Loss Analysis of Grid Connected Solar PV System: A Review

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***Abstract*: Solar energy is becoming an important source of energy all over the World and especially in India. Very few solar plants have been installed in India so far, and therefore no historical experience available. It is important to investigate the performance of solar power plants. Knowledge about the performance of solar power plants will result in correct investment decisions. In this paper, we discuss the various factors contributing to the performance of solar power plants, such as radiation, temperature and other climatic conditions, design, inverter efficiency and degradation due to aging. In this paper, review of a grid-connected photovoltaic system is presented with its performance parameter. The performance ratio and the various power losses (solar irradiation, different type of module loss, temperature, Module soiling, AC and DC losses, cable and wiring loss etc.) are examined. Also examined the performance of plant in terms of different type of plant running losses like generation loss due to grid unavailability system breakdown, inverter breakdown.**

***Keywords*: Photo Voltaic (PV); performance ratio(PR); Grid-connected mode; Generation loss; Efficiency; Air mass(AM).**

1. Introduction

At present, PV energy is one of the RES emerging technologies which generate electricity from solar radiation with continuous cost reduction and new technological progress. The photovoltaic (PV) energy as a clean and green alternative energy source due to abundant, broadly available, and pollution free [1]. The continuing advancement of power electronic and modern control technology are favourable incentives in a number of commercial acceptances of grid connected PV systems in the recent years. The solar PV system applications

Can be worked into two modes namely; stand alone or autonomous mode and grid connected mode [2]. Solar PV system enters in stand-alone mode due to maintenance, outage or economic reasons and work autonomously. Where in grid connected mode solar PV system connected from utility grid. A typical grid-connected solar PV system combine with element of grid voltage es(t), solar array, single-phase inverter, input capacitor C and filter inductor L. input capacitor maintain solar array voltage for the voltage source inverter. The full-bridge inverter converts solar array dc voltage into sinusoidal ac voltage with inductor filter and obtain output current in phase of utility grid voltage and obtain unity power factor. The output power of PV array is in intermittent nature and depend on solar illumination level and temperature [4]. A photovoltaic system (or PV system) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating or modifying the electrical output. Converting solar energy to electricity via photovoltaic cells is one of the most exciting and practical scientific discoveries of the last several hundred years. The use of solar power is far less damaging to the environment than burning fossil fuels to generate power. In comparison to other renewable energy resources such as hydro power, wind, and geothermal, solar has unmatched portability and thus flexibility. The sun shines everywhere [5]. During the development of a solar photovoltaic (PV) energy project, predicting expected energy production from a system is a key part of understanding system value. System energy production is a function of the system design and location, the mounting configuration, the power conversion system, and the module technology, as well as the solar resource. A number of system performance models have been developed and are in use, but little has been published on validation of these models and on the accuracy and uncertainty of their output [6]. First, the expected performance needs to be determined. Then, the actual performance needs to be measured. To determine the expected performance of the PV system, refer to the basis of design. Assuming that the system was sizing properly in the design phase, it should meet the owner's requirement for energy production. Based on the equipment specified, estimation the monthly annual and lifetime energy output of the system [7]. In the following sections, section II deal with solar energy scenario in India. In section III Grid connected system has been identified and Planning for PV system is analysed in section IV. Loss analysis of PV system are presented in section V. Based on operation of PV plant, Generation loss is discussed in section VI. In the last section Performance ratio are defined.

2. Solar energy scenario in India

With an installed capacity of 145 GW, the country currently faces energy shortage of 8 percent and a peak demand shortage of 11.6 percent. India faces a significant gap between electricity demand and supply [8]. India just had 2.12 megawatts of grid-connected solar generation capacity. As per National Solar

Mission, the first phase covers setting up of 1,100 MW of grid solar power and 200 MW capacity of off-grid solar applications utilizing both solar thermal and photovoltaic technologies, by 2013. In second phase by 2017 the installed base would reach 4000 MW, and in third phase 20,000 MW by 2022. India has an enormous potential of renewable energy across the various sources as indicated in the table below [9].

Table 1
Potential status of Renewable Energy

Resources	**Potential**	**Existing installed capacity**
Wind	45000 MW	~7660 MW
Small Hydro (upto 25 MW)	15000 MW	~1850 MW
Biomass power/ Cogeneration	19500 MW	~950 MW
Solar Photo Voltaic Power	50000 MW (20 Mw/sq.km)	50000 MW (20 Mw/sq.km)
Solar water Heating	140 million sq. m collector area	1.5 million sq. m collector area

3. Grid-connected PV systems

Grid-connected PV systems connected from utility grid through static transfer switch [10]. Excess Power can be managed with energy storage system and stabilized the power flow into and out of the grid. grid-connected systems are usually employed in centralized and decentralized manner in the power system. rooftop PV generators are mounted on rooftops of buildings in decentralized manner and incorporate into the grid system. Rooftop PV system continue served building energy demand and also supply excess power into grid. A typical grid connected Solar PV system consist of PV module, Inverter, main disconnect/isolator switch and utility grid where PV module directly convert sunlight into electrical energy and inverter covert dc output voltage of module into ac output voltage. Decentralized solar PV system usually lower rage of kilowatts and central solar PV system usually Higher range megawatt to kilowatt. Solar energy is most growing renewable resource across all over world [11]. improvement in cell efficiencies and improvement in technology seen tremendous growth of solar PV industry with led to drastic reduction in the cost of solar PV systems on the global market. of the voltage stability problems in a facility micro grid [21].

4. Planning for PV installation

The solar photovoltaic systems project began with a brief survey of literature. Followed a simple prefeasibility analysis (using PV Syst or other suitable software) to obtain a layout plan of the amount of generated energy of the system. Access the economics evaluation of the whole project and estimate the land requirement for the installation of the system. A standard draft procedure of grid-connected systems was prepared which will be updated from time to time for design of large-scale grid-connected solar PV systems [12].

- Analysed of the solar radiation data for particular location from metrological stations or other resources.
- Showing the various sites of land used for the project.
- Identified the various locations on the land use map and update as per necessary.
- Locate various car parks and building roofs that can be used for the project.
- Confirmed grid access and demand requirement for grid connection.
- identified the dimensions of the selected buildings roofs and car parks to be used.
- Assessment of roof orientation, effect of shading on the roofs, strength of roof, roof area, and the pitch/slope of roof type.
- Identified of collation the total area and suitable roofs available for solar PV system design.
- Collect solar PV information such as type, cost, size, weight, etc. from various solar dealers both locally and internationally.
- Draw the layout of each of the selected building roofs of the system.

5. Loss analysis

Loss analysis is the method to calculate actual loss occurred in the system. This analysis is difference between the simulated loss and actual loss. Simulated loss is the design loss which is considered during the design of the system. Through the loss analysis calculations & conclusions the system performance can be controlled in terms of design (overrating/under rating of equipment's/preventive maintenance and commercial loss [13].

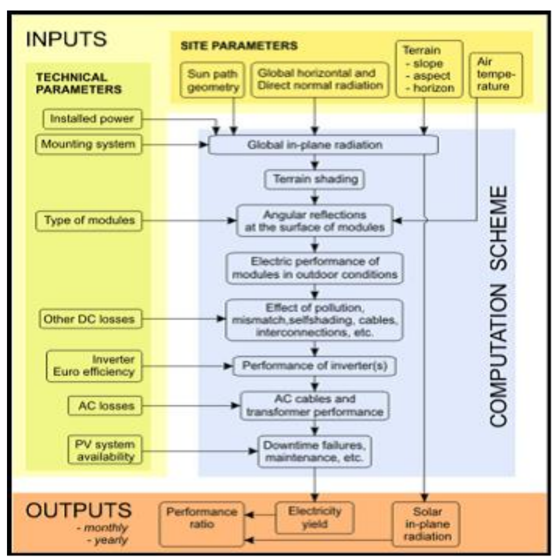

Fig. 1. Loss flow diagram

A. Solar irradiance loss

1) PV loss due to irradiance

It The performance/output of a PV system is relatively proportional to sunlight intensity. Therefore, these systems can generate electricity even on cloudy days. Greater amounts and duration of sunlight increase system performance. Sunlight intensity is called irradiance, which is measured in watts per square meter (W/m^2) [14]. In summer, when the sun is nearly directly overhead, its irradiance at the surface of the Earth, at sea level, is approximately 1000 W/m^2. This Irradiance is defined as full or peak sun, and it is the standard irradiance for testing and rating PV modules at peak sun conditions, roughly 70% of the sun that is incident at the top of the atmosphere penetrates to the surface of the Earth.

2) Loss due to shading

The Shading portions of a PV array will have the most adverse effect on the system's performance. It is important to determine during the site assessment if a potential location for the PV array will be shaded, especially between the hours of 9 a.m. and 3 p.m. This is important, as the output of PV modules may be significantly impaired by even a small amount of shading on the array [15]. A careful assessment using an hourly computer simulation program is necessary to determine the benefits of westerly orientations. A minimum of six hours of unshaded operation is important for best system performance.

3) Solar module tilt angle

The module installation angle in relation to the sun affects the module energy output. The module produces more power (Watts), and resulting energy (Watt-hours), when the light source is located perpendicular to the surface of the module. For this reason, solar module installations are often tilted towards the sun to maximize the amount and intensity of light exposure. As the sun angle changes throughout the year (higher in the sky during summer and lower in the sky during winter), the amount of light falling directly on the module changes, as does the energy output. The tilt involves primarily the angle that the panels are facing up into the sky. On a flat roof, the tilt is 0°, whereas if the angles were to be facing a wall, it would be 90°. an angle of approximately 32° is the best, but anywhere between 20° and 40° is optimal for around a 90% efficiency. As soon as a panel is tilted below 5°, efficiency will become an issue, as well as if it is placed at an angle larger than 60°. All in all, tilting is an important factor, but not as important as the orientation can be [16].

4) AM (air mass factor) on global irradiance (optical losses)

Air Mass represents how much atmosphere the solar radiation has to pass through before reaching the Earth's surface. The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust. Air Mass=1/cosθ Where θ is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1. The losses associated with angle change come under Incidence angle modifier losses (IAM losses). Generally, 2.5 to 3 % is considerable value. For this project 2.8 % is considered and a corresponding yield factor is 0.97 has been considered [17].

B. Module loss

Typical solar electric systems require more than one module to be connected to one another. The wires used to connect the modules create a slight resistance in the electrical flow, decreasing the total power output of the system, similar to low pressure water flowing through a long water hose. In addition, a slight difference in power output from module-to-module reduces the maximum power output available from each module [18]. The system AC and DC wiring losses and individual module power output differences could reduce the total system rated energy output from 3%-7%. A typical value for these losses is 5%*5.

1) Effects of temperature

A PV module will be typically rated at 25 °C under 1 kW/m^2. However, when operating in the field, they typically operate at higher temperatures and at somewhat lower Insolation conditions. In order to determine the power output of the solar cell, it is important to determine the expected operating temperature of the PV module. The Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions.

2) Loss due to hot spot

Hot-spot heating occurs when there is one low current solar cell in a string of at least several high short-circuit current solar cells, If the operating current of the overall series string approaches the short-circuit current of the "bad" cell, the overall current becomes limited by the bad cell. The extra current produced by the good cells then forward biases the good solar cells [20]. If the series string is short circuited, then the forward bias across all of these cells reverse biases the shaded cell. Hot-spot heating occurs when a large number of series connected cells cause a large reverse bias across the shaded cell, leading to large dissipation of power in the poor cell. Essentially the entire generating capacity of all the good cells is dissipated in the poor cell. The enormous power dissipation occurring in a small area results in local overheating, or "hot-spots", which in turn leads to destructive effects, such as cell or glass cracking, melting of solder or degradation of the solar cell.

C. Inverter loss

In order for the DC power from the solar modules to be converted to standard utility AC power (Used by homes and businesses), a power inverter needs to be used [21]. The conversion from DC power to AC power results in an energy decrease from approximately 6%-10%, and varies for each inverter (primarily due to energy lost in the form of heat). A typical value for this loss is 6%.

D. Ohmic loss

Ohmic power loss is the main part of losses in transmission and sub-transmission lines. Exact modeling of this part is necessary for precise evaluation of power losses and reduction of the calculation errors in comparison with real situation [22]. The main reason of losses in transmission lines is the resistance of conductors against line's current. So the main part of the losses in transmission lines is ohmic loss.

$$P_{loss} = I^2R$$

6. Generation loss analysis

Photovoltaic (PV) grid-connection systems based on either a single-stage or a two-stage configuration have been widely studied. The grid-connection PV systems can draw maximum Power from PV modules and inject the power into utility grid with unity power factor. However, the loss factors, such as operational conditions, components, and grid voltage, will deviate effective PV output power. In a grid-connection PV system (GCPVS), PV power varies with operational conditions, such as irradiance, temperature, light incident angle, reduction of sunlight transmittance on glass of module, and shading.

- Formula used for calculation of Generation loss due to grid unavailability
- Generation = Solar Insolation X PV area X conversion factor X P R /1000
- Generation loss due to grid unavailability = generation for the day (KWh/day)

(Solar irradiation for the day -Total solar irradiation when grid unavailable) x Total solar irradiation when grid unavailable.

Formula used for calculating loading percentage of inverter
Total generation of particular inverter are divided by rated capacity of the inverter multiply with running hours, running hours for solar plant is 12 hr from 6:00 am to 6:00 pm. Loading percentage = Power Generation/capacity x running hours (12hr) x100

A. *Inverter efficiency*

A solar PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use utility grid. These inverters are grid tie inverters which are used to connect the power plant to the grid. The efficiency of an inverter has to do with how well it converts the DC voltage into AC. The currently available grid connected inverters have efficiencies of 96 to 98.5%, and hence choosing the correct inverter is crucial to the design process. There are less efficient inverters below 95% also available. Inverters are also much less efficient when used at the low end of their maximum power [24]. Most inverters are most efficient in the 30% to 90% power range. The instantaneous inverter efficiency is calculated.

ή= AC Power/DC Power

Formula use for calculating input DC power

Input DC power = Solar insulation x No. of module connected with particular inverter x module area x conversion efficiency of module x conversion efficiency of inverter x no of day, Where: Conversion efficiency of inverter 90 %

B. *Breakdown loss analysis*

There exist a variety of sources through which Generation losses occur in PV systems. These losses affect the performance of PV systems thereby justifying why it is necessary to evaluate these losses using detailed performance monitoring data. Prominent among these losses are: array capture losses, system losses, cell temperature losses, soiling and degradation. Soiling and degradation losses, system breakdown, preventive maintains inverter breakdown, system downtime are more difficult to evaluate because they are small effects that occur over large fluctuations in operating conditions. Under real operating conditions the following additional losses could be observed.

Generation loss due to Breakdown condition
Generation loss = Solar Insolation X PV area for particular inverter X P R /1000

C. *Transformer losses*

The proposed transformer shall be installed outdoor suitable for hot, humid and tropical climate. The transformer will be free from annoying hum and vibration when it is in operation, even at 10% higher voltage over the rated voltage. The noise level will be in accordance with respective standards. The transformer will be designed and constructed so as not to cause any undesirable interference in radio or communication circuits [25]. The oil filled transformer will be capable of operating continuously at its rated output without exceeding the temperature rise limits as given below over design ambient temperature of 50 deg C

7. Performance ratio

The performance ratio is one of the most important variables for evaluating the efficiency of a PV plant. Specifically, the performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. For this reason, the performance ratio can be used to compare PV plants supplying the grid at different locations all over the world [26].

The performance ratio is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor. The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. It thus shows the proportion of the energy that is actually available for export to the grid after deduction of energy loss (e.g. due to thermal losses and conduction losses) and of energy consumption for operation.

Formula used for calculation
Calculate the performance ratio by yourself, you can use the following simplified formula [27]:

- The actual plant energy production in kWh can be read at the end of the year from the grid export meter. The calculated annual nominal plant output is composed as follows:
- Formula for manual calculation of the performance ratio PR = Actual reading of plant output in kWh p.a./ Calculated, nominal plant output in kWh p.a.
- Formula for calculation of the nominal plant output Annual incident solar irradiation at the generator

surface of the PV plant x relative efficiency of the PV plant.

- Performance Ratio = Expected Generation/(solar insulation X module area X No. of module X conversion efficiency of the module)
- Performance Ratio Calculation on the basis of Plant Capacity

PR=Actual generation X Solar irradiation /Plant Capacity X 1000

Daily Performance Ratio calculation: Daily performance ration calculation based on the power generation and the solar irradiation on that day and all the value divided by the plant capacity. Particular day reading taken from the TVM meter which is located on the four pole structure and this TVM reading is final reading including all loss held in the PV system. Purpose for calculating per day performance ratio of system is finding the day wise loss and also analyses which condition largely affect the system performance.

The following factors can have influence to the PR value:

Environmental factors:

- Temperature of the PV module
- Solar irradiation and power dissipation
- The measuring gage (e.g. pyranometer) is in the shade or soiled
- PV module in the shade or soiled.

Other factors:

- Recording period
- Conduction losses
- Efficiency factor of the PV modules
- Efficiency factor of the inverter
- Differences in solar cell technologies of the measuring gage (e.g. pyranometer) and of the PV modules.
- Orientation of the measurement gage (e.g. pyranometer)

8. Technical and maintenance related problems

- The power of the PV plant cannot be fed to the grid if the power supply from the grid stops. Due to this, the power from the PV Plant is not available when it is needed most and the capacity of the Plant to work effectively has been retarded [28].
- There is no tracking mechanism to locate the modules if they fail. If a module fails, it is very tiresome to identify it because no sensors have been installed for this purpose. The only the solution presently available is to wait till that the peak time to identify the Inverter (from which the output is lower). Then the Inverter has to be isolated and all the arrays connected to this inverter should be checked. Once faulty array is located, all the connected modules need to be checked to identify the faulty one.
- Presently the modules are cleaned by spraying water. But the dust accumulated on the modules turns into paste form once the modules are water sprayed, making it difficult to remove. Also, the height of the modules mounting structures makes it impossible to remove the dirt completely with wipers while standing on the ground. This has led inevitably, to the option of cleaning the modules by climbing on top of them (and then using wipers!). This will weaken the strength of solar modules as well as mounting structures in the long run and also affect the power production. Hence, it is felt that there is a need to address this issue by developing alternate method/ technology for cleaning the PV modules [29].

9. Conclusion

Solar energy is the one of the most emerging and growing field in the world. So performance of PV plant needs to be analysed yearly to gain the efficiency of the system. The daily plots showing the variation of Performance ratio of the plant, generation varies due to tilt angle, inverter wise generation of the plant, inverter loading percentage, Inverter efficiency, generation loss, breakdown condition and Revenue loss. It was found that failure in inverters were the most frequent incidents. This is mostly caused by lack of experience in the initial production stage and some unexplained inverter failures might be caused by disturbance from the grid and other interconnected issues solve all issues properly.

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