Performance Ratio and Loss Analysis for 20MW Grid Connected Solar PV System - Case Study

HemanthBabu N, Sujata Shivashimpiger, N. Samanvita, V M Parthasarathy

***Abstract** - Solar Energy is fast developing source of energy in all over the world .The total installed capacity of Solar photovoltaic plant is 20 GW in India till February 2018. Knowledge about the performance of solar PV plant will result in correct investment decision and better regulatory framework, technical enhancement of solar photovoltaic technology. The study reports the various performance parameters such as Performance Ratio (PR), loss parameters and actors contributing to the performance of solar power plants. i.e., radiation, temperature, and other climate conditions and design parameters.PR is very essential at the starting stage of plant construction to get generation yield, good performance and results of Solar Photo Voltaic (SPV) System in twenty five years of time span. Solar PV plant performance is calculated on the basis of PR for particular time span of energy generation through solar PV at any location. In this paper 20 MW Solar PV plant is considered for the case study which is located in Kolar dist Karnataka. For this analysis the performance of Solar PV plant based on the site survey and one year practical performance data is compared with simulated performance data and loss analysis through PVSYST software.*

***Keywords:** PhotoVoltaic(PV)System, Losses, PVSYST Software and Performance Ratio(PR), Efficiency.*

I. INTRODUCTION

The Solar Power has started replacing coal power plants which use to supply energy for more than 90% of our energy needs. Both of these technologies are completely different on one front as well as same on the other front. Almost all the energy on earth is beacause of sun and is responsible for photosynthesis and hence plant and animal life. After millions of years we are extracting this stored energy from deep-within earth's surface in the form of coal and crude oil. Industrial revolution brought a need for these energy resources to fulfill our daily activities and as a result of it we have almost exhausted 50% of our energy resources in just 100 years. This has lead us to a stage where earth can no longer bear the fast consumption of its resources and environment will no longer be able to tackle the magntitude of pollution and other emissions. Most of the countries are facing the effects of global warming due to which there is a change in weather condition so there is a need to swithch over from conventional to non-conventional energy sources.This vital need became the stepping-stone for the fast development of solar and wind power plants. The phenomenon of prices of commodity or technology is coming down as the scale of manufacturing goes up ,the prices of solar have come down to grid tariff which was considered as cheap sources of energy. In 5 years solar energy prices have fallen down from 20Rs/Kwh to 3.13 Rs/Kwh. The biggest difference in fossil fuel based energy and solar energy is the intermittent nature of renewable energy. We do not have a stockpile of energy with us in some reservoir, we have to depend on the instantaneous energy coming to earth in form of sunlight or wind or waves etc. By using non-conventional sources it will not affect the nature and usage of these sources are increasing currently. Performance is one of the important factors in solar generation to calculate the estimated generation. The important parameters in the field of solar generation are the reference gain, solar yield, Performance Ratio and system losses.

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II. LITERATURE SURVEY

Performance Ratio is quantum of the benchmark of a solar plant that is free of area and so often expressed as a quality factor. The Performance specified as a percentage and represents the association between the practical and theoretical energy outputs of the solar plant. It hence shows the potential that is actually available for sending to the grid after taking out energy loss and of energy usage for the work to be performed, if the performance value for a PV plant found 100%. The operating efficiency of PV plant is said to be more in real scenario, a perfect value cannot be achieved, due to uncertain losses which will occur during the performance of the PV plant. It is noticed that PR relies on the irradiation, the optimum angle of tilt, air temperature, construction parameters, standard of modules, efficiency of inverter etc. The utilization of energy goes up, there will be perpetual need to increase the electricity generation from the non-conventional energy resources. Some of the various parameters like temperature, wind speed, solar irradiance etc. also influences the performance of the PV system. In the recent day the demand for PV plant is going up due to its renewable nature and conventional sources decreasing rapidly.

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The technical analysis and performance of the photovoltaic system has to be evaluated before installation .It suggests that the actual performance ratio and simulated performance has to be compared with software packages for the same SPV plant. ISE recommends the method for monitoring PV system characteristics such as irradiance, array output, storage input and output, power conditioner input and output monitored data exchange will take place [3].It shows the design and field loss considerations in some part of the location and also simulations done with some software packages for the evaluation of overall solar PV system [4]. The losses in the conductors used in photo voltaic system are to be verified before using into the PVSYST simulation [5]. The comparison made between the performances of the monthly generated power and manually generated using the software [7]. The overall performance is done with generated data and behavior of the photo voltaic systems and also for extending the grid system in future [8].

III. PROPOSED WORK

As per the concept the large solar power plants usually have more losses when compared to small plant. In this study 20 MW solar photovoltaic grid connected system is considered. The plant has been already commissioned and generation of electricity is supplied to the grid, in this study losses and performance of the solar photovoltaic plant is highlighted. Usually losses from different areas are to be investigated and evaluate the losses and also the performance of the plant has to be monitored by its performance ratio. Here we are using PVSYST simulation to evaluate the losses across different fields and also to compare the performance ratio by actual site performance and simulated performance. The aim of this study is to measure the performance of solar PV Plants and various factors that impact the performance of Solar power plant. Evaluation of 20 MW Grid connected large scale solar power plant in terms of performance usage of correct performance measures helps in benchmarking of grid-connected photovoltaic (PV) systems that may vary with respective construction, technology or geographical area. Overall Performance of the plant measures the energy yield, solar resource, and impact of complete PR and system losses.

IV. SOLAR PATH AND GEOGRAPHICAL SITE PARAMETERS

The solar path or horizon indicates that how much useful sun is shown in Fig 1

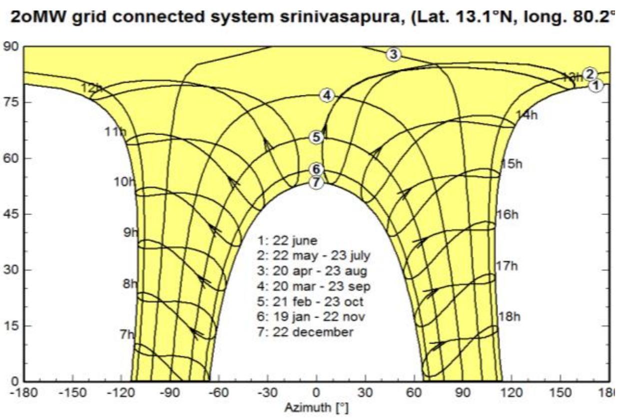
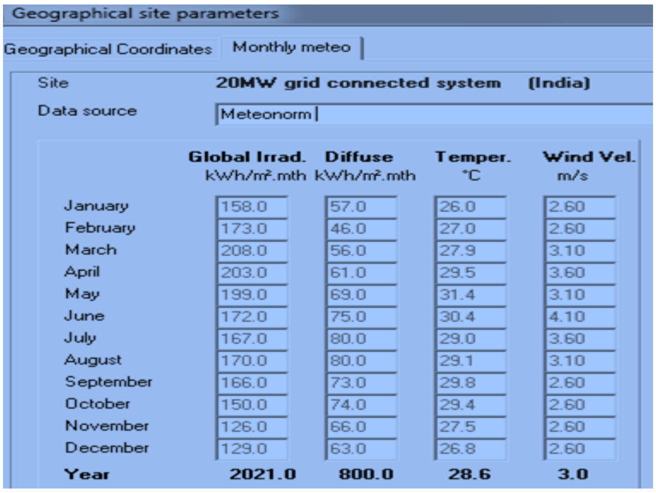


Fig 1. Solar path at the location

From the given location the monthly values of global irradiation, diffused irradiation, temperature and wind velocity of that site has been described from the PVSYST Fig 2.



Geographical site parameters

Geographical Coordinates | Monthly meteo

Site: 20MW grid connected system (India)

Data source: Meteonorm

	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	158.0	57.0	26.0	2.60
February	173.0	46.0	27.0	2.60
March	208.0	56.0	27.9	3.10
April	203.0	61.0	29.5	3.60
May	199.0	69.0	31.4	3.10
June	172.0	75.0	30.4	4.10
July	167.0	80.0	29.0	3.60
August	170.0	80.0	29.1	3.10
September	166.0	73.0	29.8	2.60
October	150.0	74.0	29.4	2.60
November	126.0	66.0	27.5	2.60
December	129.0	63.0	26.8	2.60
Year	2021.0	800.0	28.6	3.0

Fig 2. Monthly Geographical parameters

4.1 Orientation

In fig 3 the orientation and tilting of solar panel is shown. The field structure is a fixed, tilted plane of +5°, -5°, 25° seasonal tilt and azimuth angle is 0°. The optimization is given for yearly irradiation yield. In this orientation part of the angle are facing towards south and the angle panels formed will be fixed for the inclination or tilt angle. The energy consumption varies along with the seasons hence tilt angle of the solar panel changes accordingly. During summer the inclination has to be optimized.

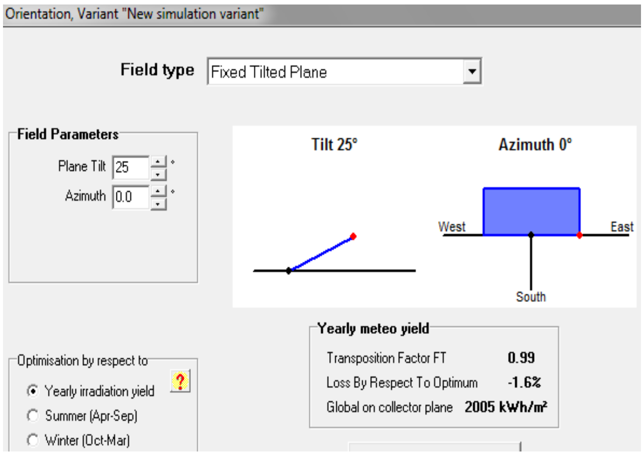


Fig3. Orientation and Tilting of solar panel

V. STUDY OF SYSTEM AND LOSSES

The Fig 4 below represents the schematic diagram of grid connected solar PV system.

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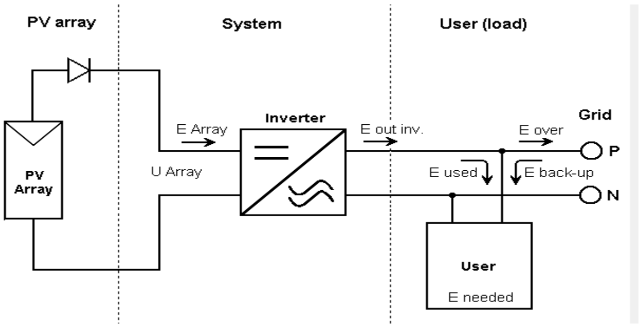

Fig4. Schematic diagram of the system

The block diagram consists of array of panels, inverters and Power conditioning Unit. The power generate by the several panels is fed to the utility grid. It is necessary to transfer the produced energy to the grid with minimal losses as possible due to less energy yield of the solar PV systems. Hence, it required to minimize these losses by removing the factors that effects the losses produced in PV systems. Shade, dust, snow, rain, temperature are some of the environmental factors that causes losses in PV system and other losses due to system components such as cables, inverters and transformers.

5. 1 Losses Due To Electrical Conductors (Ohmic losses)

When the voltage is low these losses are common. It is necessary to resize the conduit sections so that the voltage drop will be less than>1.5%. It is also necessary to place the generators near to the grid inverter to get the maximal DC voltage so that the panels and inverters can resist the conversion plant performance and reduce resistance losses. It is the ratio of the wiring ohmic losses.

$P_{wir} = R_{wir} * i_{sc}^2$ (1)

compared to nominal power $P_{nom}(array) = R_{array} * i_{sc}^2$ (2)

where $R_{array} = V_{mp}/I_{mp}$ at STC(Standard Test Condition)

where V_{mp} and I_{mp} are maximum peak voltage and current.

R_{wir} = Global wiring resistance of full system.

Ohmic losses behave in a quadratic way with the array current ($P_{loss} = R* I^2$). So that the ratio diminishes linearly with the output current. Therefore the average wiring losses are much lower during the whole running year.

5.2 Module Mismatch Losses

Mismatch8losses8are due8to the interchanging of solar PV panels in series8and8parallel. The8modules do8not have same properties from8each other. Mismatching losses are a severe problem in solar PV modules and arrays because of the execution of the overall solar PV8arrays, under worst8case conditions it is determined by the solar module with the lowest energy output. Hence the selecting of modules becomes quite useful in complete performance of the SPV plant.

5.3 Soiling Losses

Soiling of PV panels is due to accumulation of dust and dirt particles from the surroundings. In every situation, the dust is washed out from the module surface by rainfall and also dust like birds waste will stick on the surface of the panel even after heavy rainfall. The module lower edge is one of the critical part in the PV system. Generally the module is ground mounted with low level inclination so that soiling at end points of the module causes continuously accumulation of water between the glass edges there is a possible of dirt occurrence. The dust may reduce the maximum power in a module due to shading of cells from the dirt. The losses may be around less than 1 or 2% so the power is again to regenerate if the modules are regularly cleaned, so to eliminate the soil losses from the modules is possible only by cleaning in regular intervals of time. The evolution of the irradiation daily losses along the year of measurements is shown in the below equation 3. These losses(HL) represent the fraction of daily energy that a PV module will not receive as consequence of dust deposited on their surface, and are calculated as

$HL (\%) = 100 \times (Hcc-Hdc)/Hcc$ ....(3)

Where H_{CC} is the daily irradiation measured by the clean reference solar cell (W h m^{-2}) and $H_{dc}$is the daily irradiation measured by the dirty cell (W h m^{-2}).

5.4. Shading Losses, MPPT Losses & Inverter losses

a) Shading Losses: Module near shadings is due to inter row distance and also due to tall objects like central room and lightning arrestors. By shading from very tall objects, sufficient spaces are left by conducting a shadow estimating study so as to keep the photo voltaic modules free during generation time. The nearby shading loss is due to internal row spacing is however determined through simulation. In some case of seasonal tilt, the shading are low for summer tilting and high for winter tilt. Usually the shading losses may fall somewhere in between the two .

b) MPPT losses: Power output of a Solar PV module changes with change in direction of sun changes in solar insolation level and with varying temperature. The power vs voltage curve of the module there is a single maxima of power, that is there exists a peak power corresponding to a particular voltage and current. Since the module efficiency is low it is desirable to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and insolation conditions. Hence maximization of power improves the utilization of the solar PV module. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load. Maximum power point tracking is used to ensure that the panel output is always achieved at the maximum power point, using MPPT significantly increases the output from the solar power plant.

c) Inverter losses: Inverter converts power from DC to AC at certain efficiency, this results in a loss of power during conversion. The efficiency curves are inverter dependent and the inverter used is 2500kW. The efficiency loss has been calculated by the PVSYST as per the manufacturer’s provider efficiency.

5.5 Incidence Angle Modifier (IAM) Losses, Module Temperature Losses and Array Losses

IAM loss results in losses in radiation depositing the front glass of the PV modules due to angles of incidence other than perpendicular. The loss will be module dependent parameter and is calculated by using simulation as per the selecting the module. The features of a photovoltaic module are determined at STD temperature conditions of 25°C. Including the temperature coefficient of the 320Wp modules selected the module reduces to -0.4% for every °C rise in cell temperature. Module temperature loss is evaluated by simulator by adding the temperature profile of the location as per the metronome database. Since the site is located in Srinivaspura in Kolar district Karnataka it is a dry land with high temperature. Array losses tells about thermal capture loss (L_{CT}) and miscellaneous capture losses (L_{CM}) which occur in solar PV module and is shown in the V-I Characteristics of array panel which is shown in fig 5.

$F_{IAM} = 1-b_o * (1/\cos(i)-1)$ (4)

where i = Incidence angle of the plane.

For single glazed thermal solar modules, the usually accepted value for b_o is the order of 0.1. But in a PV module the lower interface in contact with the cell presents a high refractive index on our specific measurements on real crystal modules actually indicate value of b_o=0.05.

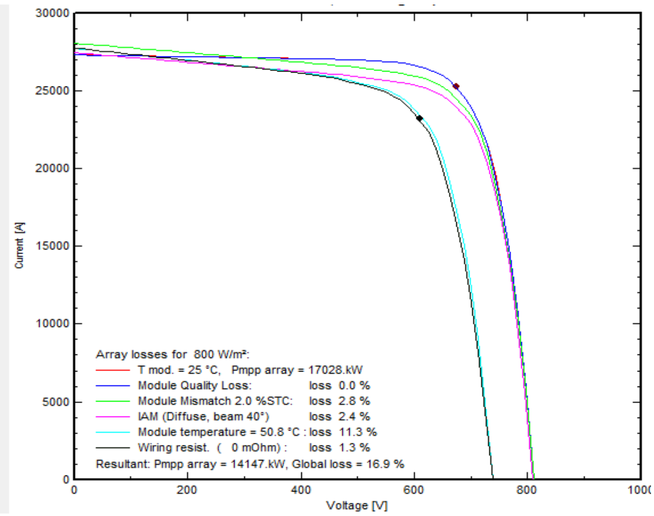

Fig 5. Array losses for Global incident radiation=W/m²

VI. SYSTEM PERFORMANCE PARAMETER

Photovoltaic systems of different configuration at different location can be compared by evaluating their normalized system performance indices such as yields, losses and efficiencies. Energy yields are quantities normalized to rated array power system efficiencies are normalized to array area and losses are the differences between reference daily yield and daily yield.

a) Daily mean yield

Daily mean yield are the quotient of energy quantities over the installed array rated output powerP0, yields indicate actual array operation relative to its rated capacity. The array yield Y_A is the daily array energy output /kW of the installed photovoltaic array

$Y_A = E_{A,d} / P_o$ (5)

Where Y_A =array yield, $E_{A,d}$= daily net energy from array, P_o=rated power output

The final photovoltaic system yield Y_f is the part of the daily net energy output from the entire plant that is injected to gird which supplied by the array per kW of installed photovoltaic array.

$Y_f = Y_A . \eta_{Load}$ (6)

Y_f =final yield, η_{Load} =load efficiency

The reference yield Y_r can be calculated by dividing the total daily in-plane irradiation by the photovoltaic reference in-plane irradiance.

$Y_r = \tau_r.X(\Sigma day\ GI)/GI, ref$ (7)

Y_r=reference yield, τ_r=reporting interval, Σday =summation for the day, GI=total irradiance in the Plane of the array, GI,ref= reference total irradiance in the plane of the array

b) Normalized losses

Normalized losses in photovoltaic normalized losses can be calculated by reference yield minus Array yield, losses can divided in two parts array capture losses and Balance of System (BOS) losses.

Array capture losses is given by

$L_c=Y_r-Y_A$ (8)

And Balance of system losses

$L_{BOS}=Y_A$ X (1- BOS) (9)

L_{BOS} = Losses in inverter

6.1 Performance Ratio

Performance Ratio(PR) is the most important parameter of the photovoltaic system for evaluation of the efficiency of the solar photovoltaic system. Performance ratio is defined as overall system performance with respect to the energy production, solar irradiance and the impact of the energy losses on the whole system.

$PR = Y_f/Y_r$ (10)

This equation is used to calculate actual performance ratio for the selected project site, it indicates the overall effect of losses on the array rated output due to the array temperature, incomplete utilization of the irradiation and system component failure or inefficiencies.

VII. SYSTEM EFFICIENCY

The inverter efficiency appropriately called as conversion efficiency is given by the ratio of AC power generated by the inverter to the DC power generated by the PV array system. The instantaneous inverter efficiency is given by,

$\eta_{inv}=P_{AC}/P_{DC}$ (11)

The instantaneous daily system efficiency is given as PV module efficiency multiplied by inverter efficiency.

$\eta_{sys}, T = \eta_{PV}, T*\eta_{inv}, T.$ (12)

The energy generated by the PV system is the measure of energy across the inverter output terminals for every minute. It is defined as the total daily monitored value of AC power output and the monthly AC energy generated.

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VIII. SIMULATION RESULT

Loss analysis and performance Ratio of 20MW grid connected system has done by using PVSYST simulation. In this software detailed study of sizing, simulation and data analysis of complete PV systems has to be executed. PVSYST is very necessary tool at educational institutions and also is widely used to build a project. It candrift the meteo data from various sites, as well as private data also this software is a tool that provides accurate analysis of different grouping and to analyse the outcome to recognise the best possible output. PVSYST is SPV system software found by the enegery group at the university of geneva switzerland and is widely used at any region that has meteo and solar insolation information. It is also used due to its many factors availble for the user to modify.

8.1 System Losses From The PVSYST

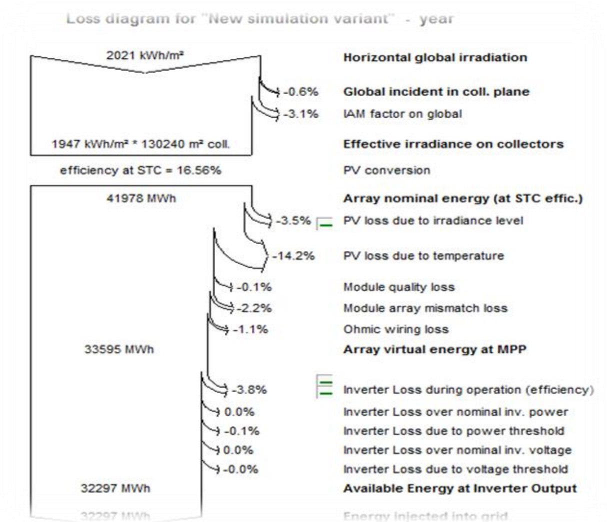

Fig 6. System loss diagram for a year

8.2 Grid Connected System

Table1. Annual main results for a year

New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	158.0	26.00	188.5	183.8	3204	3091	13.05	12.59
February	173.0	27.00	196.4	191.5	3292	3175	12.87	12.41
March	208.0	27.90	212.9	207.0	3541	3414	12.77	12.32
April	203.0	29.50	186.7	180.7	3089	2975	12.70	12.23
May	199.0	31.40	168.9	162.6	2762	2656	12.55	12.07
June	172.0	30.40	144.3	138.6	2390	2292	12.72	12.20
July	167.0	29.00	143.3	137.8	2399	2300	12.86	12.32
August	170.0	29.10	154.7	149.3	2581	2476	12.81	12.29
September	166.0	29.80	161.7	156.7	2682	2582	12.74	12.26
October	150.0	29.40	158.8	154.3	2654	2553	12.83	12.34
November	126.0	27.50	141.1	137.1	2390	2295	13.00	12.49
December	129.0	26.80	151.8	147.6	2586	2487	13.09	12.58
Year	2021.0	28.66	2009.1	1946.9	33570	32297	12.83	12.34

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

The table 1 above depicts the annual generation data and main results of a grid connected system from the fig 4 it shows that the ambient outside temperature over the year is 28.66ºC and energy supplied to the grid is 32297MW.

8.3 Daily Performance Ratio

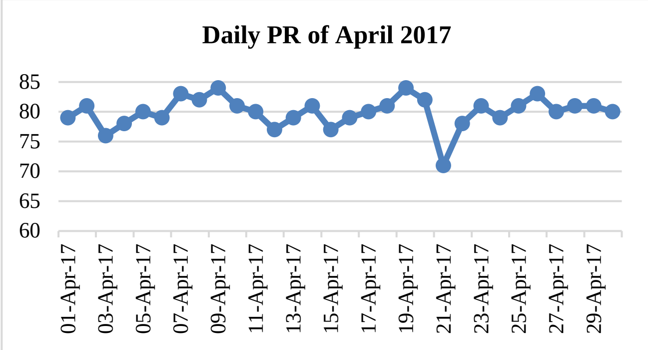

Fig 7 Graph shows the Daily PR for the month of April

We can see that the Performance Ratio in simulation software was all most similar for every month, but in actual generation data there is huge variation in performance ratio of the solar photovoltaic plant. The highest 81% PR recorded in the month of April 2018 due to the low module temperature and in month of October 2017 lowest PR recorded 68% due to the high temperature of photovoltaic modules. In figure 8 the daily variation in performance ratio on 9thApril 2017 with highest PR record of 84% and 22th April 2017 PR record of 71% due to the low grid availability is shown.

8.3.1Normalized Production (per installed KWp) for 21479 KWp

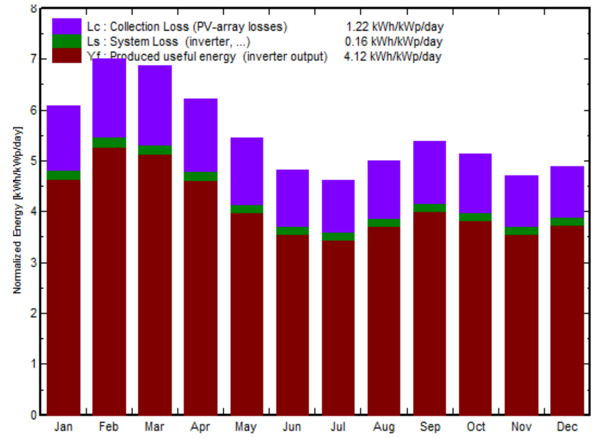

Fig 8. Normalized energy production with losses

8.3.2. Simulated Performance Ratio from PVSYST

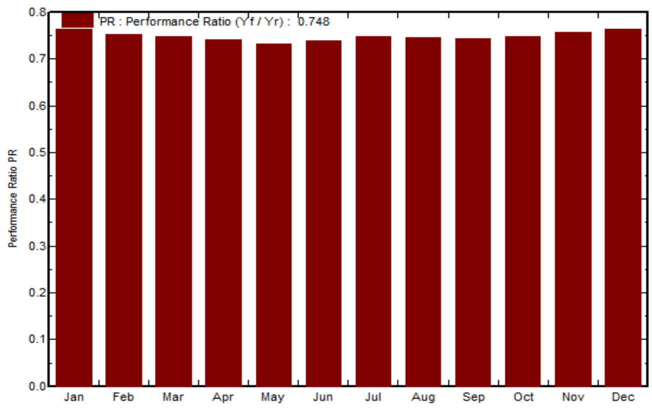

Fig 9. Performance ratio for the year

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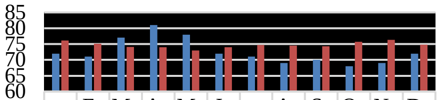
8.3.3. Comparison between PR Actual Vs PR Simulated

The PR shows the complete effects of losses on the solar module output power depends on the module temperature, inefficiency of the irradiation system component and system downtime. When PV system is simulated in PVSYST software then grid injected is 32297264KWh .The PR for similar intervals was 72% in the simulation software which means 28% of insolation was not changed into useful energy. When we collect the data for the year 2017 for the same project and evaluated the PR it is 72%, which is slightly lesser than PR in PVSYST software. In this situation we accept grid and plant availability.

Comparison of PR Actual vs PR Simulated



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PR ACTUAL	72	71	77	81	78	72	71	69	70	68	69	72
PR SIMULATED	76.1	75.1	74.1	74	73	74	74.7	74.5	74.3	75.7	76.3	74.8

PR ACTUAL   PR SIMULATED

Fig 10. Comparison of PR actual vs simulated PR

IX. CONCLUSION AND FUTURE SCOPE

The PR of 20MW grid connected solar PV system has been analyzed and compared for the duration of a year. As an outcome the average performance ratio was 74.8%for the PVSYST simulation, whereas the PR for the practical project generated is 72% considering the plant and grid availability in PR. We can conclude that the performance of the solar PV plant is quite good only less than we simulated in PVSYST. By ensuring 100% plant and grid availability we can increase the performance of the plant near to the simulation result. Solar PV system is the currently booming sector in the globe, so the PR of the plant needs to generate more energy every year to gain the better performance. The photovoltaic system performance depends on material technology, production and manufacturing process. The PV software provides analysis of various losses. PV also tries to use same models for entire PV system, along with the identified sources of losses. Solar PV is rising industry in the universe, so performance of plant needs to be tracked on yearly basis to gain the more energy from the plant. During the downtime of a plant, a lot of things need to be taken into consideration for getting better energy generation outcome, thereby reducing the financial uncertainty at the time of operation. The performance of the plant can be improved by expanding the power plant in future.

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