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LONG TERM FIELD PERFORMANCE ANALYSIS OF 100KWp GRID-CONNECTED ROOFTOP SOLAR PV POWER PLANT

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ABSTRACT: Solar PV system is one of the best substitute in renewable energy at sizable. This paper proposes the long term field performance analysis of 100kWp grid-connected rooftop solar PV power plant installed at B.V.Raju Institute of Technology (BVRIT) at Narsapur, Telangana. The monitored data of the system from five years of continuous operation is used to evaluate the performance. In this paper, the solar PV plant generated energy, performance ratio, capacity utilization factor and efficiency are measured and also compared with the simulation values obtained from pvsyst 6.8.7 software. Performance analysis of the grid connected plant will be helpful in operating, designing and effective maintenance of new grid connected systems. The average estimated energy for five years is 192334.2 kWh, average energy generated is 146616 kWh, average performance ratio is 76.22% and average capacity utilization factor is 16.74%. Here five 20 kW inverters are used for operating the plant whose output is deviated in few months of operation due to maintenance.

KEYWORDS: Capacity utilization factor, Generated energy, Normalized energy, PV plant, Performance ratio, PVSYST, System efficiency.

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I. INTRODUCTION

To meet the energy demands in India sun is one of the substitutes for energy production. The light energy produced from the sun is directly converted to electrical energy by photovoltaic energy conversion principle. The performance of the solar photovoltaic plant is dependent on type of panel technology, environmental conditions such as temperature and humidity, location of the site, seasonal fluctuations, solar insolation, air pollution and module maintenance.

In India the installed solar power capacity is 28464.17 MW as of 31 March 2019. In solar power generation capacity Karnataka stands first with the capacity of 6095.56 MW and Telangana stands second with the capacity of 3592.09 MW.

K. Padmavathi at el., (2013) [1], the performance evaluation of grid connected solar photovoltaic power plant of capacity 3 MWp located in Karnataka. The performance ratio is evaluated for two years; in 2010 it was less than 0.6 from August to November due to high inverter failure losses. The next year, 2011 PR values improved of an annual average value of 0.7 and inverter failure losses were reduced.

Vikas Pratap Singh at el., [2], the data quality check on global horizontal irradiation and tilted global horizontal irradiation to obtain the estimated performance ratio (PR) of the PV plant. The performance ratio is inversely proportional to module temperature which depends on climatic parameters. Plant under standard condition provides maximum power generation with higher performance ratio. Performance ratio is higher in winter season compared to summer or rainy season; the variation is due to thermal losses.

B. Shiva Kumar at el., (2015) [3], simulation values obtained from PV syst and PV-GIS software values are compared, plant is operating nearer to the predicted generation of energy modelling software. Utmost total energy generation of 10 MWp grid connected solar photovoltaic power plant is in the month of January and nethermost in the month of July (2014-2015). The plant is operating with good amount of PR and CUF.

Robins Anto at el., (2014) [4], the photovoltaic systems integrate power build up units generate harmonics that rely up on operating conditions of structure which impact the quality of power supply, reliable operation, life span of the system components. The efficiency of 100KWp plant is shrinking during the evening time as irradiance diminishes. Capture losses and system losses are high during the low radiation levels due to the variation of solar radiation.

Lana S. PANTIC at el., [5] Practical field study of performances of three identical monocrystalline solar modules, single power of 60 W, with different inclinations (horizontal, optimally inclined oriented toward South and vertically oriented toward South) in real meteorological conditions, in Nis, Serbia are presented. The efficiency, performance ratio and fill factors are measured and compared.

Cristina Cornaro at el., [6], the results of a two years outdoor monitoring campaign that has been carried out on the same polycrystalline photovoltaic module at two different locations in Europe: the SUPSI-ISAAC outdoor facility in Lugano, Switzerland, from April 2006 till May 2007, and the outdoor ESTER facility in Rome, from April 2008 till May 2009. The monthly PR appears higher for Lugano than for Rome apart from the April 07-09 case where the performance in Rome has been higher. A 3% maximum PR deviation between the two sites has been registered during the autumn months.

Pablo Ferrada at el., [7], the paper has reported on the performance of photovoltaic systems in the coastal zone of Antofagasta, northern Chile. It analyzed how the performance ratio is influenced by the dust accumulation and the ambient temperature associated to this place. It came out that the difference of energy yield between the technologies became larger for summer and smaller for winter, and that the performance ratio decreased due to the dust accumulation.

Lana S. PANTIC at el., [8], the performance of PV modules under actual outdoor conditions is found to be quite different from that determined under controlled laboratory conditions. Performance of PV modules will not be the same for a given PV module if it is located in places with different climate type e.g. wet tropical, dry desert or continental climate.

Gay, Rumberg and Wilson at el., [9] thirty years ago, researchers in the PV field acknowledged the need to go beyond STC, suggesting that module performance be characterized by categories of weather conditions (hot sunny, cold sunny, hot cloudy, cold cloudy, and nice).

Seung-Ho Yoo at el., [10] presented the influence of tilt angle of PV panel, building azimuth and shading effects on power generation of SPV modules were considered to optimize the performance of a Building Integrated Photovoltaic (BIPV) system located in Korea. The efficiency of this BIPV system during different months was compared. According to this study, the power generation is more influenced by the above factors in summer than in winter.

M. Shravanth Vasisht at el., [11] study showed a 20 kWp Solar Photovoltaic (SPV) system was set up on the library roof-top in Indian Institute of Science, Bangalore, India. This Roof-top photovoltaic (RTPV) system partly powers the Central Office of IISc. The main objective of setting up this SPV system was to study the performance of solar plants under different seasons and climatic conditions of Bangalore.

In this paper five operation years performance of the grid connected rooftop solar PV plant is figured out by using the parameters efficiency, performance ratio, capacity utilization factor, generated energy. System operation from 2014 to 2018 is considered for estimation of the plant. To valuate the performance ratio and to calculate theoretically generated energy values are collected from NASA.

II. EXPLICATION OF SYSTEM

The 100 KWp solar photovoltaic system installed at roof top of Aryabhatta block of B.V.Raju Institute of technology (BVRIT), Narsapur, and Hyderabad. This plant is located in South India with latitude of 17.30° N, longitude of 78.90° E, altitude of 590 m and azimuth angle of 0°. The aim of installation of solar PV plant is to extend the green technology into the institute and also to overcome the energy calamity.

Fig. 1 replicates the rooftop solar PV plant installed at BVRIT, Plant consists of 20 strings, each string is equipped with 20 modules and each module consists of 60 cells i.e. 400 PV modules of poly crystalline silicon technology with rated power 250 Wp. The module efficiency at STC is 14.3%, open circuit voltage (V_{oc}) is 37.56

V, short circuit current (I_{SC}) is 8.53 A, rated voltage (V_{MPP}) is 31.18 V, rated current (I_{MPP}) is 8.02 A, power tolerance is ±3%.

Fig. 1: Rooftop Solar PV Plant Installed at BVRIT

Five REFUsol string inverters of 20 kW_p are connected to the panel strings as shown in Fig. 2. The inverter specifications are as mentioned in table. 1.

Fig. 2: REFUsol Inverter of 20kw_p Capacity

Table 1: Inverter Specifications Used in 100 kW_p solar PV Plant

DC Specifications		**AC Specifications**	
Max. Input voltage	1000 V	Nominal operating voltage	3ϕ 400 V + N
MPP range	480-850 V	Nominal operating frequency	50/60 Hz
Max. input current total	41.0 A	Rated power	19.2kVA
Max. Input current per input pair/-triplet	25 A	Max. Active power@ cosϕ=1	19.2 kW
Operating temperature range	-25 to +55º C	Max. Output current	3*29 A= 87 A

III.INSTANCED COMPUTATIONS

Estimated energy

Estimated energy is defined as the product of peak sun hours, plant capacity and number of days in month/year.

$$Estimated\ energy\ = peak\ sun\ hours * plant\ capacity * no.of\ days\ in\ month/\ year \quad (1)$$

Peak sun hours data is collected from NASA. Estimated energy is measured in terms of kWh.

Normalized energy (P_{norm})

Normalized energy is defined as the ratio of generated energy to the product of plant capacity and number of days [15].

$$P_{norm} = \frac{generated\ energy}{plant\ capacity * no.of\ days}\ W_p/kWh \quad (2)$$

Performance ratio (PR)

Performance ratio is defined as the ratio of generated energy to the estimated energy [2], [15],[16].

$$PR = \frac{generated\ energy}{estimated\ energy}\ \% \quad (3)$$

Capacity utilization factor (CUF)

Capacity utilization factor is defined as the ratio of generated energy to the product of number of days, number of hours per day and installed plant capacity [2],[3],[12],[16].

$$CUF = \frac{generated\ energy}{no.of\ days * 24 * installed\ plant\ capacity}\ \% \quad (4)$$

Efficiency

$$system\ efficiency(\%) = \frac{practical\ energy\ generated}{solar\ irradiation\ value * no.of\ days * plant\ area}\ \% \quad (5)$$

IV. PERFORMANCE ANALYSIS

To evaluate the performance of 100 kWp solar PV plant, the data is tracked for five operational years is considered. The parameters considered in this study are

Table 2: Estimated Energy, Generated Energy, Normalized Energy, Performance Ratio and Capacity Utilization Factor for Five Years.

Year	Estimated Energy (kWh)	Generated Energy(kWh)	Normalized Energy(Wp/kWh)	PR(%)	CUF(%)
2014	193258	152687	4.19	79	17.45
2015	195176	151534	4.16	77.63	17.30
2016	188538	145914	3.99	77.39	16.62
2017	192962	147211	4.04	76.29	16.82
2018	191737	135733	3.73	70.79	15.51

Table 2 consists the values of generated energy, performance ratio and capacity utilization factor for five years. Fig.3 shows the generated energy of 100kwp solar PV plant from 2014 to 2018. The generated energy is getting decreased every year but in between 2016-2017 the generation has been increased. At intervals the generation difference from 2014 to 2015 is -0.7%, 2015 to 2016 is -3.7%, 2016 to 2017 is 0.88% incremented, 2017 to 2018 is -7.79%. The decrease in generation can be due to losses, repairs, temperature, shadow, maintenance, degradation and weather conditions.

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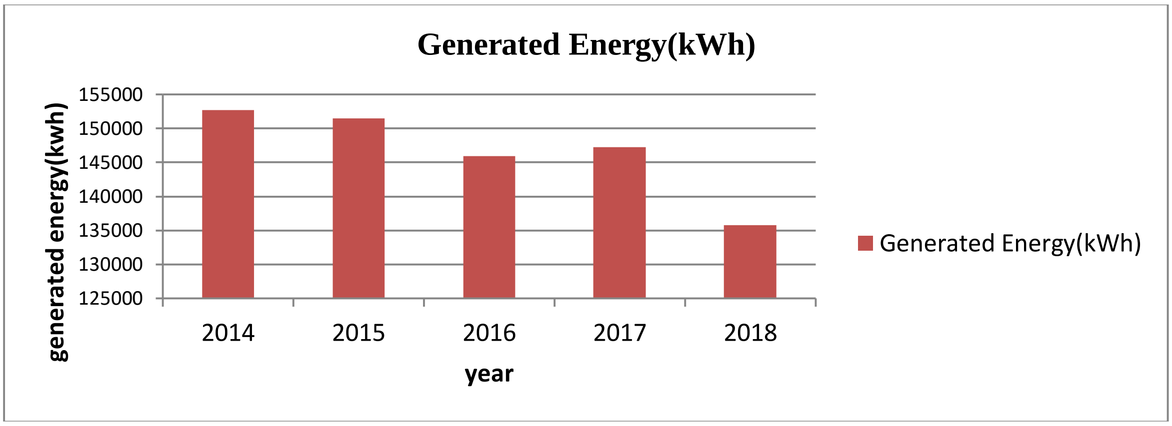

Fig. 3: Energy Generated in Five Years

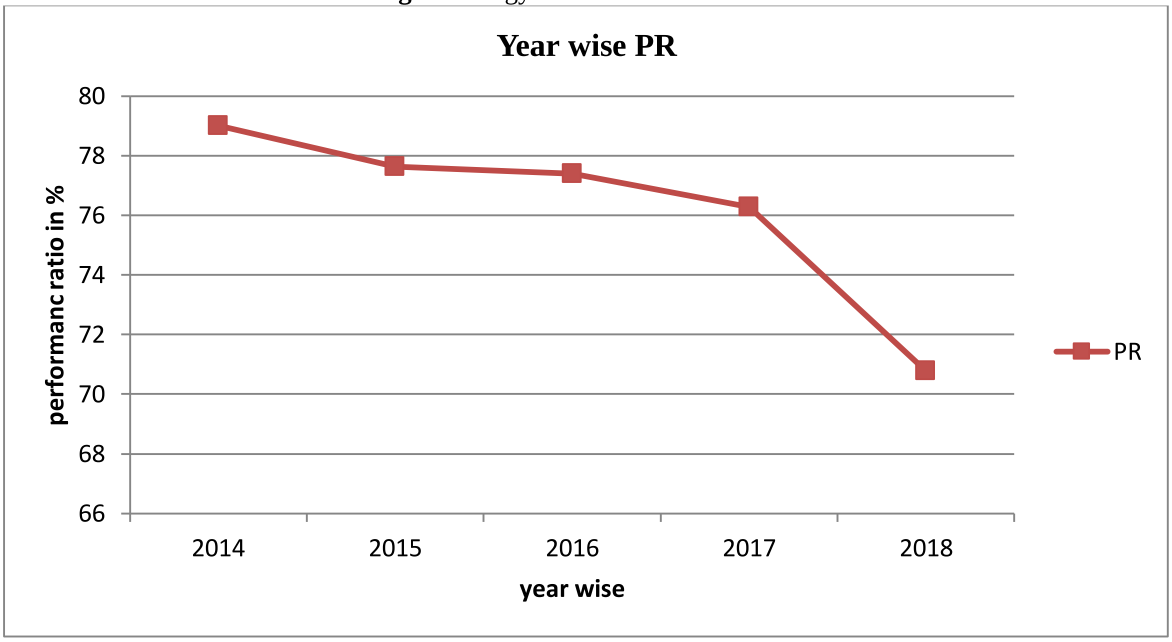

Fig.4: Year Wise Performance Ratio for Five Years

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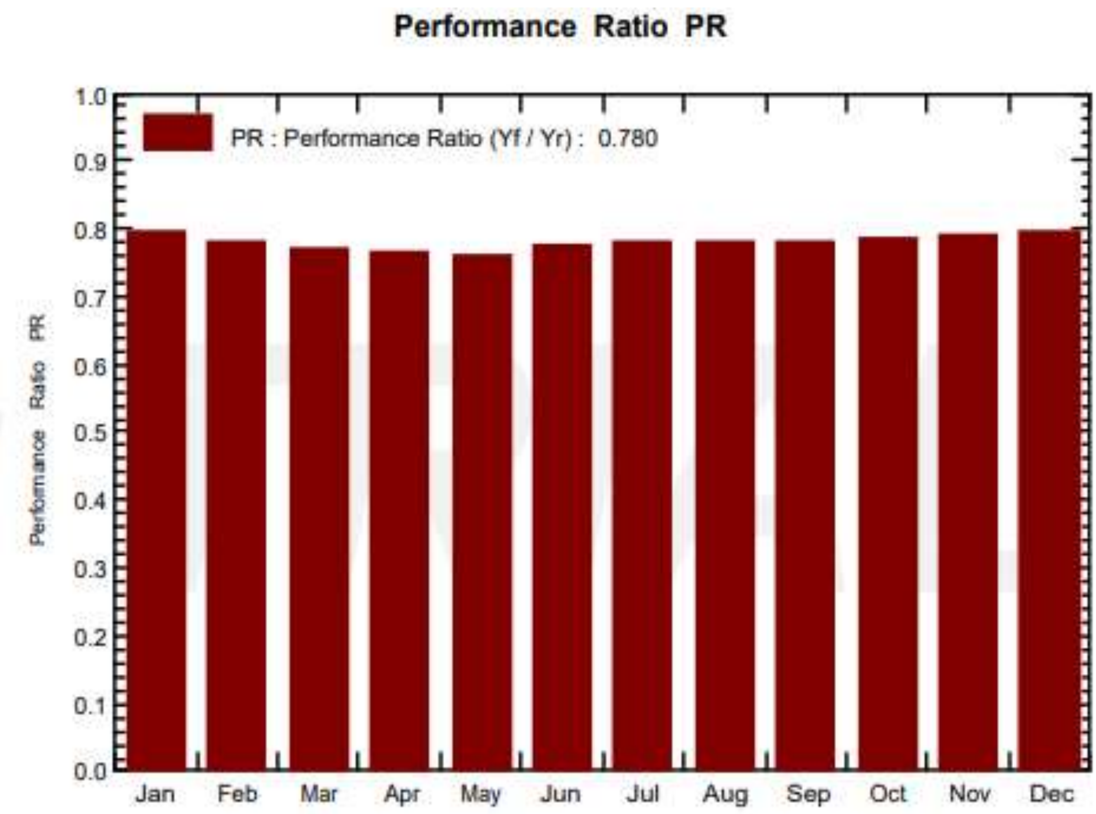

Fig.5: Performance Ratio for Year by PVSYST Software Simulation

The year wise performance ratio of plant from 2014-2018 show in fig 4. In 2014, the performance ratio is 79%, in 2015 it is 77.63%, in 2016 it is 77.39%, in 2017 it is 76.9%, and in 2018 it is 70.79%. From 2014-2018, performance ratio is gradually decreasing, from 2014-2015 performance ratio is decreased to 2%, in 2015 and 2016 it is equal, from 2016-2017 performance ratio is decreased to 1%, from 2017-2018 performance ratio is decreased to 6%. The fig 5. Shows that the annual performance ration of the solar PV plant given by the the pvsyst simulation and also seen that the performance ratio is 78% from this we can observe that the actual performance ratio is almost nearer to the pvsyst simulation report but it changed 7% in year 2018.

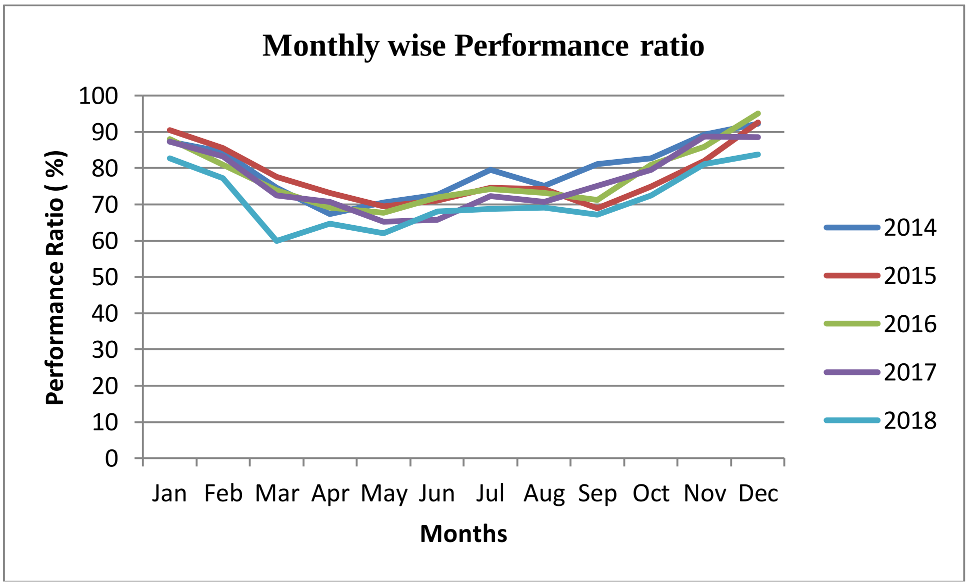

Fig.6: Monthly Wise Performance Ratio

Fig.6 shows the monthly wise performance ratio of plant for five years i.e., from 2014-2018. Generally in India the performance ratio of solar plant is about 80%. The performance ratio is higher in the months of January and

December i.e., in winter season as the temperature is low, solar irradiance will be more. In summer season i.e., in the months of April and May performance ratio is less due to more temperature and less irradiance.

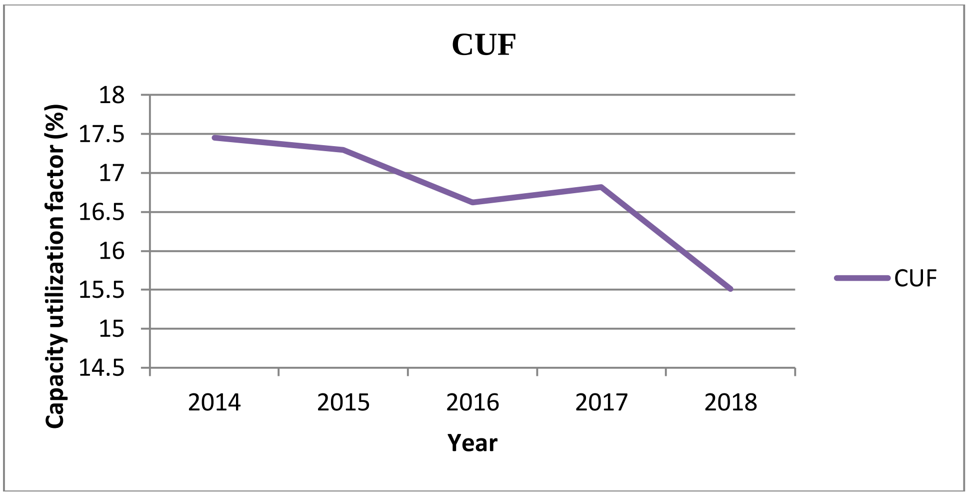

Fig.7: Capacity Utilization Factor for Five Years

Fig.7 depicts the capacity utilization factor (CUF) for different operation years. Generally in India, capacity utilization factor of solar PV plant must be about 16-17%. In 2014, 2015, 2017 the capacity utilization factor is 17% and in 2016 and 2018 it is 16%.

Table 3: All Five Inverters Energy Output in Five Years

Inverter	2014	2015	2016	2017	2018
Inverter 1	30448.7	30664.1	29368.7	29965.2	27406.3
Inverter 2	30489.2	30599.1	29345.8	29308.9	28081
Inverter 3	30653.3	29551.1	29979.8	30347.5	26607.2
Inverter 4	29979.9	29987.5	28243.7	27923.4	25694.1
Inverter 5	31115.7	30732.4	28976.5	29666.1	27944.8

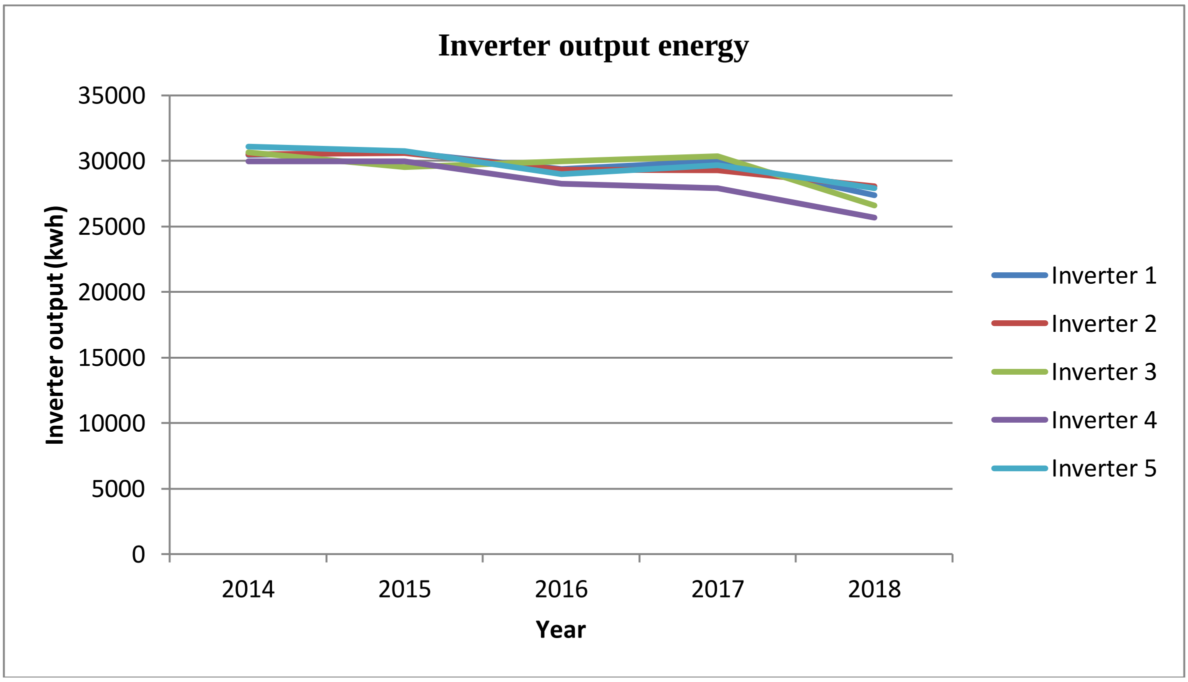

Fig.8: Inverters Output Energy in Five Years

The table.3 and fig.8 shows the year wise inverter output energy from 2014-2018. For 100kwp solar PV plant, we have five inverters of capacity 20kw each. The output of each inverter used must be equal but the inverter output energy is approximately equal for all five inverters used, from 2016 the output has been gradually decreasing for inverter 4.

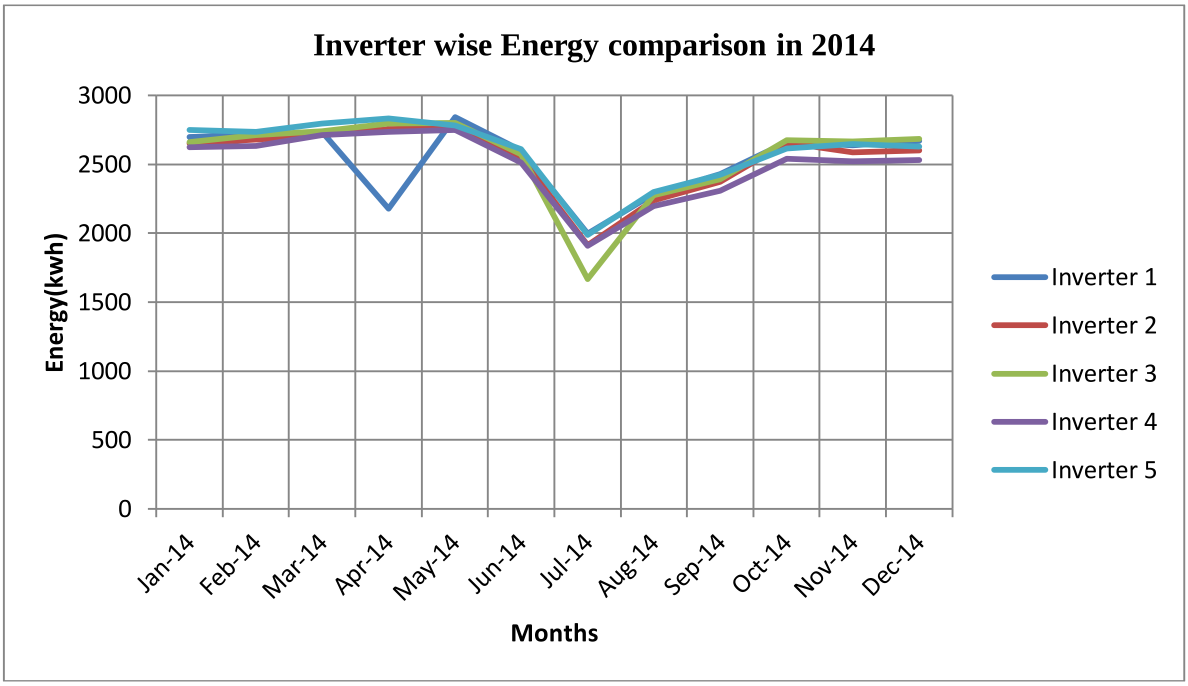

Fig.9: Inverter Wise Energy Comparison in 2014

Fig.9 shows the inverter wise energy comparison in the year 2014. In 2014, all five inverters output is almost equal in the months of January, February, March, May, June, August, September, October, November, December and in the April month the output of inverter 1 has decreased and in the month of July the output of inverter 3 has decreased.

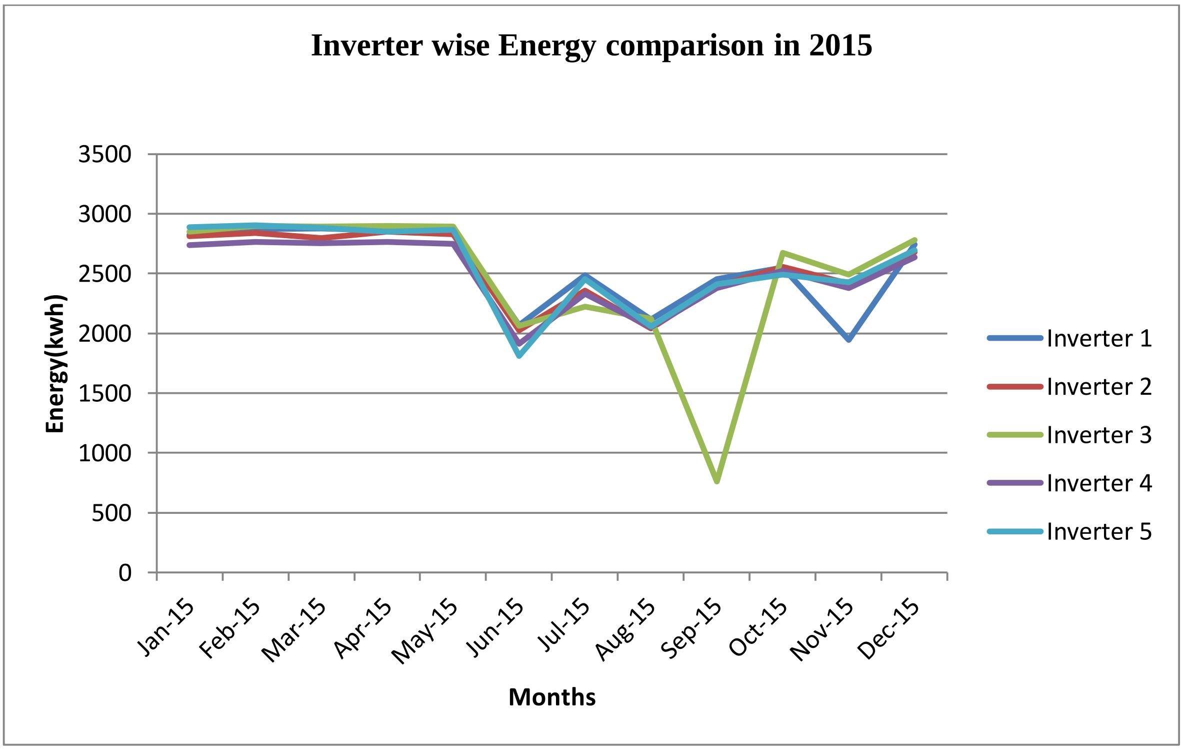

Fig.10: Inverter Wise Energy Comparison in 2015

In 2015, the output of all inverters is almost equal in all months except in September and November. In the month of September inverter 3 output decreased and in the month of November inverter 1 output decreased are shown in fig.10.

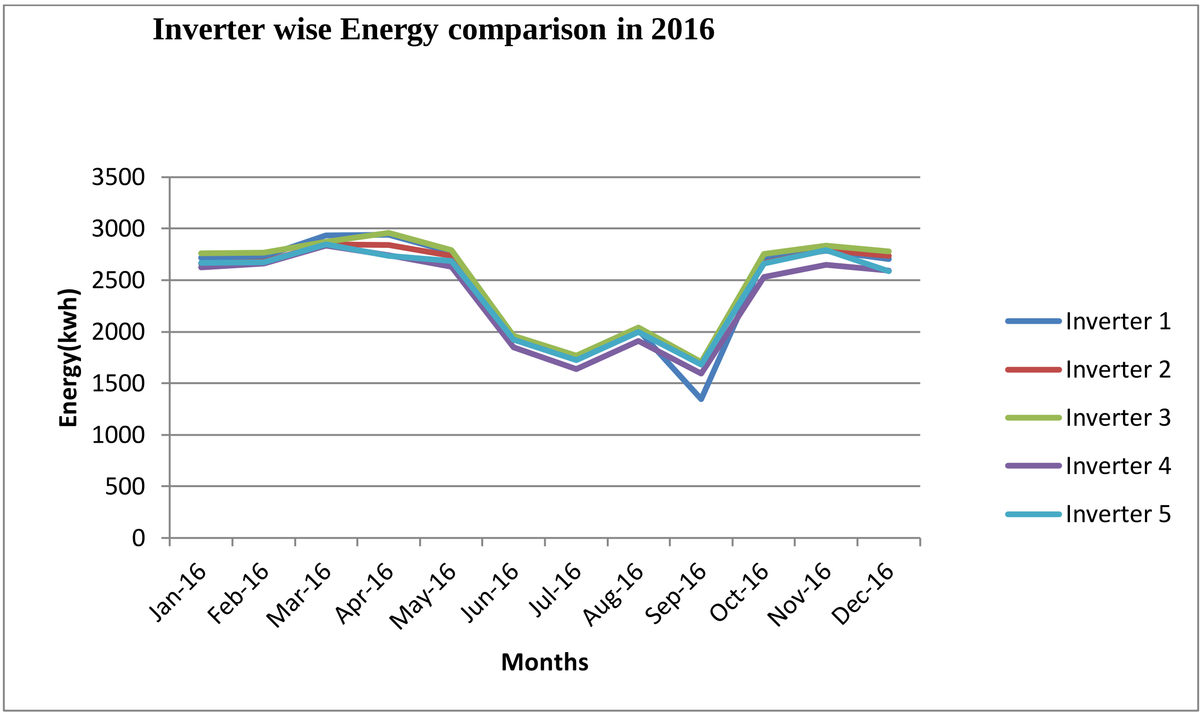

Fig.11: Inverter Wise Energy Comparison in 2016

In 2016, almost equal energy output is observed for all inverters in all months as shows in fig.11 but in the month of September inverter 1 output is less. Later the energy output is almost equal for all the inverters from the month of October.

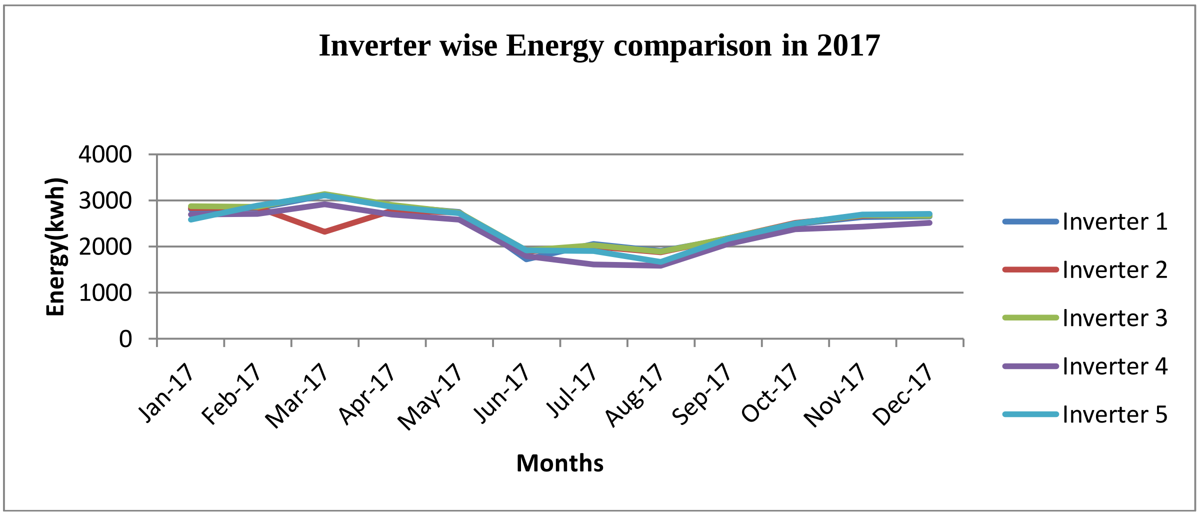

Fig.12: Inverter Wise Energy Comparison in 2017

Fig.12 shows Inverter wise energy comparison in 2017, inverter energy output is deviated in the month of March in inverter 2 and in the months of June, July, August output is decreased in inverter 4 and in July, August inverter 5 output is decreased.

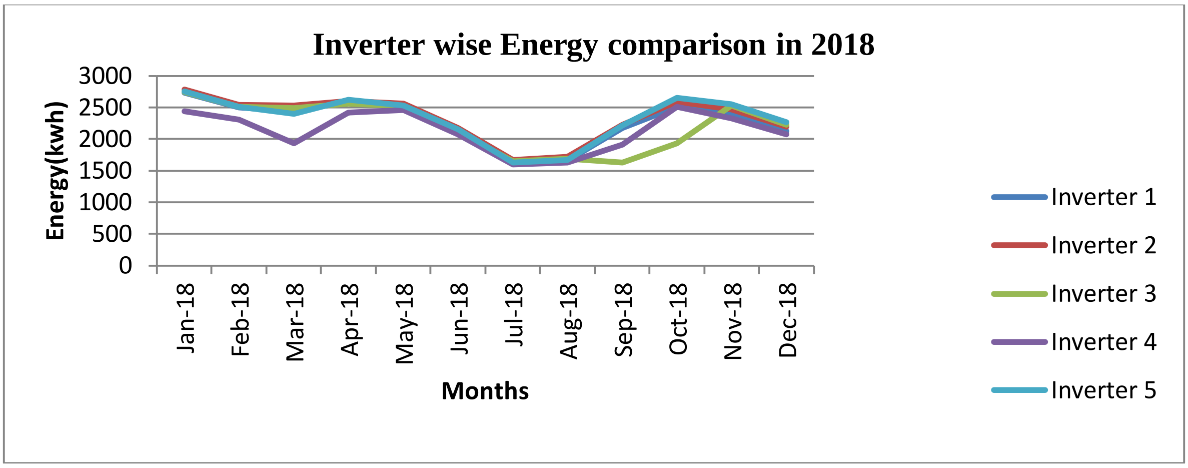

Fig.13: Inverter Wise Energy Comparison in 2018

Fig.13 shows Inverter wise energy comparison in 2018, the inverter 4 output has been decreased in January, February, March and inverter 3 output is decreased in months of September, October, November and in the months of September and October the inverter 4 is decreased.

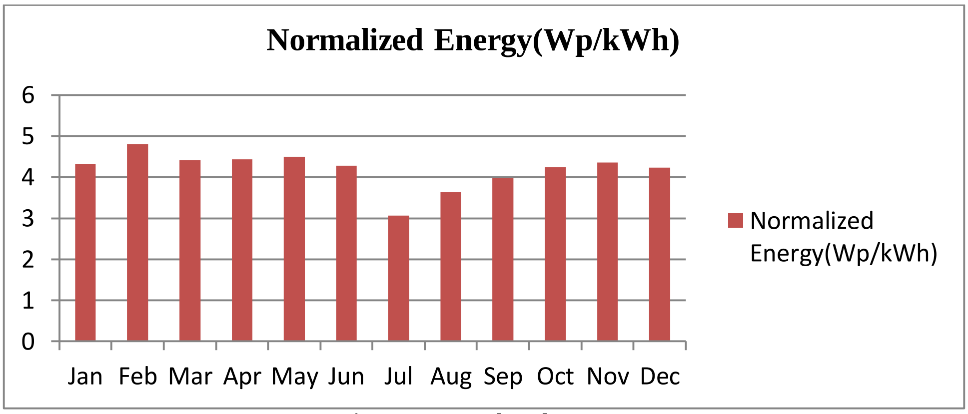

Fig.14: Normalized Energy

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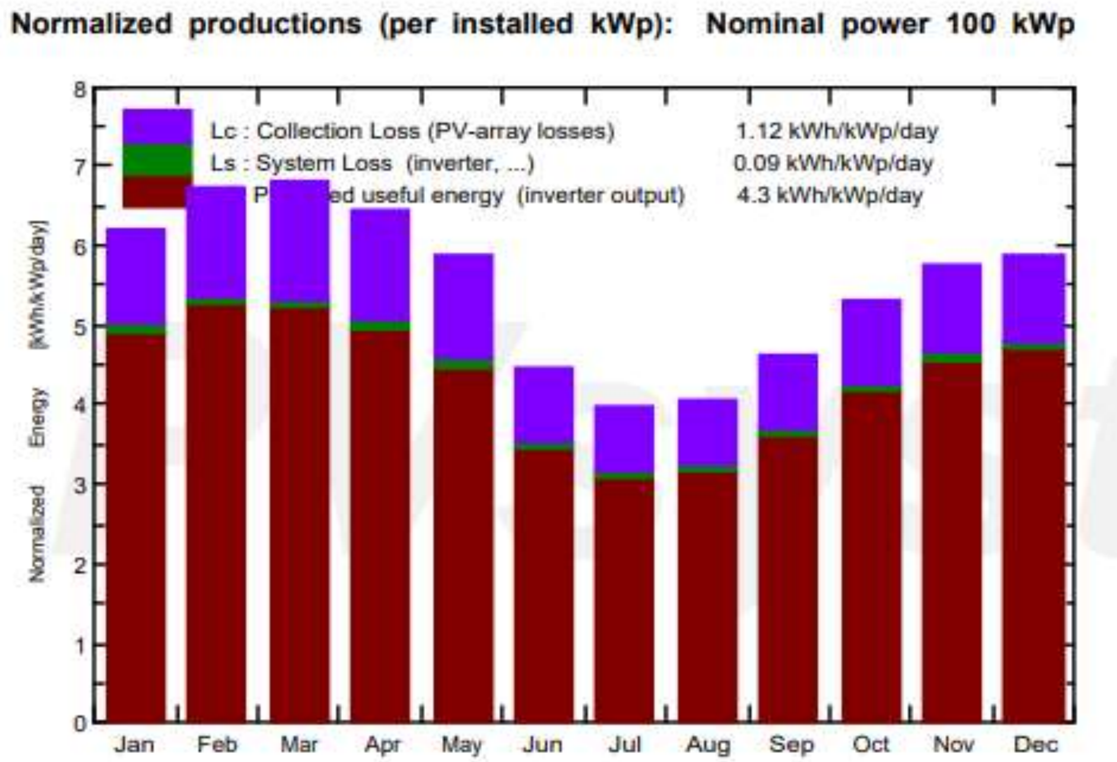

Fig.15: Normalized Energy by PVSYST Software

The fig 14 shows that the normalized energy calculated by the real time data of one year. Fig 15 shows the normalized energy produced by the pvsyst software simulation for year. From the normalized energy graphs we can observe that the normalized energy produced by the plant is 4.19 kwh/kwp/day and the normalized energy produced by the pvsyst simulation report is 4.3 kwh/kwp/day. For Five years normalized energy are like this 2014 it is 4.19kwh/kwp/day, 2015 it is 4.16 kwh/kwp/day, 2016 it is 3.99 kwh/kwp/day, 2017 it is 4.04 kwh/kwp/day and in 2018 Normalized energy is 3.73 kwh/kwp/day. Comparing with the pvsyst simulation report the normalized energy production is less it dependence on the generated energy pvsyst gives the simulation without considering the failures and losses of the plant like module cleaning, weather condition, module failures, junction box damages and due to other problems the energy production may varies from the pvsyst simulation report to real time PV plant output.

Table 4: PV System Efficiency of 100 kW_p Solar PV Plant for Five Years

	2014	**2015**	**2016**	**2017**	**2018**
Jan	11.06	11.47	11.15	11.06	10.48
Feb	10.71	10.84	10.26	10.55	9.78
Mar	9.45	9.84	9.35	9.17	7.58
Apr	8.52	9.28	8.76	8.95	8.19
May	8.94	8.81	8.57	8.25	7.87
Jun	9.21	9.01	9.11	8.32	8.62
Jul	10.09	9.44	9.41	9.16	8.72
Aug	9.52	9.41	9.28	8.96	8.75
Sep	10.28	8.73	9.03	9.51	8.52
Oct	10.48	9.49	10.25	10.08	9.18
Nov	11.30	10.39	10.89	11.23	10.29
Dec	11.68	11.74	11.67	11.22	10.62

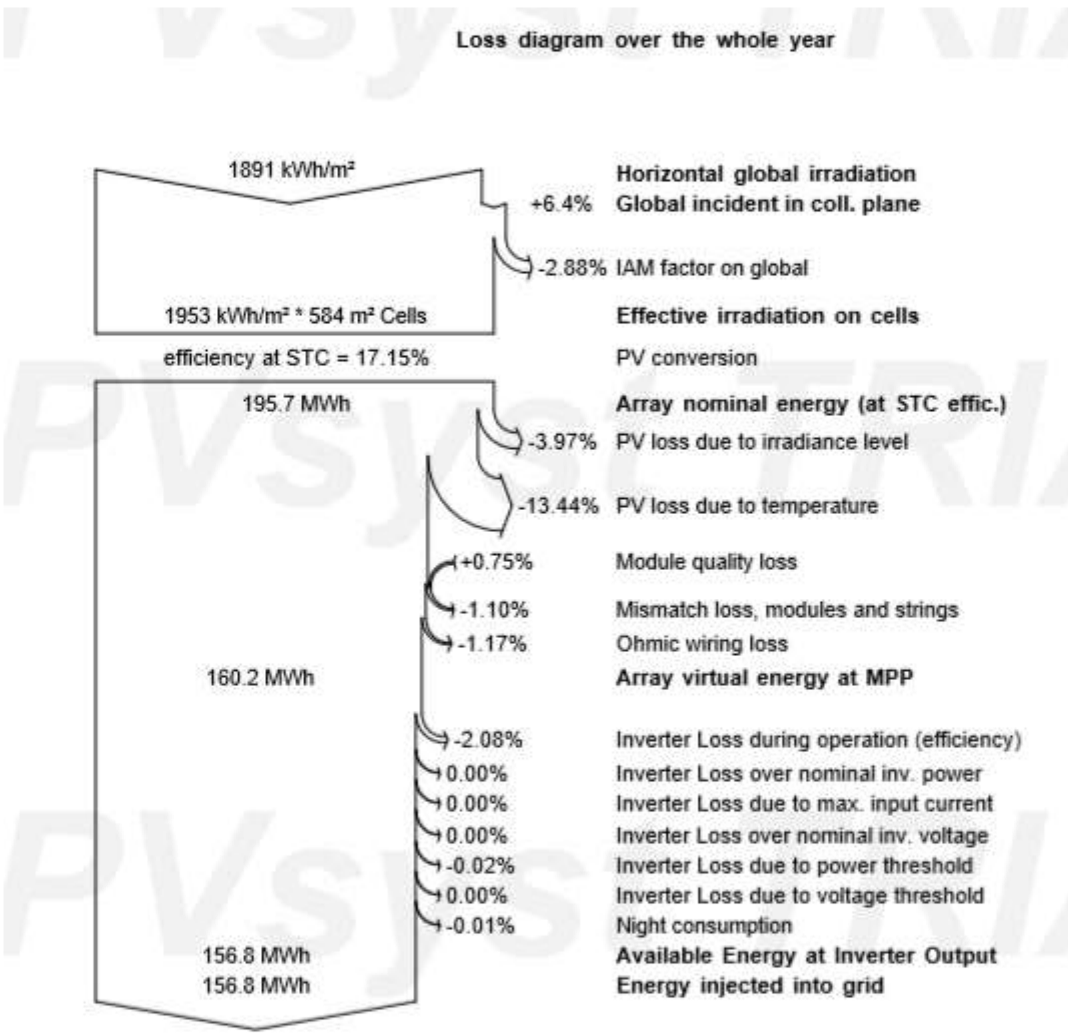

Fig.16: Loss Diagram Over the Whole Year by PVSYST Software

The PV system efficiencies for five years monthly wise are listed in the table 4 and also the system efficiency at standard test condition given by the pvsyst simulation is shown in the loss diagram fig 16.Efficiency at standard test condition is 17.15% for whole year from the table 4 we can see that the PV system efficiency for the year 2014 is 10.10%, 2015 is 9.87%, 2016 is 9.81%, 2017 is 9.70% and 2018 is 9.05%.comparing with the pvsyst report 100kwp solar PV system get the 58.89% efficiency in the year 2014, 57.55% in 2015, 57.20% in 2016, 56.58% in 2017 and 52.76% of efficiency in the 2018 year [13],[14].

V. CONCLUSION

Long term field performance analysis of 100KWp grid-connected rooftop solar PV power plant installed at BVRIT was studied and the following observations are drawn.

The generated energy is getting decreased every year but in between 2016-2017 the generation has been increased. The year wise performance ratio of plant from 2014-2018 is getting decreased progressively, in winter season the performance ratio is more compared to summer season. Performance ratio of the 100kwp solar PV plant is nearer to the pvsyst simulation Performance ratio. Capacity utilization factor of plant is varying between 16-17%. The output of all five inverters in five operation years is almost equal except in some months. Mainly the output of inverter 4 is comparatively less as the panel strings connected to this inverter are under shaded region. The PV system efficiency compared to the pvsyst simulation report getting 58.89% to 52.76% of standard test condition.

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