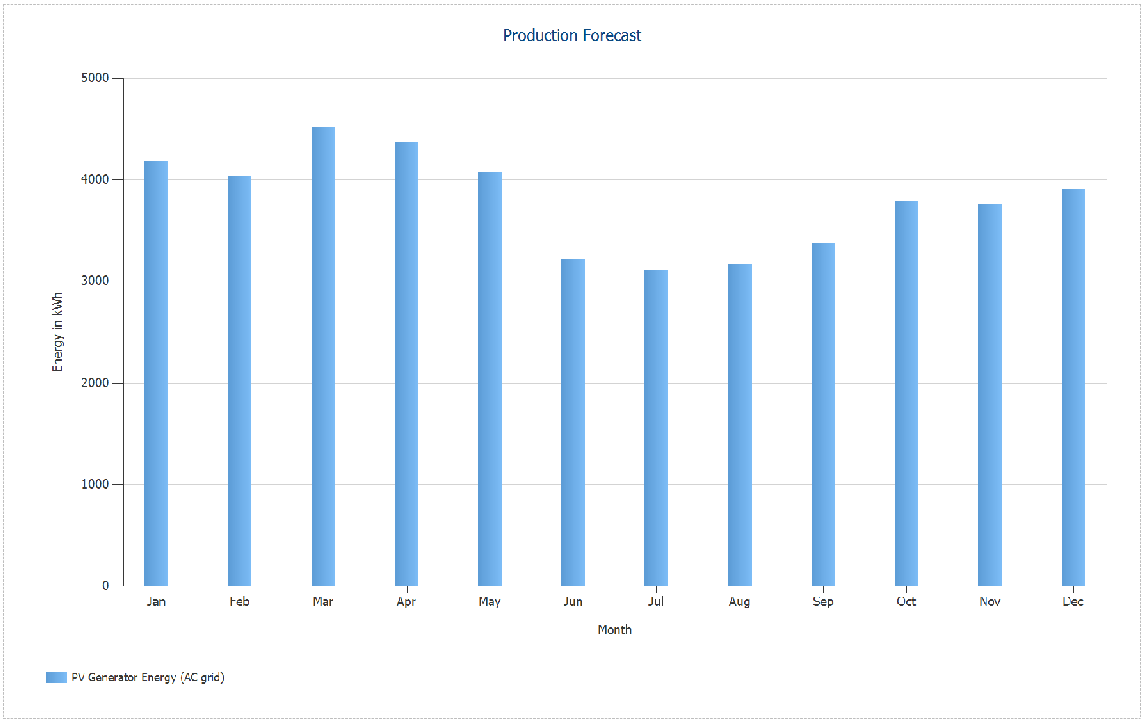


Figure: Production Forecast

Results per Module Area

PV Generator Output	30	kWp
PV Generator Surface	193.4	m²
Global Radiation at the Module	1842.1	kWh/m²
PV Generator Energy (AC grid)	45532.6	kWh/year
Spec. Annual Yield	1517.8	kWh/kWp
Performance Ratio (PR)	82.4	%

PV System Energy Balance

Global radiation - horizontal	**1,869.9**	**kWh/m²**	
Deviation from standard spectrum	-18.70	kWh/m²	-1.00 %
Ground Reflection (Albedo)	4.53	kWh/m²	0.24 %
Orientation and inclination of the module surface	63.17	kWh/m²	3.40 %
Shading	-76.75	kWh/m²	-4.00 %
Reflection on the Module Interface	-14.75	kWh/m²	-0.80 %
Global Radiation at the Module	**1,827.3**	**kWh/m²**	
	1,827.3	kWh/m²	
	x 193.44	m²	
	= 353,481.7	kWh	
Global PV Radiation	**353,481.7**	**kWh**	
Soiling	-17,674.08	kWh	-5.00 %
STC Conversion (Rated Efficiency of Module 15.51 %)	-283,723.02	kWh	-84.49 %
Rated PV Energy	**52,084.5**	**kWh**	
Low-light performance	-186.95	kWh	-0.36 %
Deviation from the nominal module temperature	-3,670.30	kWh	-7.07 %
Diodes	-482.27	kWh	-1.00 %
Mismatch (Manufacturer Information)	-954.90	kWh	-2.00 %
Mismatch (Configuration/Shading)	0.00	kWh	0.00 %
String Cable	-63.85	kWh	-0.14 %
PV Energy (DC) without inverter regulation	**46,726.3**	**kWh**	
Regulation on account of the MPP Voltage Range	0.00	kWh	0.00 %
Regulation on account of the max. DC Current	0.00	kWh	0.00 %
Regulation on account of the max. DC Power	0.00	kWh	0.00 %
Regulation on account of the max. AC Power/cos phi	-0.13	kWh	0.00 %
MPP Matching	-127.33	kWh	-0.27 %
PV energy (DC)	**46,598.8**	**kWh**	
Energy at the Inverter Input	**46,598.8**	**kWh**	
Input voltage deviates from rated voltage	-66.04	kWh	-0.14 %
DC/AC Conversion	-851.61	kWh	-1.83 %
Stand-by Consumption	-11.25	kWh	-0.02 %
AC Cable	-148.61	kWh	-0.33 %
PV energy (AC) minus standby use	**45,521.3**	**kWh**	
Grid Feed-in	**45,532.6**	**kWh**	

Financial Analysis

System Data

Grid Feed-in in the first year (incl. module degradation)	45,366	kWh/year
PV Generator Output	30	kWp
Start of Operation of the System	25-05-2017	
Assessment Period	25	Years

Economic Parameters

Return on Assets	9.58	%
Accrued Cash Flow (Cash Balance)	12,77,572.59	Rs.
Amortization Period	11.7	Years
Electricity Production Costs	3.1	Rs./kWh

Payment Overview

Specific Investment Costs	63,306.10	Rs./kWp
Investment Costs	18,99,183.00	Rs.
One-off Payments	0.00	Rs.
Incoming Subsidies	0.00	Rs.
Annual Costs	22,500.00	Rs./year
Other Revenue or Savings	0.00	Rs./year

Remuneration and Savings

Total Payment from Utility in First Year	2,38,171.75	Rs./year
Remuneration of Electricity sold to Third Party		
Price of Electricity sold to Third Party	5.25	Rs./kWh
Remuneration of Electricity sold to Third Party	2,38,171.75	Rs./year

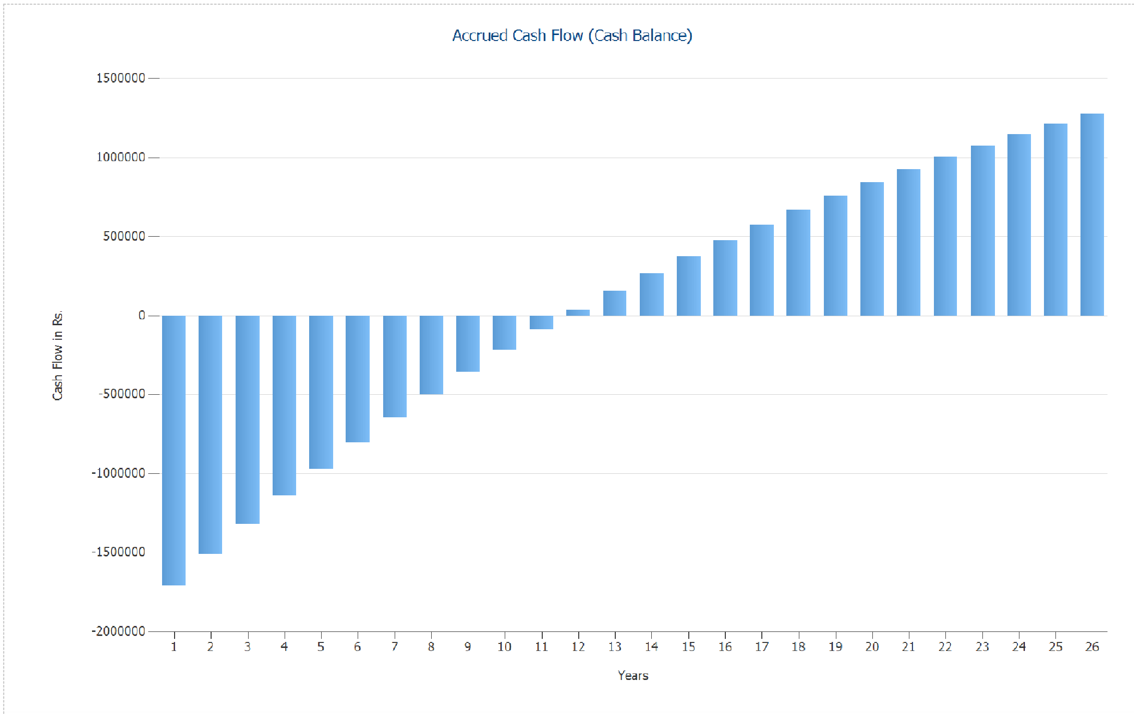


Figure: Accrued Cash Flow (Cash Balance)

Cashflow Table

	year 1	year 2	year 3	year 4	year 5
Investments	Rs. -18,99,183.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -21,634.62	Rs. -20,802.51	Rs. -20,002.42	Rs. -19,233.09	Rs. -18,493.36
Feed-in / Export Tariff	Rs. 2,13,089.69	Rs. 2,18,778.98	Rs. 2,08,994.98	Rs. 1,99,639.96	Rs. 1,90,695.40
Annual Cash Flow	**Rs. -17,07,727.92**	**Rs. 1,97,976.46**	**Rs. 1,88,992.56**	**Rs. 1,80,406.87**	**Rs. 1,72,202.04**
Accrued Cash Flow (Cash Balance)	Rs. -17,07,727.92	Rs. -15,09,751.46	Rs. -13,20,758.89	Rs. -11,40,352.03	Rs. -9,68,149.99

	year 6	year 7	year 8	year 9	year 10
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -17,782.08	Rs. -17,098.15	Rs. -16,440.53	Rs. -15,808.20	Rs. -15,200.19
Feed-in / Export Tariff	Rs. 1,82,143.55	Rs. 1,73,967.44	Rs. 1,66,150.82	Rs. 1,58,678.13	Rs. 1,51,534.48
Annual Cash Flow	**Rs. 1,64,361.47**	**Rs. 1,56,869.29**	**Rs. 1,49,710.29**	**Rs. 1,42,869.93**	**Rs. 1,36,334.29**
Accrued Cash Flow (Cash Balance)	Rs. -8,03,788.52	Rs. -6,46,919.23	Rs. -4,97,208.93	Rs. -3,54,339.00	Rs. -2,18,004.71

	year 11	year 12	year 13	year 14	year 15
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -14,615.57	Rs. -14,053.43	Rs. -13,512.92	Rs. -12,993.19	Rs. -12,493.45
Feed-in / Export Tariff	Rs. 1,44,705.61	Rs. 1,38,177.87	Rs. 1,31,938.21	Rs. 1,25,974.11	Rs. 1,20,273.62
Annual Cash Flow	**Rs. 1,30,090.04**	**Rs. 1,24,124.44**	**Rs. 1,18,425.29**	**Rs. 1,12,980.92**	**Rs. 1,07,780.17**
Accrued Cash Flow (Cash Balance)	Rs. -87,914.68	Rs. 36,209.76	Rs. 1,54,635.05	Rs. 2,67,615.98	Rs. 3,75,396.14

	year 16	year 17	year 18	year 19	year 20
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -12,012.93	Rs. -11,550.90	Rs. -11,106.63	Rs. -10,679.45	Rs. -10,268.71
Feed-in / Export Tariff	Rs. 1,14,825.27	Rs. 1,09,618.11	Rs. 1,04,641.64	Rs. 99,885.81	Rs. 95,341.03
Annual Cash Flow	**Rs. 1,02,812.34**	**Rs. 98,067.21**	**Rs. 93,535.00**	**Rs. 89,206.36**	**Rs. 85,072.32**
Accrued Cash Flow (Cash Balance)	Rs. 4,78,208.48	Rs. 5,76,275.69	Rs. 6,69,810.69	Rs. 7,59,017.05	Rs. 8,44,089.38

	year 21	year 22	year 23	year 24	year 25
Investments	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00
Operating costs	Rs. -9,873.76	Rs. -9,494.00	Rs. -9,128.84	Rs. -8,777.73	Rs. -8,440.13
Feed-in / Export Tariff	Rs. 90,998.08	Rs. 86,848.17	Rs. 82,882.87	Rs. 79,094.12	Rs. 75,474.20
Annual Cash Flow	**Rs. 81,124.32**	**Rs. 77,354.17**	**Rs. 73,754.03**	**Rs. 70,316.39**	**Rs. 67,034.08**
Accrued Cash Flow (Cash Balance)	Rs. 9,25,213.70	Rs. 10,02,567.87	Rs. 10,76,321.90	Rs. 11,46,638.29	Rs. 12,13,672.36

	year 26
Investments	Rs. 0.00
Operating costs	Rs. -8,115.51
Feed-in / Export Tariff	Rs. 72,015.74
Annual Cash Flow	**Rs. 63,900.23**
Accrued Cash Flow (Cash Balance)	Rs. 12,77,572.59

Degradation and inflation rates are applied on a monthly basis over the entire observation period.
This is done in the first year.

PV Module: ZT300P

Manufacturer	Zytech Solar
Available	Yes

Electrical Data

Cell Type	Si polycrystalline
Only Transformer Inverters suitable	No
Number of Cells	72
Number of Bypass Diodes	3

Mechanical Data

Width	1000	mm
Height	1965	mm
Depth	50	mm
Frame Width	35	mm
Weight	26	kg
Framed	No	

I/V Characteristics at STC

MPP Voltage	36.72	V
MPP Current	8.17	A
Nominal output	300	W
Open Circuit Voltage	45.5	V
Short-Circuit Current	8.65	A
Increase open circuit voltage before stabilisation	0	%

I/V Part Load Characteristics

Values source	Manufacturer/user-created	
Irradiance	200	W/m²
Voltage in MPP at Part Load	36.719	V
Current in MPP at Part Load	1.6078	A
Open Circuit Voltage (Part Load)	43.374	V
Short Circuit Current at Part Load	1.6746	A

Further

Voltage Coefficient	120 ±5	mV/°C
Electricity Coefficient	0.04	%/°C
Output Coefficient	-0.35	%/°C
Incident Angle Modifier	99	%
Maximum System Voltage	1000	V
Spec. Heat Capacity	920	J/(kg*K)
Absorption Coefficient	70	%
Emissions Coefficient	85	%

Inverter: RPI M30A

Manufacturer	Delta Energy Systems
Available	Yes

Electrical Data

DC Power Rating	38 kW
AC Power Rating	30 kW
Max. DC Power	35 kW
Max. AC Power	33 kW
Stand-by Consumption	2.5 W
Night Consumption	2.5 W
Feed-in from	40 W
Max. Input Current	60 A
Max. Input Voltage	1100 V
Nom. DC Voltage	600 V
Number of Feed-in Phases	3
Number of DC Inlets	6
With Transformer	No
Change in Efficiency when Input Voltage deviates from Rated Voltage	0.2 %/100V

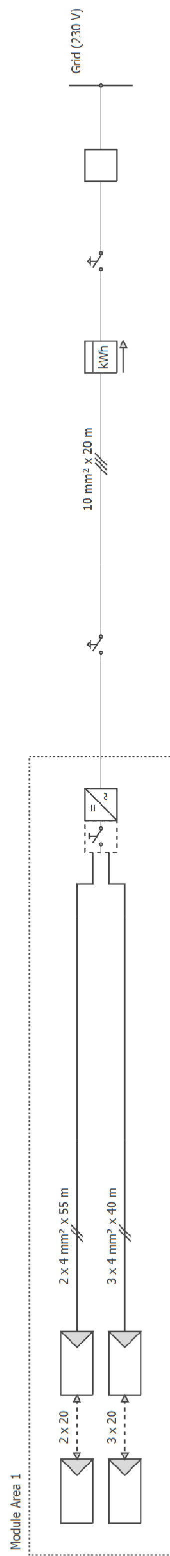
MPP Tracker

Output Range < 20% of Power Rating	98.5 %
Output Range > 20% of Power Rating	99.8 %
No. of MPP Trackers	2
Max. Input Current per MPP Tracker	30 A
Max. Input Power per MPP Tracker	19 kW
Min. MPP Voltage	250 V
Max. MPP Voltage	800 V

Project Number: May 17-3
Date of Offer: 25-05-2017

Project Designer: Naveen Kumar
Company: Please enter in Options > User data.

Visakhapatnam 30 KW



4.3.2 Grid connected 30 KW wind-solar hybrid system

Initial investment-

Table 4.15 Costing of hybrid system for Vishakhapatnam

S. No.	Item/ Material	Qty.	Unit	Price/unit	Individual Mat. Cost (in Rs.)
	19.8 KW wind				
1	Land	1836	sq. m.	480	881280
2	Wind turbines	6	nos.	330000	1980000
3	Wind interface	6	nos.	38366	230196
4	Wind inverter	1	no.	483556	483556
5	Earthing and Protection	2	nos.	3240	6480
6	Accessories	1	nos.	5000	5000
7	Wire 1Cx 10 Sq.mm	30	mtrs.	130	3900
8	Wire 1Cx 4 Sq.mm	540	mtrs.	49.28	26611
9	3 phase meter	1	no.	8500	8500
10	MCB 63 A	1	no.	1388	1388
11	MCB 1 pole 16 A	6	nos.	1760	10560
12	Civil works	1	no.	215820	215820
	10.2 KW Solar				
13	Solar Modules	34	nos.	8400	285600
14	Mounting structures	600	nos.	77.22	46332
15	Earthing and Protection	1	no.	3240	3240
16	Accessories	1	nos.	2288	2288
17	Wire 1Cx 10 Sq.mm	20	mtrs.	130	2600
18	Wire 1Cx 4 Sq.mm	70	mtrs.	49.28	3449.6
19	Solar inverter	1	no.	151250	151250
20	3 phase meter	1	no.	8500	8500
21	MCB 32 A	1	no.	925	925
22	MCB 1 pole 16 A	2	no.	1760	3520
23	Civil works	1	no.	96390	96390
	Others				
24	Documentation charges	1	no.	50000	50000
				Total investment	**4507386**

Annual operation and maintenance cost (estimation) for hybrid plant-

Table 4.16 Operating cost of hybrid for Visakhapatnam

S. No.	Operation	Rs./KW/Month	Annual Cost
1	Scheduled maintenance/cleaning	500	15000
2	Unscheduled maintenance	250	7500
		Total investment	22500

Grid feed-in-

Table 4.17 KWh calculation of hybrid system for Visakhapatnam

19.8 KW Wind	
Wind energy generated	9286 KWh
Losses accounted	10%
Grid feed-in	9286 X 0.9 = 8357 KWh
Feed- in tariff (Rs.)	8357 X 4.84= 40447
10.2 KW Solar	
Solar energy generated	16773 KWh
Losses accounted	10%
Grid feed- in	16773 X 0.9 = 15095 KWh
Feed- in tariff (Rs.)	15095 X 5.25 = 79248
Total Feed in tariff for 30 KW (Rs.)	119695
Capital cost (Rs.)	4507386
Annual operating and maintenance cost (Rs.)	22500
Rupee depreciation rate	4%
Working life of plant	25 years
Total cash generated through energy export (Rs.)	1837375

Table 4.18 Calculation of annual cash flow: Visakhapatnam

Years	Investment (Rs.)	Operating and maint. cost (Rs.)	Feed -in /Export tariff (Rs.)	Annual cash flow (Rs.)	Cash balance (Rs.)
Year 1	-4507386	21600.00	114907.20	-4414078.80	-4414078.80
Year 2	0	20736.00	110310.91	89574.91	-4324503.89
Year 3	0	19906.56	105898.48	85991.92	-4238511.97
Year 4	0	19110.30	101662.54	82552.24	-4155959.73
Year 5	0	18345.89	97596.04	79250.15	-4076709.58
Year 6	0	17612.05	93692.19	76080.14	-4000629.44
Year 7	0	16907.57	89944.51	73036.94	-3927592.50
Year 8	0	16231.27	86346.73	70115.46	-3857477.04
Year 9	0	15582.01	82892.86	67310.84	-3790166.20
Year 10	0	14958.73	79577.14	64618.41	-3725547.79
Year 11	0	14360.38	76394.06	62033.67	-3663514.12
Year 12	0	13785.97	73338.29	59552.32	-3603961.80
Year 13	0	13234.53	70404.76	57170.23	-3546791.56
Year 14	0	12705.15	67588.57	54883.42	-3491908.14
Year 15	0	12196.94	64885.03	52688.09	-3439220.06
Year 16	0	11709.07	62289.63	50580.56	-3388639.49
Year 17	0	11240.70	59798.04	48557.34	-3340082.15
Year 18	0	10791.08	57406.12	46615.05	-3293467.11
Year 19	0	10359.43	55109.88	44750.44	-3248716.66
Year 20	0	9945.05	52905.48	42960.43	-3205756.24
Year 21	0	9547.25	50789.26	41242.01	-3164514.23
Year 22	0	9165.36	48757.69	39592.33	-3124921.90
Year 23	0	8798.75	46807.38	38008.64	-3086913.26
Year 24	0	8446.80	44935.09	36488.29	-3050424.97
Year 25	0	8108.93	43137.69	35028.76	-3015396.21

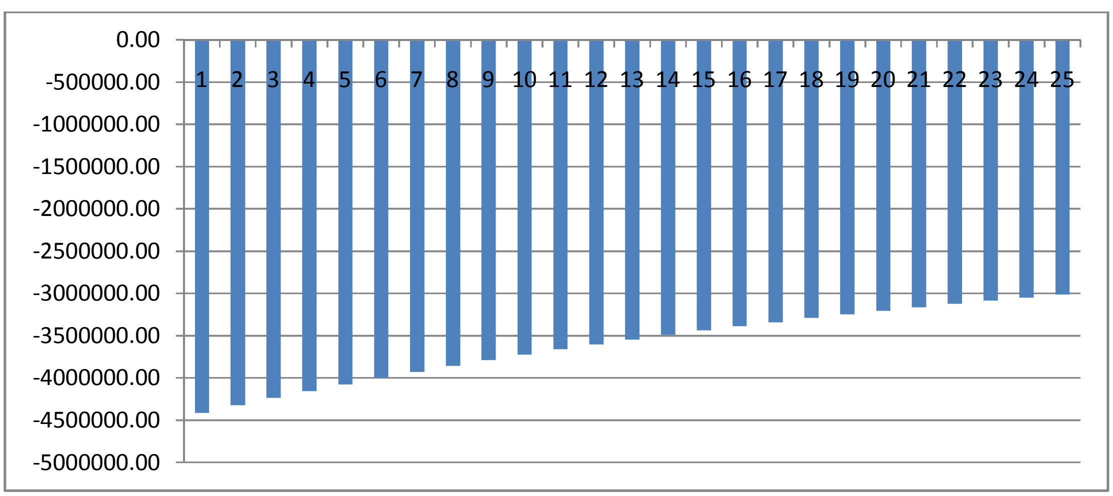


Fig. 4.4 Payback Curve

4.3.3 Wire plan for 30 KW wind-solar hybrid

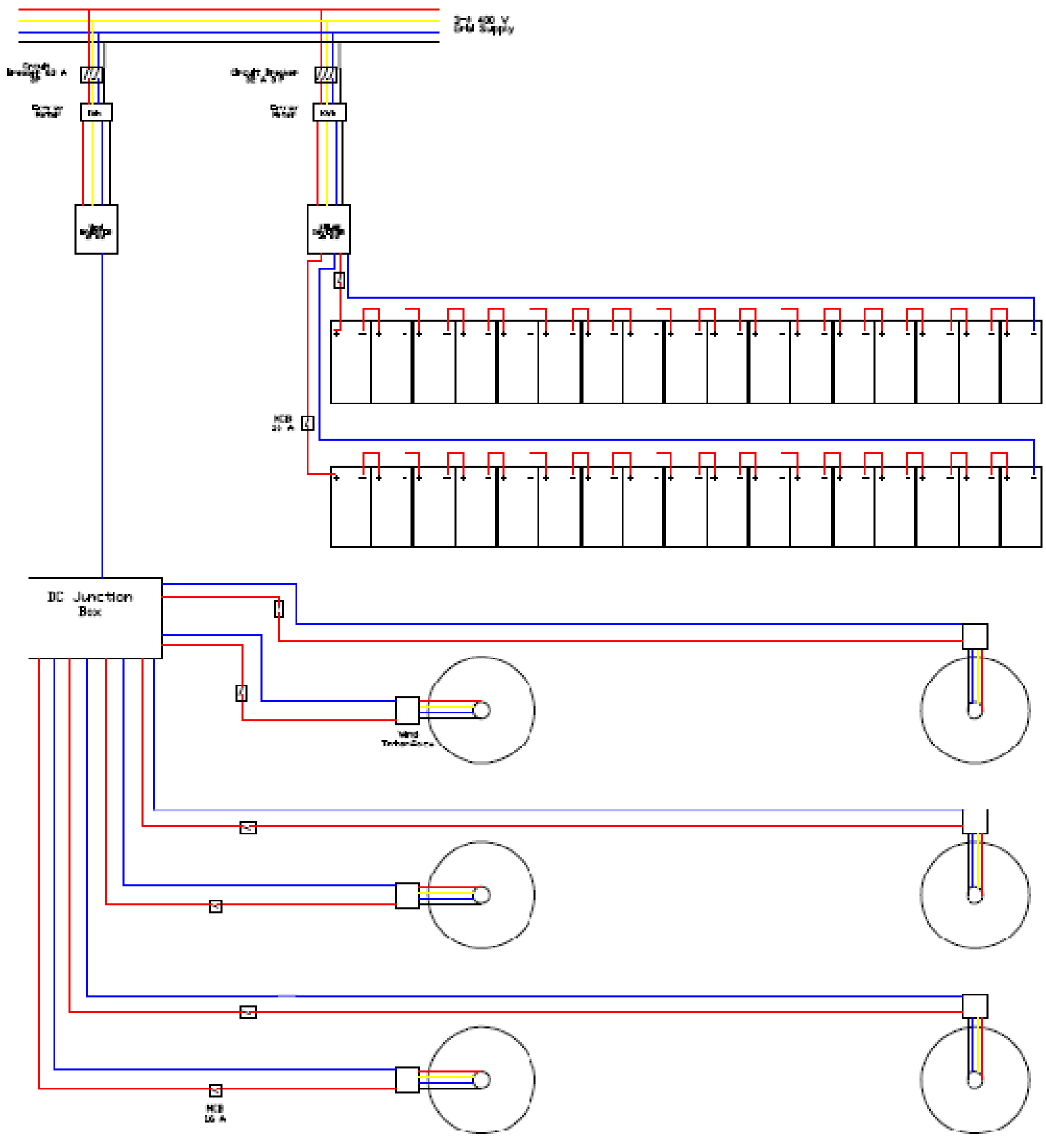


Fig. 4.5 Wire plan for 30 KW wind-solar hybrid (for all location)

4.4 Comparison of Results

Brief of both types of plant at all the locations is presented in tabular form-

Table 4.19 Comparison of result

Location	30 KW GCPV			30 KW Wind-Solar Hybrid			Remarks
	KWh Feed-in/ year	Cash Balance (Rs.)	Payback Period (yrs.)	KWh Feed-in/ year	Cash Balance (Rs.)	Payback Period (yrs.)	
Pantnagar	50726	3024712/-	7	22428	-2871495/-	Not found	Lowest wind KWh
Porbandar	52108	6447249/-	3.9	25108	-1419696/-	Not found	Max tariff for solar
Visakhapatnam	45533	1277572/-	11.7	23452	-3015396/-	Not found	Max. wind KWh

4.5 Discussion

Following statements are made on the basis of comparison-

i. Hybrid system is not feasible at any of the selected location, as payback period is not found throughout the whole expected life of plant.
ii. Pantnagar and Visakhapatnam are suitable for solar alone grid connected system.
iii. Porbandar is most suitable for solar alone grid connected system, as the energy yield is better and solar tariff if high.
iv. Visakhapatnam has lowest solar energy yield and solar tariff.

Reason of poor performance of wind-solar hybrid system-

i. Wind speed is low at the selected height i.e. 15 m for wind generator also the swept area is low.
ii. Wind power tariffs are low as compared to solar power tariffs.
iii. High investments in wind generator, wind interface and wind inverter as compared to same rating of solar system.
iv. Land area required for wind turbine placement is much larger.

But, on the other hand some positive results shown by the wind-solar hybrid system. These are -

i. Output of energy is available at the night time too.

ii. Output is available in rainy/ winter season when the solar alone system stops energy generation.

iii. Thus wind solar hybrid system can be used where finance doesn't matter but the energy reliability is must.

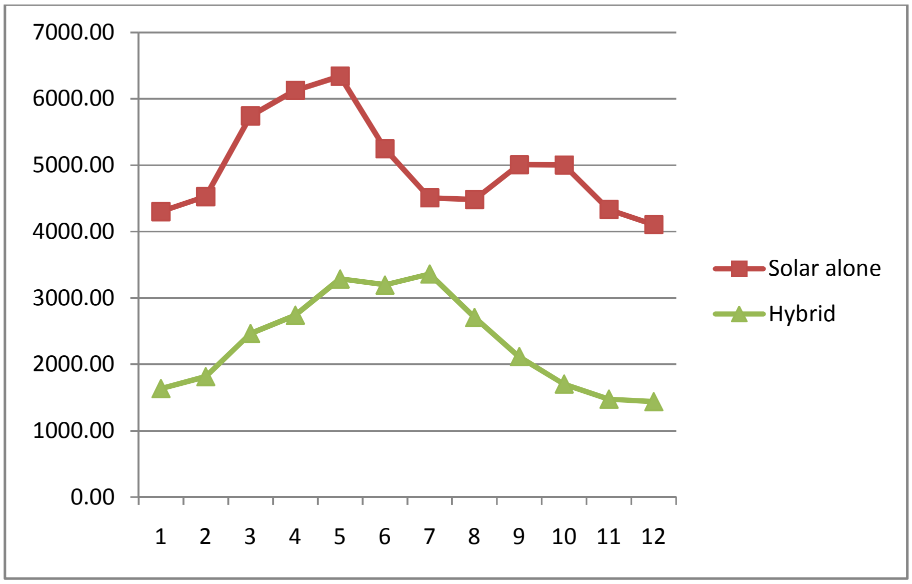


Fig. 4.6 KWh generated throughout a year from each type of plant at Porbandar

Thus the above proposed work shows that for commercial purpose small level grid connected system, solar system is profitable.

Summary & Conclusion

CHAPTER 5 SUMMARY AND CONCLUSIONS

The aim of this work is to present a comparison between grid connected solar photovoltaic plant and wind-solar hybrid plant of each rating 30 KW. As the set up assumed at three locations in different states, so the perfect location is found out for installation of plant.

5.1 Summary

Designing of 30 KW GCPV at Pantnagar (Uttarakhand), Porbandar (Gujarat) and Visakhapatnam (Andhra Pradesh) is done. Analyzed the investment, energy output, payback period of each solar power plant with PV*SOL Premium software. Economic comparing of the solar power plant with wind-solar hybrid power plant of rating 30 KW (19.8 KW wind + 10.2 KW solar) at the above mentioned location. Found out which type of plant is more economically efficient at mentioned location.

5.1 Conclusion

After analyzing it is found that 30 KW GCPV at Porbandar is most profitable project among all. Commercially small wind-solar hybrid is not economically feasible at any of the selected locations. If hybrid system is not viewed commercially, then reliability in terms of output energy is better than solar alone system, i.e. energy is available almost all the time irrespective of night or day or any season. Hybrid system can be used as off grid but at higher investment.

5.2 Future Scope

The hybrid system can be analyzed further to improve its energy output. It can be done by finding the optimal height of small wind generators. Also another thing can be find to optimize the hybrid system is the ratio of wind and solar installed capacity.

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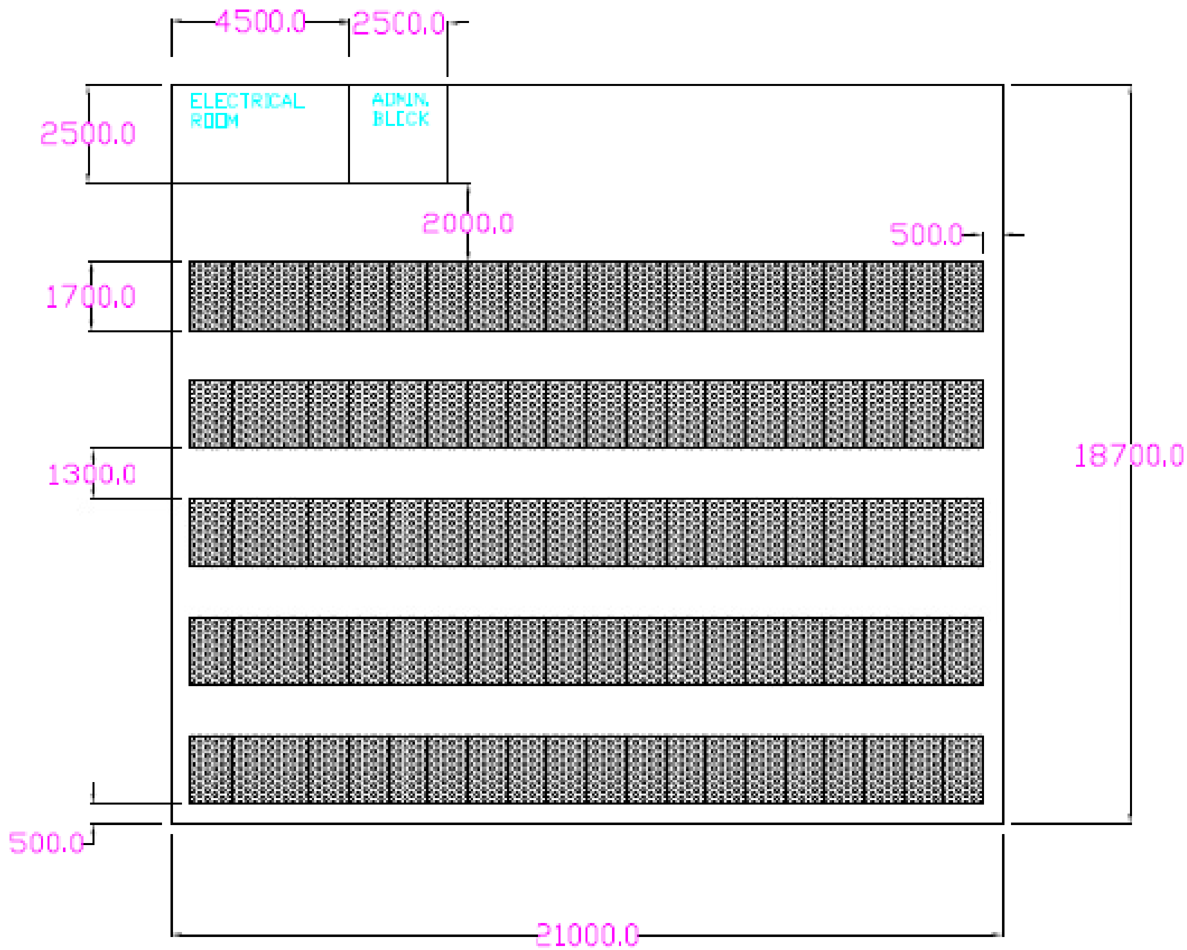
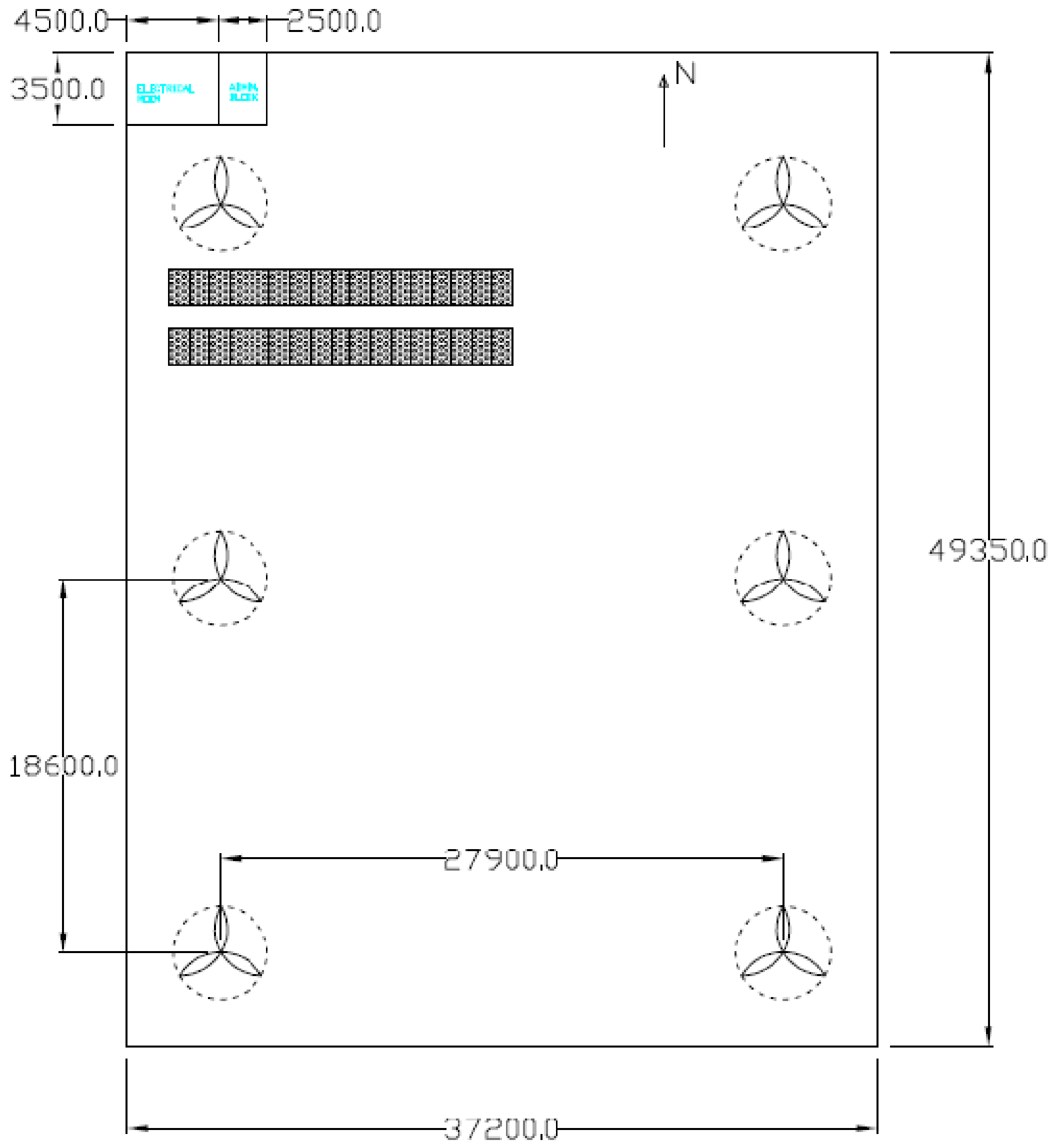
Annexure

Plant layout of 30 KW GCPV



Layout of 30 KW GCPV (All dim. in mm)

Plant layout of 30 KW wind-solar hybrid



Layout of 30 KW wind-solar hybrid system (All dim. in mm)

VITA

The author, Naveen Kumar was born on 28th June, 1991 at Rudrapur, (Uttarakhand). He passed his High School Examination in 2006 and Intermediate Examination in 2008 from Uttarakhand Board. He earned his B.Tech. in Electrical and Electronics Engineering in 2012 from Uttrakhand Technical University with first division. He worked with a private firm, Parksons Packaging Ltd. from Nov. 12 to July 15. After that he took admission in the College of Post Graduate Studies in G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand in July 2015, for Master's Degree in Electrical Energy System.

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ABSTRACT

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Semester and Year of Admission	**:**	First, 2015-16	**Degree**	**:**	M. Tech (EES)
			Department	**:**	Electrical Engineering
Major	**:**	Electrical Energy System			
Advisor	**:**	Dr. S. K. Goel (Professor, Electrical Engineering)			
Thesis title	**:**	**“Design and Feasibility Analysis of 30 KW GCPV and Wind-Solar Hybrid System”**			

With the increasing energy demand and target of climate pledge to cut down the carbon emissions of its GDP by 33 to 35 percent by 2030 from 2005 levels has forced India to move with renewable sources of power generation. As solar and wind are the most promising sources of renewable energy but geographically solar is feasible at almost every place in India. There is an issue with solar power that it is available only with emergence of sun. Wind-solar hybrid is a better option as the reliability of system is higher than any of the single component. This is necessary to find out the overall comparison of these two types of grid connected plant before installation. So this has given the idea of technical and financial analysis of both types of plants at different geographical location. GCPV plant is designed with the help of PV*SOL simulator while the output of hybrid system is analyzed in MS excel. Result shows that small GCPV is commercially feasible at all selected geographical location. Further, hybrid system has higher reliability and can be installed at where power cut is unavoidable, but at higher capital and operating cost.

(S. K. Goel)
Advisor

(Naveen Kumar)
Author

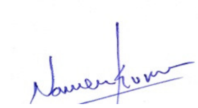
सारांश

नाम	:	नवीन कुमार	**परिचायंक**	:	49419
प्रवेश का सत्र एवं वर्ष	**:**	प्रथम, 2015-16	**उपाधि**	:	प्रौद्योगिकी में परास्नातक (ईईएस)
मुख्य विषय शोध	:	विद्युत ऊर्जा प्रणाली	**विभाग**	:	विद्युत अभियांत्रिकी
सलाहकार	**:**	डॉ एस के गोयल (प्राध्यापक, विद्युत अभियांत्रिकी)			
शोध का शीर्षक	**:**	**"30 किलोवाट जीसीपीवी और विंड-सोलर हाइब्रिड सिस्टम का डिजाइन और व्यवहार्यता विश्लेषण"**			

2005 के स्तर से 2030 तक 33% से 35% तक कार्बन उत्सर्जन में कटौती करने के लिए जलवायु प्रतिज्ञा की बढ़ती हुई ऊर्जा मांग और लक्ष्य के कारण भारत को बिजली उत्पादन के नवीकरणीय स्रोतों से आगे बढ़ने के लिए मजबूर किया गया है। चूंकि सौर और पवन अक्षय ऊर्जा का सबसे होनहार स्रोत हैं लेकिन भारत में लगभग हर जगह भौगोलिक दृष्टि से सौर संभव है। सौर ऊर्जा के साथ एक मुद्दा है कि यह केवल सूर्य के उदय के साथ उपलब्ध है। पवन सौर हाइब्रिड एक बेहतर विकल्प है क्योंकि प्रणाली की विश्वसनीयता किसी एकल घटक से अधिक है। स्थापना के पहले इन दो प्रकार के ग्रिड बंध संयंत्रों की समग्र तुलना पता लगाना आवश्यक है। इसलिए इसने विभिन्न भौगोलिक स्थान पर दोनों प्रकार के संयंत्रों के तकनीकी और वित्तीय विश्लेषण का विचार दिया है। जीसीपीवी सयंत्र पीवी * एसओएल सिम्युलेटर की मदद से डिज़ाइन किया गया है, जबकि एमएस एक्सल में हाइब्रिड सिस्टम का विश्लेषण किया जाता है। परिणाम से पता चलता है कि सभी चयनित भौगोलिक स्थान पर छोटे जीसीपीवी व्यावसायिक रूप से व्यावहारिक है। इसके अलावा, हाइब्रिड सिस्टम में उच्च विश्वसनीयता है और इसे स्थापित किया जा सकता है जहां बिजली कटौती अपरिहार्य है, लेकिन उच्च पूंजी और परिचालन लागत पर।

(एस के गोयल)

सलाहकार



(नवीन कुमार)

लेखक