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FEASIBILITY STUDY OF GRID CONNECTED ROOFTOP BASED SOLAR POWER PLANT

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Abstract— Renewable energy sources are fast growing. The diminishing fossil-fuel reserves and increasing energy demand makes it mandatory to look forward towards the new ways of energy generation. This paper deals with the feasibility analysis of the grid connected rooftop based solar photovoltaic system by studying the basic renewable integrated grid connected system. This paper describes the major components of solar photovoltaic system that are required to be connected in a grid integrated system and includes the site selection, solar panel arrangement, annual energy calculations and depreciation cost calculations for each year among the life span of the project and per unit capital cost calculations. Total cost incurred as well as income from the plant is calculated because energy can be sold to the grid at the time of low power demand at the site. A detailed cost analysis is conducted to know whether setting up the solar power plant is economically feasible or not. In this paper main emphasis is placed on the photovoltaic system, calculation of the payback period and then checking the feasibility of the solar photovoltaic power plant.

Index Terms— Depreciation cost, life span, per unit capital cost, payback period, feasibility.

1. INTRODUCTION

Global warming and climate shift has become a major concern now-a-days. Because of this most of the countries have begun to turn their attention towards the clean green renewable energy sources. This is currently widely used which poses a bright future for the world's raising energy needs. Many researchers have started to focus on this area as these are the sustainable and convenient alternative. With the advancement in technology and innovations we are able to solve energy crises and the best answer is the use of renewable energy sources. The two main reasons for adopting solar photovoltaic technology is that PV arrays are durable, produce no emission and demand minimal maintenance to operate and second one is the diminishing fossil fuels and increasing demand of energy. But the main problem with this alternative is that it is time dependent. Solar energy is not available during night time and cloudy days which are unpredictable. Numbers of efforts are being undertaken by Indian government towards the usage of solar energy for the generation of electricity. Solar Photovoltaic technology is one of the biggest renewable energy sources to generate electrical power and the fastest growing power generation in the world.

Presented a paper about the status of solar and wind renewable energies in India. In this paper various constraints have been discussed hindering the development of renewable energy in India [1]. Various challenges and opportunities have been discussed in the development of renewable resources by describing various obstacles in terms of financial barriers, regulatory basis and market based risks. List of potential state and national level organizations have been presented which play great role in supporting renewable energy development in India. [2] presented a paper in which financial feasibility of 100 KW solar rooftop power has been carried out for an educational institute in Bangalore. Presently the institute is using utility power and diesel generator for power outages. Study is carried out by considering state of art technology solar modules with fixed mounting structures and power electronics. Standard performance parameters have been used for the performance of financial analysis with present system cost based on life cycle cost taken into account the consideration of various factors like solar insolation variability at the site, operational and maintenance cost, interest rates etc. [3] described a method of measuring the potential of solar electricity generation in Patiala on the basis of solar radiation data obtained from the accessible weather station installed within University campus. Plant capacity is estimated from the chosen area as well as from the peak output results available from the solar radiation readings. Available are for calculation is considered to be $100m^2$. Calculations have been available for the month of May and June for which solar radiation levels obtained higher throughout the year so the results obtained would have been more accurate and yield higher plant capacity. [4] presented the design of grid connected solar photovoltaic power plant. Grid connected system without battery is used because of higher installation cost. Transformer for boosting the ac voltage, import and export meters for readings are used in the system. Difference of the import meter reading and export meter reading gives the power which can be fed to the grid. In this paper to measure solar photovoltaic generation potential, solar radiation readings are taken for each month. From this daily, average monthly output and yearly output is calculated [5]. Presented a paper in which renewable energy trends have been discussed [6]. presented a paper in which sensitivity analysis and cost optimization is carried out for grid connected PV systems, PV/battery and grid only systems. The environmental impact was also evaluated by estimating emissions. The grid only systems showed the lowest net present value and cost of energy By taking assumption that PV cost decrease and grid cost increase the grid/PV, grid/PV/battery systems found to be economically more competitive than grid only systems. By introducing feed-in tariffs, it can be seen that PV systems could generate more profits by selling excess of energy to the grid in off-peak hours [7]. Explained the reasons for mounting interest in photovoltaic technology and has provided quick synopsis of the operation, applications of technology and the market trends. Photovoltaic technology have received great attention over the last decade in response of challenges to the global warming, high fuel cost, emissions and pollutants, increasing energy demands.

The performance of the PV system is highly dependent on the loss factors like PV array temperature rise, mismatch, shading, availability of sunlight, solar intensity, power conditioning units' losses etc. Achieving grid synchronization is also a big problem in case of grid connected solar power plants. The above studied systems may have frequency mismatch problem too. Also the conversion efficiency of the PV modules is also less. For the above limitations setting up the solar power plant is economically feasible or not is a major point of concern.

In this paper, we assume that the PV solar unit is a grid-tied system rather than an off-grid (stand-alone system). In fact, the grid tied unit is preferred not only because it has higher energy efficiency but also because the off-grid unit requires a bank of batteries for storing power thus resulting in extra cost. A detailed cost analysis can be conducted to know whether setting up the grid connected rooftop based solar power plant is economically viable or not and this can be done by carrying out the feasibility and cost analysis which has been described in the later sections.

The remainder of this paper is structured as follows: Section 2 introduces various components of the solar power plant. Section 3 describes how the solar energy Distributed Generation Unit can be integrated to the power grid. Section 4 presents the objectives which are to be achieved during this work. Section 5 presents the method by which the objectives are achieved. Section 6 presents the site details along with the location and other parameters. Section 7 describes the arrangement of solar panels at the site and series and parallel combination of the solar panels. Section 8 involves the data which is required for the analysis and calculations. Section 9 describes the equations which are required for the calculations. Section 10 presents the electrical calculations for the solar power plant. Section 11 analyses the cost of the solar power plant. Section 12 presents the results of payback analysis.

2. COMPONENTS OF SOLAR POWER PLANT

Solar PV systems include different components the selection of which is made on the basis of site location, system type and the applications. The major components of solar PV system include solar module, charge controller, battery, inverter and load.

2.1 PV MODULE

A solar panel (also solar module, photovoltaic module or photovoltaic panel) is a packaged, connected assembly of photovoltaic cells. A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell which, when exposed to light, can generate and support an electric current without being attached to any external voltage source, but do require an external load for power consumption.

2.2 CHARGE CONTROLLER

Charge controller regulates the flow of electricity from PV module to the battery and load. Charge controller is also called charge regulator and is basically a voltage regulator or current regulator to keep batteries protected from overcharging. it regulates the voltage and current coming from solar modules and going to the battery. when the controller senses that the battery is fully charged, it stops the flow of charge from the modules.

2.3 INVERTER

AC systems require an inverter which changes DC electricity produced by PV modules and stored in batteries into AC electricity. Grid tie inverters convert DC voltage directly into standard AC voltage and feed to the consumer without the use of batteries.

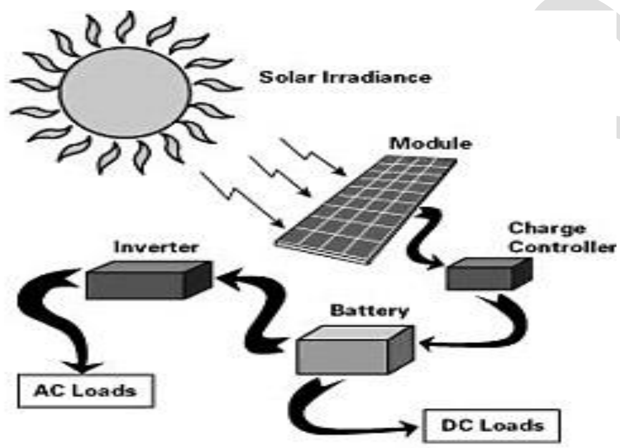

Fig.2.1 COMPONENTS OF SOLAR POWER PLANT

2.4 BATTERY

Battery is a device which stores energy when there is an excess coming in and distribute it back out when there is a demand. Solar PV panels continue to re-charge batteries each day to maintain battery charge.

2.5 LOAD

A load includes anything that uses electricity from your power source.

3. SOLAR ENERGY SOURCES INTEGRATION TO MAIN GRID

Renewable energy sources can be integrated to the power grid via two means. These can be either connected through direct connection or via power electronic interfacing. Constant speed wind turbines integration to power grid is an example of direct connection whereas solar power plant integration to main grid is an example of connection through electronic interfacing. One major limitation of direct connection is the violation of operational limits owing to the grid synchronization due to the intermittent nature of the renewable energy sources. This limitation can be overcome by using power electronic interfacing instead of direct connection [8]. Distributed Generation units when interfaced through inverters maintain grid synchronization under wide variations of frequency. In solar Distributed generation unit integration to the power grid, solar panels are connected to DC bus via DC-DC converters.

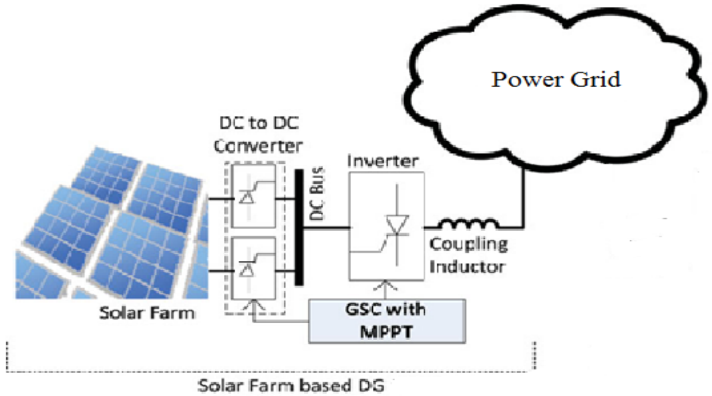

Fig. 3.1 SOLAR DG UNIT INTEGRATION TO MAIN GRID

The function of DC-DC converters is to maintain constant DC voltage irrespective of the variations in solar radiations/ insolation intensity. DC bus is further connected at the input side of the inverter. Inverter is also called power conditioning unit. Inverter is used to transform the DC voltage obtained from solar panels into AC voltage in order to maintain grid synchronization to the power grid. Coupling inductor is connected at the output side of the inverter and is used to interconnect the output of the inverter to the power grid. Micro controller based grid synchronizing controller is used to achieve grid synchronization and power flow control of the inverters. GSC operates the inverter in current controlled mode so that the power exported to the power grid is restricted to the preset values. The preset values of power are determined by MPPT (Maximum Power Point Tracker) so that the maximum power can be extracted under the given operating conditions. MPPT is a kind of algorithm which is used to trace the point at which maximum power can be obtained from the distributed generation unit.

4. OBJECTIVES

The objective of this work is to estimate the potential of grid connected solar photovoltaic power system at the site selected and finally develop a system based on the potential estimations for the chosen area. Then the cost analysis of the system is carried out and payback period is estimated to show that whether to install a solar photovoltaic power system is feasible or not. The list of proposed objectives which are to be achieved during this work are as follows

4.1 GENERAL OBJECTIVES

- Promote interest in PV for utilities by making them aware of the value added services and potential offered by the various Distributed energy resources on their network with power electronic device interface so that it can be controlled remotely.
- An approach to protection from islanding during the feeder outages.
- Provide pathway to significant cost reduction on utility scale.
- Allows operation of the PV generation during grid disturbances without any risk to public safety and personnel.

4.2 CALCULATION OBJECTIVES

- Energy calculations for the site.
- Electrical calculations and other calculations of PV plant
- Cost calculations and analysis.
- Per unit capital cost calculation.
- Payback period calculations.
- Checking the feasibility of the plant.

5 METHODOLOGY

The project began with the simple prefeasibility study to obtain an idea about the amount of energy generation by the system and to obtain the total area required for the solar photovoltaic plant to be installed and access the economics of the whole project. Then this solar photovoltaic power plant can be used in integration with the grid in order to meet load requirement. So the draft procedure involves the following steps:

- Collection of solar photovoltaic data from the chosen site (dimensions of the selected roof top building, roof properties such as roof type, roof area, roof orientation, pitch/slope, strength of roof and effect of shading on roof).
- Electrical calculations for the selected PV module will be done.
- Calculation of the total cost of the solar PV rooftop power plant
- Per unit capital cost calculations.
- Payback period will be calculated.
- Checking the feasibility of the solar power plant.
- Identify the grid access and requirement for grid connection.

5.1 SITE DETAILS

The site selected for designing and implementing grid connected solar power plant is 201 kW_p Solar Power Plant, Samrala, Punjab. Site is selected because Punjab Government thrust on the use of renewable energy resources. In Punjab there is a vast scope of solar power generation because in Punjab throughout the whole year there are almost 300 sunny days available but the land is not much in use of renewable sources available. Punjab government encourages people for setting the solar power generation to harness the vast solar potential in the state and promote stand-alone and roof-top projects. 201 KW_P power plant is roof-top based solar plant. Site has been selected for grid connected solar PV plant because of the following points which are to be considered. The main points considering for this site are

- Abundant area is available at this site.
- Abundant sunlight throughout the year is available at this site.
- Availability of grid.

The whole site consists of two main buildings that is gill cold storage building and the gill resorts. That is why two different PV plants have been considered on each building of the site. The distribution of capacity is done on the basis of available area. So 140 KW_P SPV power plant is installed at Gill's Cold Storage and 61 KW_P SPV power plant is installed at Gill Resort (metal shed).

Site receives 11kv supply from the grid and then it is step down to 415 volts with the help of 11kv/415 V step down transformer. The site is having load with daily average value of about 196 KVA. Considering the quantum of priority loads, roof top area and peak load timings, a grid interactive solar photovoltaic plant of 201 KW_P seems to be suitable to augment and support the essential power requirement of each building. During periods of non-utilization the power can be exported to grid as well.

The ratings of various equipments needed for the installation of solar power plant are based on the load requirement and these ratings are needed to be calculated. Location details of SPV power plant are as follows

Address of the site	Gill's Cold Storage Samrala, Punjab
Access	Road
Ambient temperature	45^0C
Available area	5 acre
Connected load	160 KW approx
Longitude	76.19^0 E
Latitude	30.84^0 N

Average solar radiation	5.23 kWh/m^2/day
Technology used	Solar photovoltaic

5.2 SOLAR PANEL ARRANGEMENT

The total number of modules connected at 201 KW_p solar power plant are 670**.** 16 or 15 number of modules are connected in series in 140 KW_p solar power plant. 16 strings are connected with series combination of 16 modules and 14 strings are connected with series combination of 15 modules for 140 KW_p. Similarly 21 or 20 number of modules are connected in series in 61 KW_p solar power plant. 6 strings are required with series combination of 20 modules and 4 strings are required with series combination of 21 modules for 61 KW_p Modules are connected in series to increase the voltage and in parallel to increase the current.

5.3 DATA USED

The annual total energy generation from the plant is 241352 KWh. Data required for the analysis is presented in the Table 8.1

Table 5.1 MODULE TECHNICAL DETAILS

Rated power (P_{max})	300 W
Nominal power (P_{mpp})	0 to +4.99 W_p
Nominal voltage (V_{mpp})	37.28 V
Nominal current (I_{mpp})	8.05 A
Open circuit voltage (V_{oc})	45.1 V
Short circuit current (I_{sc})	8.74 A
Module efficiency (%)	15.63
Module area	15 sq. ft.
Temperature range	-40^{0}C to +85^{0}C
T.C of power	-0.41o% /^{0}C
Dimensions (L*W*H)	(1955*982*36)mm

5.4 EQUATIONS USED

The general equations which are to be used in order to carry out this work are as follows:

- For number of modules/panels required
  Number of modules = no. of series modules * no. of strings
- Output voltage
  Output voltage of series modules = no. of series modules * nominal voltage of module
- Output current
  Output current of PV plant = no. of strings * nominal current
- Output power of 1 string of series combination
  Output power of 1 string of series combination = output voltage of series modules * nominal current of module

- Total output power = no. of strings * output power of 1 string of series combination
- Solar panel cost = no. of panels * cost of 1 solar panel
- Inverter cost = no. of inverters required * cost of 1 inverter
- Subtotal = solar panel cost + inverter cost
- Total estimated PV cost = (Subtotal + cost estimate of the system)
- Net capital cost= Total estimated PV cost – Subsidy
- Depreciation cost (C) = $P (1 - x/100)^n$
- Total depreciation cost $C_n = \sum_{p=1}^{n} Cp$
- Per unit capital cost = Total depreciation cost / (number of useful years * number of units generated per annum)
- Total cost = Net capital cost + annual operating cost
- Income = no. of units generated * cost per unit generation
- Payback = Total cost/income

5.5 ELECTRICAL CALCULATIONS

5.5.1 ELECTRICAL CALCULATIONS FOR 140 KW_P

Output voltage of 16 series modules = (16*37.28)

= 596.48 V

Output voltage of 15 series modules = (15*37.28)

= 559.2 V

Output current of each string = 8.05 A

Output current of 140 KW_p PV plant = 30*8.05

= 241.5 A

5.5.2 DC POWER OUTPUT CALCULATIONS FOR 140 KW_P

Output power of 1 string of 16 series combination = 596.48 * 8.05 = 4801.664 watts

Output power of 1 string of 15 series combination = 559.2 * 8.05 = 4501.56 watts

Output power including strings = (16 *4801.664) + (14 *4501.56)

= 139848.464 watts or 139.8 kW

5.5.3 ELECTRICAL CALCULATIONS FOR 61 KW_P

Output voltage of 20 series modules = (20*37.28) = 745.6 V

Output voltage of 21 series modules = (21*37.28) = 782.88 V

Output current of each string = 8.05 A

Output current of PV plant of 61 KW_p capacity = 10*8.05 = 80.5 A

5.5.4 DC POWER OUTPUT CALCULATIONS FOR 61 KW_P

Output power of 1 string of 20 series combination =745.6 * 8.05 = 6002.08 watts

Output power of 1 string of 21 series combination = 782.88 * 8.05 = 6302.184 watts

Output power including strings = (6 * 6002.08) + (4 * 6302.184)

= 61221.216 watts or 61.2 kW

Total power output = 139.8 + 61.2 = 201 kW_p

5.6 COST ANALYSIS FOR 201 KW_p SOLAR PV PLANT

SOLAR PANEL COST

Per watt cost of solar module = Rs 50/watt
Then the cost of 300 watt module will be (300*50) = Rs 15000
Total number of modules which have been used at the site is 670
So total cost of panels = 670*15000 = Rs 10050000

INVERTER COST

Number of inverters required = 4
Capacity of each inverter = 50 kW
Cost of 1 inverter = Rs 675000
So total cost of inverters = (4* 675000) = Rs 2700000

SUBTOTAL = Rs 12750000

COST ESTIMATE

Multiply the above calculated subtotal by 0.2 (20%) to cover the balance of system cost (wires, switches, fuses, MCBs etc)

Cost estimate = Rs 2550000

TOTAL ESTIMATED PV COST

Total estimated PV cost = (Subtotal + cost estimate of the system) = Rs 15300000

OPERATING COST

Annual Operating cost is taken to be 2 lakh as according to the information provided by dealer.

NET CAPITAL COST

Total estimated PV cost = Rs 15300000
Subsidy = 30% of the capital cost = Rs 4590000
Net capital cost =Total estimated PV cost – Subsidy = Rs 10710000

PER UNIT CAPITAL COST CALCULATIONS

Per unit capital cost is calculated by using depreciation method.

Depreciation cost (C) = P (1 - x/100)^n
where, x = depreciation rate (5%)
n = no. of life years of plant (25 years)
P = net capital cost

TABLE 5.1 DEPRICIATION COST

C_1	10174500
C_2	9665775

C_3	9182486.25
C_4	8723361.9375
C_5	8287193.840625
C_6	7872834.14859375
C_7	7479192.44116406
C_8	7105232.81910586
C_9	6749971.17815057
C_{10}	6412472.61924304
C_{11}	6091848.98828089
C_{12}	5787256.53886685
C_{13}	5497893.71192351
C_{14}	5222999.02032733
C_{15}	4961849.07501096
C_{16}	4713756.62126041
C_{17}	4478068.79019739
C_{18}	4254165.35068752
C_{19}	4041457.08315314
C_{20}	3839384.22899548
C_{21}	3647415.01754571
C_{22}	3465044.26666842
C_{23}	3291792.053335
C_{24}	3127202.45066825
C_{25}	2970842.32813484

Total depreciation cost = Rs 147043995.76

Number of units generated per annum = 241352 kWh

Per unit capital cost = Total depreciation cost / (useful years * number of units generated per annum)

= Rs 24.37

So the per unit cost of 201KW solar PV plant is Rs 24.37

6. RESULTS AND CONCLUSIONS

Total cost = Net capital cost + Annual operating cost

= Rs 10910000

Income = Energy * Cost per unit of generation

= Rs 1689464

Payback period = Total cost / Annual income

= 6.5 years (approx)

Payback period of solar power plant comes out to be 6.5 years and the life of power plant is 25 years. After payback period analysis it is recommended to install 201 KW_p grid connected rooftop based solar power plant at Samrala. After the analysis and calculations the solar photovoltaic power plant comes out to be feasible with 6 years and 5 months of payback time.

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