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Performance Evaluation of 190 kWp Rooftop Solar Photovoltaic Plant in CMPDI, Ranchi.

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Abstract– *In this paper, the performance evaluation of 190 kWp rooftop solar photovoltaic plant has been done. The plant locates at Central Mine Planning and Designs Institute (CMPDI), Ranchi in the state of Jharkhand, India. The rooftop solar plant with smart meters is installed on five different buildings of the institute. The data is considered from March, 2015 to February, 2016. The analysis is based onreal time data which are collected from smart meters and simulation using PVsyst software. Both results are compared and discussed to analyse the performance of the system. These results also reflect the performance of such plants under real operating condition in India.*

Keyword- Rooftop solar photovoltaic plant, Performance Ratio, Capacity Utilization Factor, PVsyst Software, Weather Monitoring System

Nomenclature

°C	degree celsius
A	net plant area in square meter
AC	alternative current
ACDB	alterative current distribution box
CMPDI	central mine planning and design institute
CUF	capacity utilization factor
DC	direct current
DCDB	direct current distribution box
E_Grid	energy injected in to grid
E_{Array}	effective energy at the output of the array
E_e	estimated energy generation by the plant kilo watt hour
Eff_{ArrR}	efficient energy output of array/ rough area
Eff_{systR}	efficient energy output of system/ rough area
E_m	energy production by the plant in m^{th} month in kilowatt hour
E_t	annual energy generation by the plant in kilo watt hour
$Glob_{Eff}$	effective global irradiance
$Glob_{Hor}$	horizontal global irradiation
$Glob_{inc}$	global incident in collector plane
H_t	annual insolation in kilo watt hour per square meter of the location.
H	total number of hours in one year
kW	kilo watt
kWh	kilo watt hour
kWp	kilo watt peak
L_c	collection loss
L_s	system loss
MPPT	maximum power point tracking
MWh	mega watt hour
M	Meter
η_o	efficiency of photovoltaic module in actual operating condition

PR	performance ratio
P	total installed capacity of the plant in kilo watt peak
PV	Photovoltaic
STC	standard test condition
T_{amb}	ambient temperature
W	Watt
Y_f	produced useful energy
Y_s	specific yield

I. INTRODUCTION

Energy is the finest source of the economic producement of any country. In sense, India as developing country, energy shortage can hedge in the development of the nation. Energy generation goes high in order to match energy demand. Energy shortage is due to imbalance between energy generation and energy demand. Presently most of the electricity demand is tried to fulfill by conventional sources (coal, oil etc.). This is characterized climate changes, green gas emissions and environmental pollution etc. So,energy security is required with assurance of environmental benefits. Renewable energy sources are the suitable option [1]. India has good solar radiation throughout the year. So, solar source might be a suitable among the all renewable energy sources. The solarsystem gives green and clean energy for very long time[2][3][4].

The CMPDI had large energy shortage from utility. There is huge imbalance between energy provided by utility and load demand of the institute. There were three diesel generators to fulfill the energy shortage. Main objectives to install the rooftop solar photovoltaic plant are to reduce diesel consumption, carbon emission and better utilization of renewable energy sources. The efficiency of the PV system is expected to be more without energy storage system and generated energy is directly fed to the load of the institute. The performance evaluation of this plant is carried out to analyse the effectiveness of the solar PV system during the entire year after the installation.

II. DESCRIPTION OF ROOFTOP SOLAR PHOTOVOLTAIC PLANT

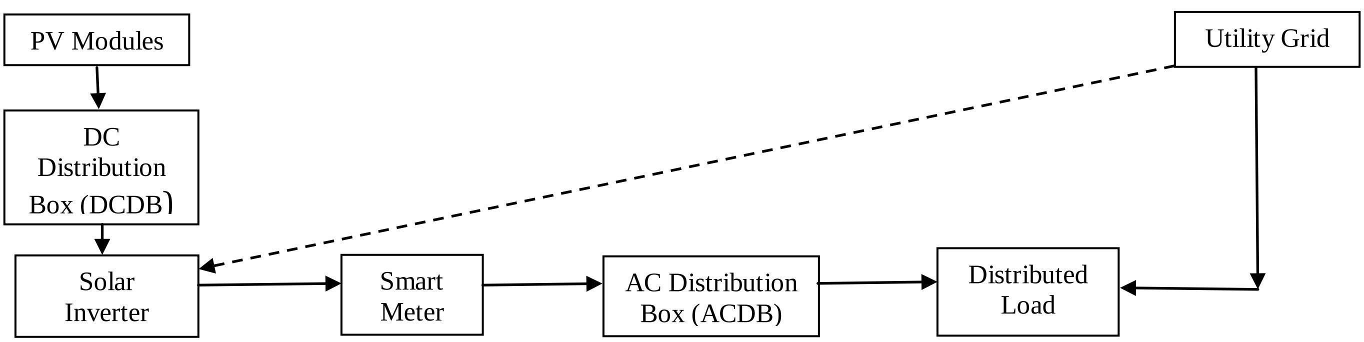

Figure 1. Block diagram of PV plant

The PV plant consist of PV modules, weather monitoring system, DC distribution box, solar inverters, AC distribution box and smart meters etc. The detail of site layout, geographic location, specification of solar panels and solar inverters are discussed below.

2.1. Geographical location of the plant

The 190 kWp PV plant is situated in the CMPDI, Ranchi in the state of Jharkhand, India. CMPDI is a fully owned subsidiary of Coal India Limited under the Government of India whichis located at a latitude23.35°N, longitude 85.3° E and at an altitude of 651 meters. Geographical conditions are good for solar power plant throughoutthe year.

Table 1.Geographical details of the site

Site Name	Central Mine Planning and Design Institute, Ranchi, Jharkhand, India.
Latitude	23.35°N
Longitude	85.3° E
Altitude	651 meter
Time Zone	UTC+ 05:30
Temperature Range	16° C to 31°C

2.2. Plant Layout

The institute hasPV plant on roofsof the five buildings. The entire system is in decentralized form and supply green power generation for in house consumption across various loads in the buildings. Total plant capacity of 190 kWp spaced over approximate 1240 m^2. Arrangement of the modules is basis on the maximum availability of shadow free area on the roofs of the buildings during the whole year. All modules are installed on fixed tilt angle of 15° and azimuth angle of 0°. Set of modules which are connected in series is called string. 16 string, 20 string, 10 string and 10 string consist 18 module per string, 20 module per string, 10 module per string and 17 module per string respectively[4].

Table 2. Specification of PV modules

PV Module	Specification	Specification
Type of material	Monocrystalline	Monocrystalline
Make	Titan Energy System Ltd.	Titan Energy System Ltd.
Model	M6-72 series	M6-72 series
Maximum power(Pm)	270 watt	300 watt
Power tolerance	-2.5 % to +2.5 %	-2.5 % to +2.5 %
Maximum power voltage(Vmp)	34.75 volt	36.72 volt
Maximum Power current(Imp)	7.77 ampere	8.17 ampere
Open circuit voltage	43.70 volt	45.50 volt
Short circuit current	8.34 ampere	8.65 ampere
Electrical parameter tolerance	-5 % to +5%	-5 % to +5%
Pm temperature coefficient(ϒ)	-0.41%/ °C	-0.41%/ °C
Isc temperature coefficient(α)	+0.04%/°C	+0.04%/°C
Voc temperature coefficient(β)	-0.32%/°C	-0.32%/°C
No of Module	20	618

These modules are connected to DCDB on the particular building. Solar inverters convert the DC energy generated by PV module to AC energy. Inverters take the reference input (voltage, frequency and phase angle) from utility grid (Jharakhand State Electricity Board). Inverters take the input from the DCDB and give it to AC loads of the particular buildings through ACDB. Total 29 inverters with the rating of 172 kW are placed in the plant in which9 of them are string inverters and remaining is micro inverter.

Table 3.Specification of solar inverter

Inverter	Specification			
Make	Refusol	Refusol	Refusol	Darfon
Recommended maximum PV power kWp	12 kW	20.4 kW	24 kW	250 watt
MPPT Range	370-850 volt	460-850 volt	490-850 volt	24-40 volt
DC start voltage	350 volt	350 volt	350 volt	24 volt
Maximum Dc voltage	1000 volt	1000 volt	1000 volt	60 volt
Maximum DC current	25 Ampere	41.8 Ampere	41.8 Ampere	10 ampere
Rated AC Power	10 kW	17 kW	20 kW	220 watt
AC Voltage Range	320 – 460 volt	320-460 volt	320-460 volt	211-264 volt
Efficiency	97.4%	97.8%	97.8%	94.1%
Number of Inverter	1	1	7	20

The weather monitoring system is fixed on the site which is common for five building. It is collected the data set of solar irradiance in w*m^{-2}, wind velocity in m*s^{-1}, module temperature in °Cand ambient temperature in °C. It has featured to be integrated with the local system and facilitated to operate remotely by the web orstandard modem. It records and transmits the data which can be monitored, downloaded and analysed. Smart meters have been installed to understand the load pattern of campus, energy generation by the plant, weather parameters of the location etc. ASingle smart meteris capable to monitor sixteen electrical parameters which can be transmitted by standard medium to server.
The plant is designed in a way that the energy generation on different roof can be fed to the ACDB of the particular building. Transmission loss and voltage drop is least in this design. It is not occupied any additional area of the institute. Module mounting structure of the plant is not drilled on the roofs of the buildings;there is no water leakage during monsoon season. Moreover, it is provided cooling during the summer season.

III. METHODOLOGY FOR PERFORMANCE ANALYSIS OF THE PV SYSTEM

3.1. Manually considered parameters to evaluate the PV plant

International Energy Agency under photovoltaic power system programme has framed objects for operation, performance and maintenance of solar power plant. Many parameters are used to define the performance study of the PV plant. Some parameters are considered and discussed below.

3.1.1. Total energy generated by PV plant

$$E_t = \sum_{m=January}^{December} Em$$

Where,m= January, February…,December.
Here, Instantaneous energy generated by PV plant is monitored and collected on 15 minute interval by smart meters. So, total produced energy is obtained on monthly and annually basis. This is also called actual energy generated by the plant.

3.1.2. Estimated energy generated by PV plant

$$Ee = Ht * A * \eta_o$$

Here, Annual insolation is obtained from the data of the weather monitoring system.

3.1.3. Performance Ratio(PR)

$$PR = \frac{Et}{Ee}$$

Performance ratio is the ratio of the actual energy generated from PV plant to estimated energy generated of PV plant. It is also known as quality factor. PR ratio is denoted in percentage. PR ratio represents the actual energy obtained after the loss effect. The most efficient solar power plant has PR ratio nearer to 100%. But practically it never achieve. Depending on geographical location and season, the PR value falls normally within the range 40% to 90%. For a well-designed system, the PR ratio range is from 75% to 90%.

3.1.4. CapacityUtilization Factor(CUF)

$$CUF = \frac{Et}{H*P} * 100\%$$

CUF is actual output of the plant over a period of one year and its output if it had operated at nominal power on entire year.

3.1.5. Specific Yield(Ys)

$$Ys = \frac{Et}{P}$$

Specific yield is used to compare operating results from different technology and systems.

3.2. Performance evaluation of the plant by manual calculations.

The weather data from March, 2015 to February, 2016 are shown in Table 4.

Table 4. Weather data of the site

Month	Irradiance ($w*m^{-2}$)	Wind velocity ($m*s^{-1}$)	Module temperature (°C)	Ambient temperature (°C)
March, 2015	237.54	1.19	31.67	25.87
April, 2015	227.58	1.15	33.82	27.71
May, 2015	209.21	1.14	37.00	31.21
June, 2015	168.17	1.28	32.97	27.66
July, 2015	152.40	1.46	31.60	26.56
August, 2015	189.84	1.40	32.83	27.04
September, 2015	218.94	1.18	34.00	27.87
October, 2015	221.39	0.64	33.04	26.60
November, 2015	199.69	0.53	29.45	23.45
December, 2015	165.54	0.83	23.32	18.18
January, 2016	206.34	0.99	23.80	18.24
February, 2016	197.70	1.01	28.30	22.69

PV module converts light energy to electrical energy. The power output of the PV Module mainly depends on the weather conditions (solar irradiance, wind velocity and ambient temperature). Everyday poweroutput of the PV Modules fluctuateson the basis of availability of solar radiation. PV plant may also stop to generate the power due to rainy season or less solar irradiance availability. Smart meters collect data on 15 minute interval. We can easily analyse the system performance with respect to weather conditions. The average power output, monthly energy generation by the plant and annual energy generation by the plant are mentioned in the Table 5.

Table 5. Actual generation of the PV plant

Month	Averagepower output (kW)	Energygeneration by PV plant (kWh)	Annual energy generation (kWh)
March, 2015	32.62	24611.40	215539.1
April, 2015	29.25	21238.60	
May, 2015	24.01	18018.30	
June, 2015	20.64	15098.60	
July, 2015	18.18	13486.92	
August, 2015	21.24	15773.30	
September, 2015	25.04	18066.80	
October, 2015	27.80	20633.90	
November, 2015	24.80	18154.66	
December, 2015	22.26	16169.18	
January, 2016	23.81	18055.18	
February, 2016	23.91	16232.30	

The annual energy generation is about 215 MWh. The highest energy generation is 24 MWhin March, 2015 and the lowest is 13 MWh in July, 2015.The annual average PR ratio is approximately 73.92%. In this the maximum value of PR is83.47% in March, 2015 and theminimum value of PR is 66.94% in August, 2015 (See Figure 2). The annual average CUF is approximately 12.27%. The maximum CUF is 17.41% in March, 2015 and the minimum CUF is obtained 9.54% in July, 2015(See Figure 3).

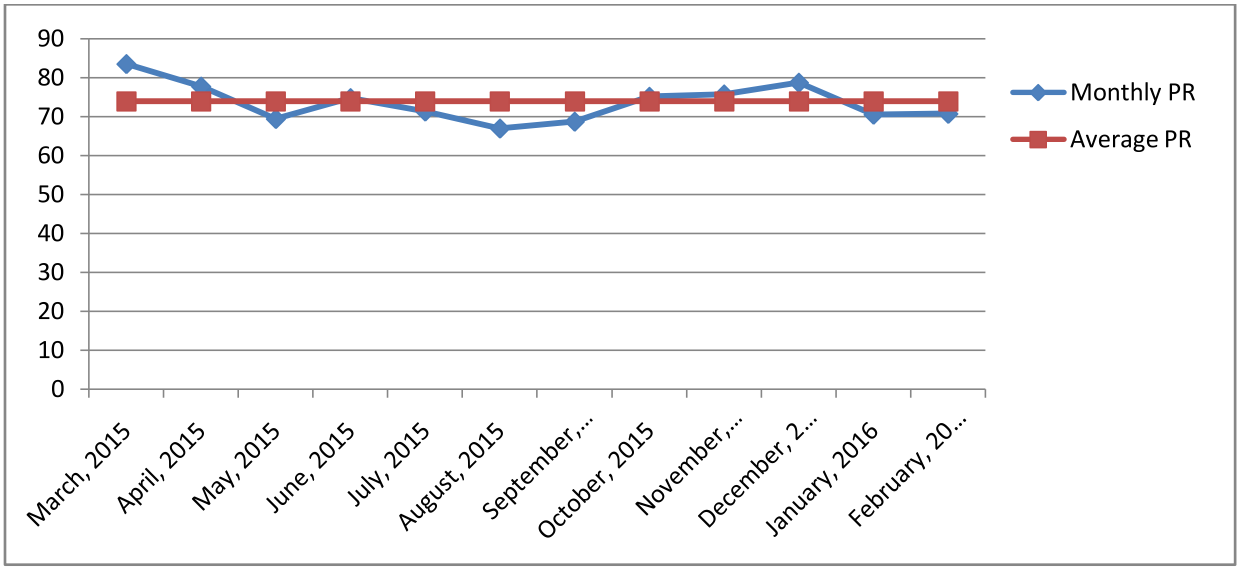

Figure 2.Average PR in various months

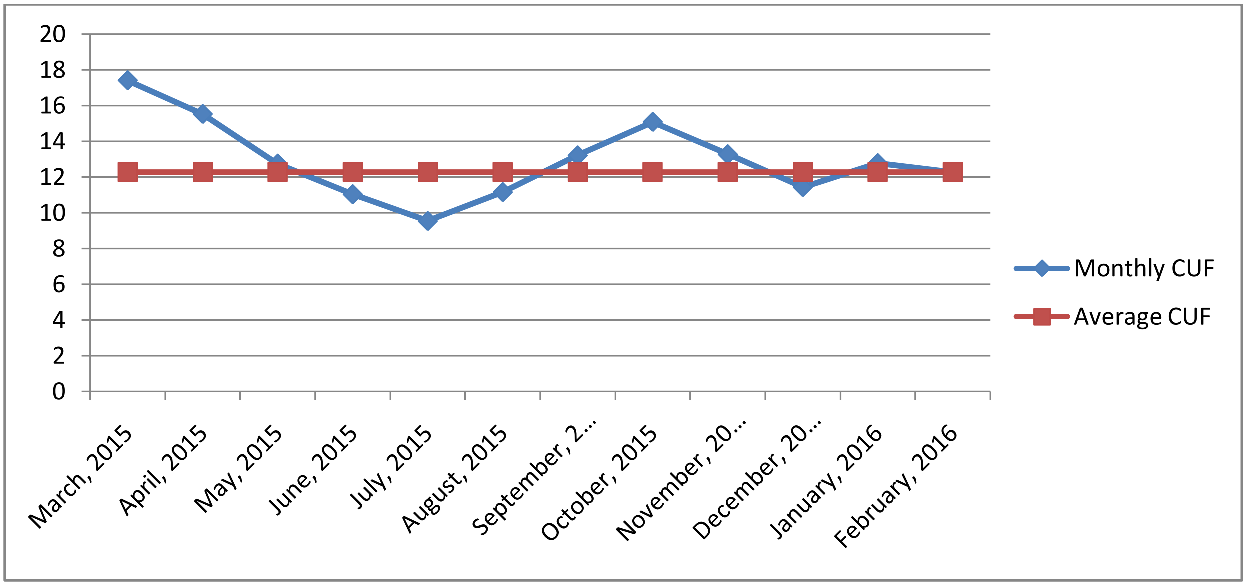

Figure 3.Average CUF in various months

3.3. Simulation using PVsyst

PVsyst is the software to study, sizing and analyzing of grid connected, stand alone, pumping and DC grid solar system. It is facilitated with technical, economical and environmental analysis of solar system[5]. From PVsyst report, the maximum energy generation is 28.45MWh in the month of October, 2015 and minimum energy generation is 15.94 MWh in the month of July, 2015.For the reason total useful amount of energy is 278.21 MWh.

3.3.1. Balance sheet and main result

Annual global horizontal irradiation is 1712.4 kWh*m^{-2}. Global incident energy that is incident on the collector plane annually is 1852.6 kWh*m^{-2}. Total energy obtained from the output of the PV array is 288.48 MWh.

Table 6.Balance sheet

	$Glob_{Hor}$ (kWh/m^2)	T_{amb} (°C)	$Glob_{inc}$ (kWh/ m^2)	$Glob_{Eff}$ (kWh/m^2)	E_{Array} (MWh)	E_Grid (MWh)	Eff_{ArrR} (%)	Eff_{SystR} (%)
January	137.0	16.70	167.3	157.5	26.99	26.58	13.12	12.93
February	147.4	19.90	170.7	161.1	27.18	26.76	12.95	12.75
March	143.5	25.90	152.8	143.8	23.53	23.15	12.52	12.32
April	163.8	27.70	165.4	155.0	25.32	24.93	12.45	12.26
May	155.7	31.20	151.6	142	22.81	22.45	12.24	12.04
June	121.1	27.70	116.3	108.6	17.79	17.50	12.44	12.24
July	113.4	26.6	109.9	102.5	16.93	15.94	12.53	11.80
August	141.2	27.00	139.8	130.7	21.6	21.27	12.57	12.38
September	157.7	27.90	165.2	155.3	25.50	22.41	12.56	11.04
October	164.7	26.60	186.8	176.0	28.90	28.45	12.59	12.39
November	143.7	23.40	173.8	164.0	27.35	24.54	12.80	11.48
December	123.2	18.19	152.8	143.6	24.59	24.22	13.09	12.89
Year	1712.3	24.92	1852.6	1740.2	288.48	278.21	12.67	12.22

3.3.2. Performance Ratio

Average annual performance ratio is 79.5% which almost same as manually calculated PR.

3.3.3. Normalized production

Lc, Ls and Yf is 0.894 kWh per kWp per day, 0.149 kWh per kWp per day and 4.03 kWh per kWp per day respectively.

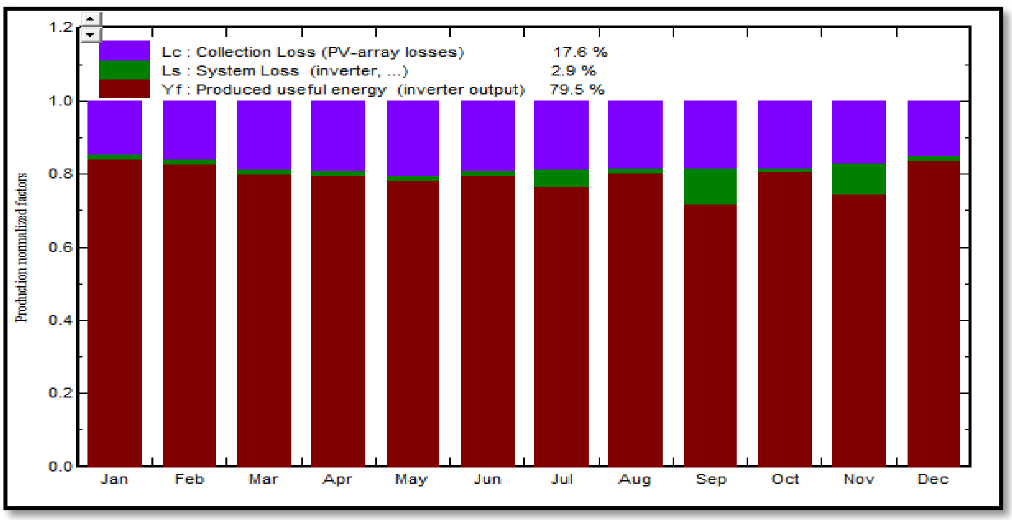

Figure 4.Normalised production and loss factor

3.3.4. Loss Diagram

Total horizontal irradiation global incident in collector plane is 1712 kWh*m^{-2}. Total approximate module area is 1229 m^2. Efficiency of PV module is 15.45% at STC[1]. Effective irradiation on collector is 1740 kWh*m^{-2}. This irradiance fall on PV module and this energy converted to electrical energy. 330.5 MWh is the array nominal energy at STC. After PV loss due to irradiance level, temperature, module array mismatch and ohmic loss, array virtual energy at MPP is 289.5 MWh. Highest loss is due to temperature loss which is 7.9%. After inverter losses, the available output energy from inverter is 278.2 MWh.

[1]Standard Test Conditions create uniform test conditions which make it possible to conduct uniform comparisons of photovoltaic modules by different manufacturers. The test conditions are defined as follows - irradiation: 1000 W/m², temperature: 25°C, AM: 1.5 (AM stands for Air Mass, the thickness of the atmosphere; at the equator).

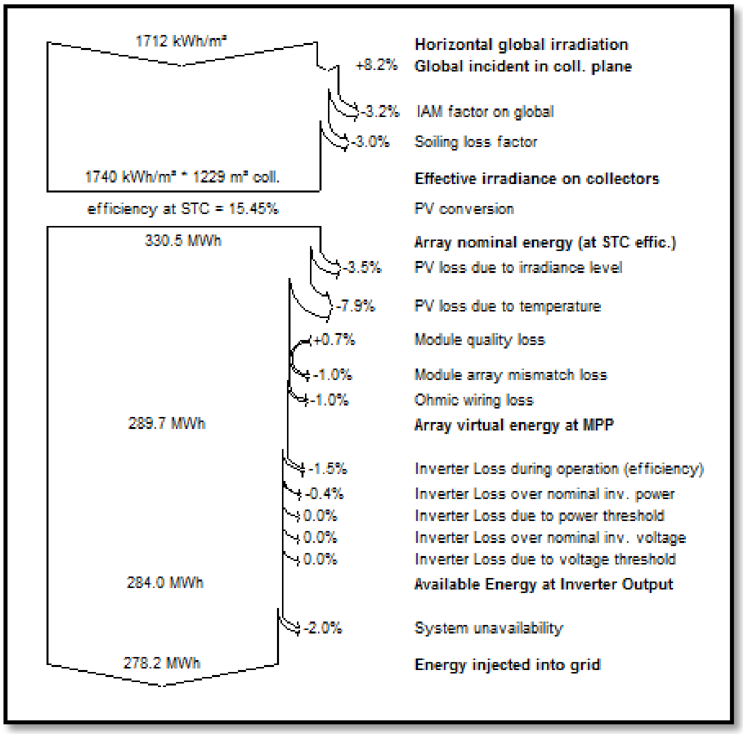

Figure 5. Loss diagram

IV. CONCLUSION

Performance evaluation of 190 kWp PV plant in CMPDI was evaluated on annual basis. The highest recorded monthly average power output is 40 kW in March, 2015 and lowest monthly average power output is 2.18 kW in the month of August, 2015 from the plant. Comparison of results from metered data with PVsyst simulation result shows that plant is operating nearer to the predicated generation of PVsyst software. The plant is operating with good amount of PR and CUF. Plant operates as per estimated performancefrom metered data and operating condition of system. Similar system design can be applied for future large scale projects.

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