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Availability factor of a PV power plant: evaluation based on generation and inverter running periods

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Abstract

In a solar PV power plant, the plant availability factor is one of the important factors to be evaluated. This depends on the operative functioning of various components and grid regulation. In this paper, a simple method is proposed to evaluate the availability factors of a solar PV plant by considering the real time data of 1 MWp solar power plant that was commissioned in 2011 in south India. Generation start time, end time, and actual running periods of the inverter were selected as prominent data in the study. A consecutive five financial years of data (2011–2012; 2012–2013; 2013–2014; 2014–2015; 2015–2016) was used to observe the variations in availability factors of inverters, as well as the plant availability factors. From the analysis, it is observed that tripping time greatly effects the availability factor of inverter as well as the PV plant. The variation in availability factor over the five consecutive financial years is seen to be within the range of 92.44 % to 95.69 %. This clearly states that, on average 4.31 % to 7.56 %, the installed solar PV power is technically not generated any power. Hence, estimating the availability factor could be very much essential to deal with the performance of the PV systems and possible options of reducing energy losses due to availability factors could be suggested.

Keywords: solar energy; PV power plant; inverter availability factor; plant availability factor; inverter outages; PV plant generation periods

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1. Introduction

Solar energy is most freely available energy resource on a global level serving variety of needs in conventional form as well as by integrating with modern technology. Solar energy can be harvested in to useful energy with the help of photovoltaic cells, and solar thermal collectors [1]. Authors interest in this paper is photovoltaics, these can generate electrical energy without the involvement of complex components that are witnessed in traditional power plants. Photovoltaic systems generate electricity by direct conversion of solar irradiance that is incident on its surface. These systems became most popular and widely accepted due its advantages in terms of easy operation, limited emission release, elimination in fuel cost, abundant availability etc. [2]. It is one of the primary technology that gave a scope for transformation in energy and environment sector by shifting to decarbonized energy generation on centralized levels as well as in distributed levels. Initially these systems were economically not affordable, but due to the advancements in technological growth, rapid down fall in the cost is witnessed. On other side promotional activities and policies towards the green and sustainable aspects gave an uptrend move to the photovoltaics. All these factors gave positive support for the growth of PV sector in the electricity markets.

Even though, PV systems have seen remarkable growth in present energy sector, the productivity of the solar PV system significantly depending on various other factors like ambient conditions, technology, type of installation, design followed etc. [3]. Hence, the evaluation of PV productivity considering various influential parameters is needed. Many studies exist in the literature dealing with the performance study of photovoltaic systems considering various parameters. Among these, simulated studies dealing with the performance of solar PV systems in different configurations, sizes, and in different locations [4–7]. Similarly, different studies on the real time performance of PV system with respect to specific weather conditions also exist [8–11]. Few studies dealt with the performance on consideration of different PV technologies, electrical system components, installation configuration. Among these almost all the studies followed the performance parameters (array yield, reference yield, final yield, performance ratio, capacity factor, efficiency, losses) of International Energy Agency (IEA) [12], and National Renewable Energy Laboratory (NREL) [13]. Among these, availability factor is one among the loss parameters, in most of the studies this factor is assumed based on certain assumptions and regulations.

Availability factor of any power generating system cannot be assumed or cannot be kept constant. It depends various aspects of system reliability, dependability on grid regulation, power purchase agreements, periodic maintenance of the system etc. [14]. Due to these aspects, interruptions are possible in the power generation facility. From this, availability factor of a typical power plant is defined as the percentage of time duration that could not generate a power due to certain inabilities. In PV systems also, the availability factor plays a notable effect on the energy generations. For instance, in actual point of view, the PV systems can generate power from the sunrise situation to sunset situation. But in practical and real time conditions, due to the limitations of system reliability, running interruptions, component failures etc. the generation ability and generation periods reduces giving a scope for quantifying actual availability time of PV system [15, 16].

In this paper, a study on availability factor and its evaluation based on the real time monitored parameters from a 1 MWp solar PV plant is executed. A method based on generation start time, end time, and actual running periods of the inverters is proposed and for convenient purpose, this is generalized and can be applied for any power plant with the relevant data monitored from the power plant.

2. Materials and methodology

This section, description of the inspected power plant, data collection, and the proposed methodology is discussed.

2.1. Description of the PV plant

The solar photovoltaic plant that is under investigation is installed in the Revulapally (Latitude: 16.3°N and Longitude: 77.6°E), Mahbubnagar District, Telangana, India. The nominal capacity of the solar PV plant is 1 MWp or 1000 kWp installed in 5 acres site with fixed tilt and allowing a provision for seasonal tilt variation. This 1 MWp PV project was allotted to Telangana State Power Generation Corporation Limited (TSGENCO) [17] under the Government of India's strongest vision on promotional incentives offered for solar PV projects under the Jawaharlal

Nehru National Solar Mission (JNNSM) [18]. Supply, erection, and the civil works towards the installation of the project with in the stipulated times were awarded to M/S. Photon Energy Systems Ltd, Hyderabad on EPC basis. The solar PV project consists a total of 4284 PV modules each having a 235 Wp capacity, 4 inverters each having 250 kW, and 2 power transformers each of 630 kVA. PV array installation of the investigated project is shown in Fig. 1. And the specifications were tabulated in Table 1.

Fig. 1. 1 MWp solar PV plant commissioned at Revulapally, Mahbubnagar District, Telangana, India (image courtesy: plant site).

Table 1. PV plant specifications.

Component or parameter	Name or value	Units/Notation
Latitude	16.3	°N
Longitude	77.6	°E
PV plant capacity	1	MWp
Inverter capacity	1000	kW
No. of Inverters	4 (each of 250 kW)	Inv-x (where ‘x’ is the inverter number)
Type of PV module	Poly crystalline	c-Si
Total area	5	acres

2.2. Data collection

Data collection is done by physical visit to the site where PV plant is installed and commissioned. Five financial years (starting from the commissioning date to March 2016) of data containing generation start time, generation end time, and tripping caused due to inverter etc. are collected. Financial year is typically considered from April of preset year to March of next year. Data durations along with the method of inspection or measuring is shown in Table 2.

Table 2. Data collection from the solar PV plant.

Parameter	Measuring method	Data duration (For each financial year)	Units
PV plant start time in a day	Manual	2011–2012; 2012–2013; 2013–2014; 2014–2015; 2015–2016	Hours:minute:seconds
PV plant end time in a day	Manual	2011–2012; 2012–2013; 2013–2014; 2014–2015; 2015–2016	Hours:minute:seconds
Possible duration of Tripping	Automation	2011–2012; 2012–2013; 2013–2014; 2014–2015; 2015–2016	Hours:minute:seconds

2.3. Methodology

A methodology based on generation periods and inverter running periods is proposed here. The methodology describes the relation between PV plant generation periods to actual running periods in the form of an availability factor. Initially the availability factor is evaluated for each inverter, then depending on the number of inverter used in the PV plant, the plant availability factor is evaluated. Methodology proposed here is shown from Eq. (1) to Eq. (4).

$$Generation\ \ Period = End\ \ Time - Start\ \ Time \tag{1}$$

Eq. (1), is used to estimate the generation period of the PV plant. In Eq. (1), the end time represents the time at which no power is generated from a PV plant i.e. typically happens in the night times. Start time represents, the time at which power generation is possible i.e. typically in the morning. Generation period is the time for which the PV plant is made to operate i.e. from morning time (start time) to evening time (end time). These three parameters are typically measured in hours: minutes: seconds.

$$Running\ Periods = Generation\ Period\ - Trippings \tag{2}$$

Running hours are estimated using Eq. (2), and it is difference of generation periods to the tripping caused in the PV plant and its components. In any PV plant, the running periods are bit lower than the maximum possible generation periods this is because of the hurdles or problems caused by various components in PV system like grid failure, inverter failure etc. Running periods are typically measured in hours: minutes: seconds.

$$Availability\ \ Factor_{Inverter}\,(AF_{inverter}) = \frac{Running\ Periods}{Generation\ \ Periods} \cdot 100 \tag{3}$$

Inverter availability factor of an inverter is estimated using the Eq. (3). In PV plant inverter is one of major component, that helps in the conversion of DC electricity generated by the PV arrays to the AC electricity required by the utility. Typically, in a PV plant, the number of inverter they use depends on the capacity of the PV plant. The availability factor is defined as the ratio of inverter running periods to the maximum generation periods. It is mostly measured in terms of percentages; hence the units are possible.

$$Plant\ \ Availability\ \ Factor\,(PAF) = \frac{1}{n} \cdot (AF_{inverter\,1} + AF_{inverter\,2} + \ldots + AF_{inverter\,n}) \tag{4}$$

Plant availability factor is estimated using the Eq. (4), and it is average sum of the availability factors of inverters in solar PV plant.

3. Results and discussion

This section presents the evaluated results of inverter and PV plant availability factors. Monitoring the generating periods of the PV plant and running hours of the inverter are most responsible factors for calculating the availability factors of the inverters installed over the PV plant site. Generating periods are monitored as per the starting time and ending time on daily basis as per the Eq. (1) over the period of five financial years. Similarly, using Eq. (2) running periods are monitored with reference to the possible tripping over study duration. During the first financial years, only few month data was collected as the PV plant commissioned almost in the ending of the financial year. Generation periods are measured in hours:minutes:seconds as 3654:16:00, 16604:00:00, 16591:08:00, 16489:04:00, and 15675:44:00 for the financial years 2011–2012, 2012–2013, 2013–2014, 2014–2015, 2015–2016 respectively. Running periods are measured in hours: minutes: seconds as 3453:44:00, 15607:43:00, 15875:44:00, 15415:15:00, and 14490:52:00 for the financial years 2011–2012, 2012–2013, 2013–2014, 2014–2015, 2015–2016 respectively.

Average generation periods and running periods over the study duration were shown in Fig. 2. Average generation periods in hours: minutes: seconds are as 913:34:00, 4151:00:00, 4147:47:00, 4122:16:00, and 3918:56:00 and average running periods in hours: minutes: seconds are 863:26:00, 3901:55:45, 3968:56:00, 3853:48:45, 3622:43:00 for financial years 2011–2012, 2012–2013, 2013–2014, 2014–2015, 2015–2016 respectively.

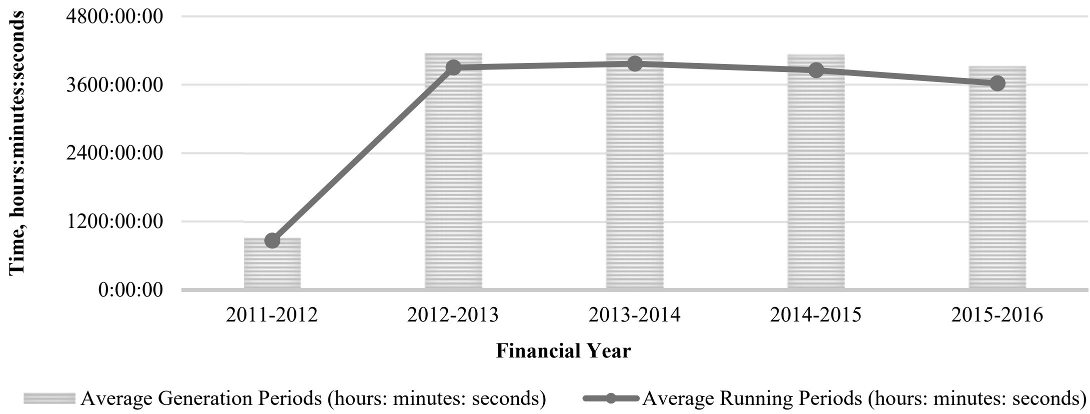

Fig. 2. Average generation and running periods over the study period of five financial years.

Fig. 3. Average generation and running periods over the study period of five financial years.

From the Fig. 2, it is observed that, the running hours of the PV plant will always be lesser than that of the actual generating periods. The reason for this would be due to the failure of the PV system components, or any other external influences such as grid failure, grid regulation etc. In the studied PV plant, there are four 250 kW inverters, hence each inverter availability factor is calculated using Eq. (3). The calculated availability factors of Inv-1, Inv-2, Inv-3, and Inv-4 in the study period of five financial years represented in Fig. 3. From the analysis, it is observed that during the financial years 2011–2012, 2013–2014, 2015–2016 all the four inverters shown an availability factor of 94.51 % (not available is 5.49 %), 95.69 % (not available is 4.31 %), and 92.44 % (not available is 7.56 %) respectively. For the financial years 2012–2013, and 2014–2015, the available factors of inverters 1 to 4 are observed to be 93.83 %, 93.66 %, 93.57 %, 94.95 %, and 93.50 %, 93.46 %, 94.50 %, 93.50 % respectively. It is observed that, the availability factor varies from time to time and its depends on many factors, on an average energy equivalent to the not available factor is lost. From the observed available factors of inverters, the plant availability factor is estimated using Eq. (4). It is average sum of the inverter available factors. In our study, four 250 kW inverter were utilized in the 1MWp solar power plant, hence the average sum of the four inverter availability factors was considered for each financial year, and the value of PAF is computed and shown in Fig. 4. PAF is observed to be in the range of 92.44 % to 95.69 %. As the age of PV plant increases the availability factor of the plant is observed to be reduced. But during the financial year 2013–2014, PAF value is seen to be slightly higher than previous financial year. Summary of the results is shown in Table 3.

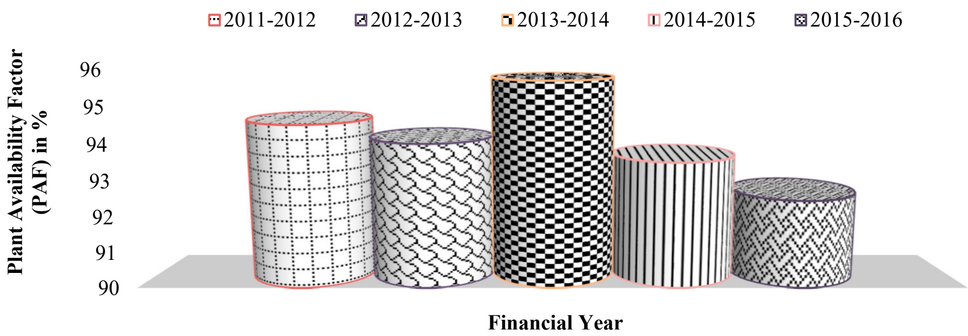

Fig. 4. Average generation and running periods over the study period of five financial years.

Table 3. Summary of the availability factor results.

Financial year	Inverter number	Generation period (hours:minutes:seconds)	Running period (hours:minutes:seconds)	Availability factor of inverter, %	PAF, %
2011–2012	Inv-1	913:34:00	863:26:00	94.51	94.51
	Inv-2	913:34:00	863:26:00	94.51	
	Inv-3	913:34:00	863:26:00	94.51	
	Inv-4	913:34:00	863:26:00	94.51	
2012–2013	Inv-1	4151:00:00	3894:44:00	93.83	94.00
	Inv-2	4151:00:00	3887:55:00	93.66	
	Inv-3	4151:00:00	3883:53:00	93.57	
	Inv-4	4151:00:00	3941:11:00	94.95	
2013–2014	Inv-1	4147:47:00	3968:56:00	95.69	95.69
	Inv-2	4147:47:00	3968:56:00	95.69	
	Inv-3	4147:47:00	3968:56:00	95.69	
	Inv-4	4147:47:00	3968:56:00	95.69	
2014–2015	Inv-1	4122:16:00	3854:15:00	93.50	93.49
	Inv-2	4122:16:00	3852:30:00	93.46	
	Inv-3	4122:16:00	3854:15:00	93.50	
	Inv-4	4122:16:00	3854:15:00	93.50	
2015–2016	Inv-1	3918:56:00	3622:43:00	92.44	92.44
	Inv-2	3918:56:00	3622:43:00	92.44	
	Inv-3	3918:56:00	3622:43:00	92.44	
	Inv-4	3918:56:00	3622:43:00	92.44	

In Table 3 the summary of the availability factors evaluated for each inverter, PV plant specific to each financial year is tabulated. Also, the generation periods and running periods during of the PV plant specific to inverter are represented. It is observed that, as the age of the PV plant increases the availability factor is slightly reduced.

4. Conclusion

The study carried out in this paper, investigates on the availability factors of inverter and the PV plant that is in the Revulapally, Mahbubnagar district of Telangana State, India. A monitoring period of five financial years is considered during the evaluation of availability factors in this study. The work presented in this paper, provides a clear understanding of the availability factor and how it is influenced by generation periods, inverter running periods. The evaluated availability factors of the inverter and PV plant for the 1 MWp solar PV under study are summarized as follows: The variation in availability factor is observed to be in the range of 92.44 % to 95.69 % over the five consecutive financial years. On an average, the PV system is found to have energy reductions over the five consecutive financial years ranging in between 4.31 % to 7.56 %. The reasons for not achieving the 100 % availability factors are the occurrence of failure in the solar inverter. Other reasons are strings continuity failure, failure in cables and connections. Here, mostly the specified two reasons occurred. The work supports future research aiming towards the improvement in performance of PV plant keeping the availability as one of witness factors affecting the energy yields.

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