Performance analysis of gird connected solar and wind power station for the reliability calculation

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Abstract— The Utilization of Renewable Energy Sources for energy generation is growing at a high rate nowadays due to increased consumption of fossil fuel resources and serious environmental concerns. In this context wind and solar energies are of the most successfully utilized sources. However, the renewable sources suffer from the drawback of lesser reliability and most of the times they need the appropriate back up. This requires the knowledge of performance factors of the renewable energy source. This paper discusses about the performance analysis of Grid Connected Solar Power Plant (GCSPVP) and Grid Connected Wind Power Plant (GCWPP).One of the reliability indices Expected Energy Not Served (EENS) is calculated for GCSPVP. The performance analysis of both GCSPVP and GCWPP are validated by considering real time power stations

Index Terms—Expected Energy Not Served (EENS), Grid Connected Solar PV Plant (GCSPVP), Grid Connected Wind Power Plant (GCWPP), Renewable Energy Sources (RES), System Advisor Model (SAM), National renewable energy laboratory(NREL).

1 Introduction

The energy requirement of the world is ever increasing. The increasing energy demand put a lot of pressure on the conventional energy source (oil, gas and coal). But the fossil fuel-based energy sources are limited in quantity and also cause environmental pollution. Therefore, development of clean, secure, sustainable and affordable energy source should be our priority. Renewable Energy Sources (RES) are the best option for this [1]. Renewable Energy Sources playing a vital role to meet the increasing energy demand and reduce the consumption of fossil fuels. But Renewable energy resources have an intermittent generation nature. Therefore, these resources cannot be a reliable source of energy when used in standalone mode. For this reason, these resources are often employed together with the other types of energy sources which are readily dispatchable. As a result, integration of renewable energy sources such as wind turbine (WT) and solar Photovoltaic (PV) systems into conventional power grid have significantly increased[2,3].

Reliability is the probability that a components or a system performing desired operation for a given period of time under certain defined operating conditions. In other words, it is the probability of non-failure of the system over the time period, t. This paper focuses on reliability evaluation of large scale Gird Connected Solar PV Plant (GCSPVP). Large scale GCSPVP are coming up in North Karnataka area. However they suffering from the draw back of low reliability, due to inconsistent input. It is possible to improve their reliability by the integrated operation with the other sources in the vicinity if permits.

In early days, the percentage reserve or the largest unit as the reserve is used as a reliability criteria. The Loss of Load Probability (LOLP) is one of the popular reliability index. Energy Not Served (ENS) or the Expected Energy Not Served (EENS) is another probability index, which reflects the probable energy which cannot be served to the customers is a better index for the Power system planners. Utilization of EENS is now increasing, since it reflects the true risk and has more physical significance than LOLP or LOLE. It is now accepted that EENS is more meaningful in both system planning and system operation. The techniques used for EENS evaluation can be broadly classified as analytical and simulation techniques [4].

The paper is organized as follows: Section 2 Presents the methodology. Section 3 shows the study cases. The result and discussions are presented in Section 4. Section 5 Discribes about conclusions and lastly the future scope is drawn.

2 METHODOLOGY

2.1 Performance analysis of GCSPVP

The performance analysis of a GCSPVP is carried out in the following way. The real time input data of one of the prominent GCSPVP are collected from the competent authorities. Different performance indices required for the analysis are defined. The National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) which is one of the most suitable performance evaluation tools is used for the evaluation of the performance indices defined. The evaluated indices are validated by comparing them with the actual values of the GCSPVP.

2.1.1 System Advisor Model (SAM)

SAM is a performance and financial model designed to facilitate decision making for user and it is designed by NREL

(National renewable energy laboratory). SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model.
Creating a SAM file involves choosing both a performance model and a financial model to represent your project. SAM automatically populates input variables with a set of default values based on your choices. After you create the file, you

modify the inputs to provide information about the project's location, the type of equipment in the system, the cost of installing and operating the system, and financial and incentives assumptions. It is your responsibility as an analyst to review and modify all of the input data as appropriate for each analysis. Once you are satisfied with the input variable values, you run simulations, and then examine results. A typical analysis involves running simulations, examining results, revising inputs, and repeating that process until you understand and have confidence in the results [5].

2.1.2 Different Performance Indices

The performance of a grid connected PV system is usually examined using selected set of performance indices. However most important of these indices are Total energy generated, final yield, reference yield, performance ratio and capacity factor [6].

A. Total energy generated: The total daily, monthly, and yearly alternating current (AC) energy generated by the solar PV system over a given period.

B. Final Yield (Y_F): The final yield can be defined as the total AC energy during a given period divided by the rated PV array power and is given by

$$Y_F = [E_{AC} / Ppv, rated]$$

Where, E_{AC} is the total AC energy output from the inverter generated by the PV power system for a specific period (kWh).

C. Reference Yield (Y_R): The reference yield is the ratio of total in-plane solar radiation to the reference irradiance at standard test conditions (STC) and is given by

$$Y_R = [S_R / H_R]$$

Where, S_R is the total in-plane solar radiation (kWh/m2) and H_R is the array reference irradiance at STC (1 kW/m2).

D. Performance Ratio (PR): The performance ratio (PR) is the ratio of the final energy yield of the PV system to the reference yield. It provides information about the overall losses incurred in converting DC to AC power. Therefore, it represents the percentage of energy actually available after deducting energy losses.

$$PR = [Y_F / Y_R]$$

Where, Y_F = Final yield and Y_R = Reference yield

E. Capacity factor (CF): It is one of the key performance indices which is the ratio of actual annual energy output E_{AC} to the amount of energy the solar PV power plant would generate if it is operated at full rated power P_{STC} for 24 h per day for a year $CF = [E_{AC}/ P_{STC} \times 24 \times 365]$

2.1.3 Expected Energy Not Served (EENS)

Since the power systems are in fact energy system, where energy sale is the real revenue for the electric company, so, the essential and most needed reliability index known as Expected Energy Not Served (EENS). This index measures the expected amount of energy which will fail to be supplied per year due to generative capacity differences. Typical unit of measure is MWhr/year. This index helps in planning and expansion of the system.
The two main approaches for reliability index evaluation are
a. Analytical Method
b. Simulation Method

a. Analytical Method

Steps to Calculate EENS for Grid Connected Solar PV Plant (GCSPVP)

- Daily energy produced by the considered GCSPVP is tabulated.
- Monthly average energy is calculated.
- Then EENS is defined as follows,
- EENS as a function of time
- EENS per month

EENS as a function of time: If energy produced ($E_{Produced}$) less than average energy ($E_{Average}$), then Energy not served for that day.

i.e $E_{Produced} < E_{Average}$

- Thus the number of days in each month for the above case is calculated and plotted.

EENS per month: Difference between average energy and produced energy gives the not served energy per month.

i.e $EENS = [E_{Average} - E_{Produced}]$

- The accumulated values of these for the entire month is calculated and plotted. i.e EENS in KWh.

2.2 Modeling of Grid Connected Wind Power Plant (GCWPP)

The first wind turbines were based on a direct grid coupled synchronous generator with pitch controlled rotor blades to limit the mechanical power in high wind speeds. Therefore, the first modelling efforts were devoted to this wind turbine concept the directly grid coupled synchronous generator was followed by a directly grid coupled asynchronous squirrel cage induction generator. To limit the power extracted from the wind at high wind speeds, either pitch control or stall control can be applied. Many papers on modelling of a wind turbine with a directly grid coupled squirrel cage induction generator can be found in the literature, both in combination with pitch control and with stall control of the mechanical power, and Nowadays, a more modern variable speed wind turbine with a doubly fed induction generator has replaced the conventional constant speed wind turbine with a directly grid coupled squirrel cage induction generator. As the power developed is proportional to the cube of the wind speed it is obviously important to locate any electricity generating turbines in areas of high mean annual wind speed, and the available wind resource is an important factor in determining where the wind farms are sited.Wind power palnt is modeled using MATLAB, SIMULINK.

3 CASE STUDY

This study considers a Grid Connected Solar PV Plant (GCSPVP) of capcity 1MW which is located at Mundargi and Grid Connected Wind Power Plant (GCWPP) of capacity 4.5MW which is located at Kapathagudda for reliability index calculation.

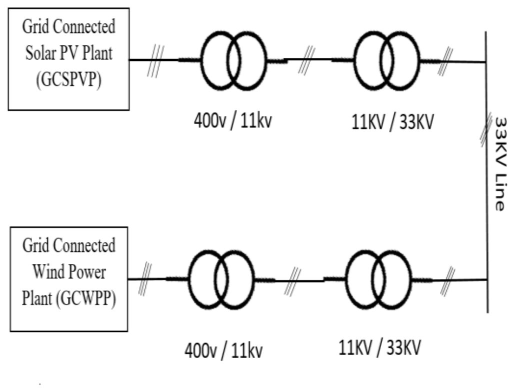

Fig .1.schematic diagram of geographically proximal power stations under consideration

3.1 GCSPVP at Mundargi

Solar power plant of 1 MW capacity located at Mundargi, in Gadag district, Karnataka. The plant consist of 3240 modules, in series 20 modules are connected and in parallel there are in total 27 strings, connecting to single AJB. Such 6 AJBs are present and are connected to a single inverter, of 1000 kW capacity through DC cable. The output of the inverter is grid connected through three phase transformers.

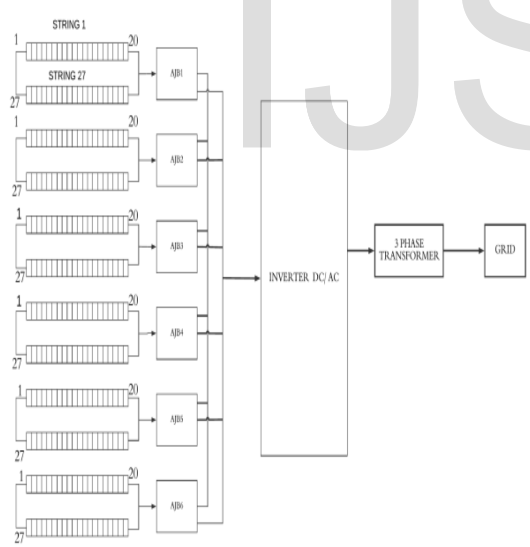

Fig. 2.Plant Layout

3.2 GCWPP at Kapathgudda

Wind Power Plant of 4.5MW capacity located at Kapathagudda, in the Gadag District of the central part of Karnataka. In this plant, the wind turbine with a specific generator type with a rating of 4.5 MW is connected to a 400V bus from where the power is transmitted to a 33 kV grid after stepping up the voltage to 33kV. The grid is located at a distance of about 30 km from the wind farm.

TABLE 1
PLANT SPECIFICATIONS

1	Name of the Solar site	Mundargi, Gadag, Karnataka, India
2	Geographical Location	Latitude 15.20 N and Longitude 75.88 E
3	Meteorological data source for system sizing and EYA	NASA
4	Daily average Global Solar Irradiance	5.77 kWh/m2
5	Annual Global Solar Irradiance	2106 kWh/m2
6	Daily average diffuse irradiance	2.31kWh/m2
7	Annual diffuse irradiance	843kWh/m2
8	Annual average ambient temperature	25.5 o C
9	Annual average relative humidity	30%
10	Annual average wind speed	2.7 m/s
11	Land availability (acres)	More than 5 acres
12	Minimum plant size capacity	1 MW
13	Solar PV Module Manufacturers	Zhongly Talesun

TABLE 2
System Specifications

Modules-Make	ZHONGLI TALESUN
Technology	POLYCRYSTALLINE
Number of modules	3240

TRANSFORMER	
LV voltage (kv)	0.38
LV current (a)	1671.3
HV voltage (kv)	11
HV current (a)	57.7
Number	1

INVERTER	
Make	ABB
Number	1
Rating (kW)	1000
DC voltage (v)	690
DC current (a)	1000
AC voltage (v)	380
AC current (a)	1671.3

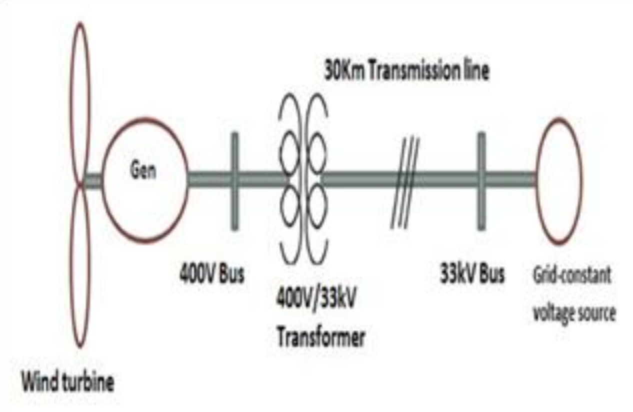

Fig. 3. Line diagram of Wind Power Plant

3.2.1 Modeling of Wind Power Plant

The model is developed using MATLAB SIMULINK. The wind turbines cannot always operate at their rated capacity due to the variation of wind speed. In order to obtain the power produced by the wind turbines the monthly average wind speed is considered for the convenience of simulation. The monthly average wind speed is collected from the concerned authorities for the wind farm. This approximation will not make any notable differences in the estimated power produced compared to actual values, as both DFIG and Synchronous Generators operate mostly in the constant speed regions. Once the power produced is estimated, the annual harvestable energy is obtained from the simulation for the considered period of time.

TABLE 3
PLANT SPECIFICATIONS

1	Name of the wind site	Kapathagudda Wind Farm ,Gadag Karnataka,India
2	Geo-graphical location	Latitude:15º25″56.4′ Longitude:75º38″17.7′
3	Nominal power rating	4.55 MW(225kWx9+230kWx11)
4	Power density	3.1KW/m2
5	Start up wind speed	4m/s
6	Nominal wind speed	15 m/s
7	Max. wind speed	25 m/s
8	Output voltage	400 V
9	Grid	33kV
10	Location	Gadag(30 km from the wind farm)
11	Annual gross energy yield	12MU
12	Operator	Karnataka Power Corporation Ltd.(KPCL)

TABLE 4
MONTHLY AVERAGE WIND SPEED

Month	Average Wind Speed (m/s)
JANUARY	5.79
FEBRUARY	6.35
MARCH	6.05
APRIL	7.83
MAY	10.90
JUNE	10.48
JULY	11.76
AUGUST	10.41
SEPTEMBER	8.28
OCTOBER	5.65
NOVEMBER	7.50
DECEMBER	6.63

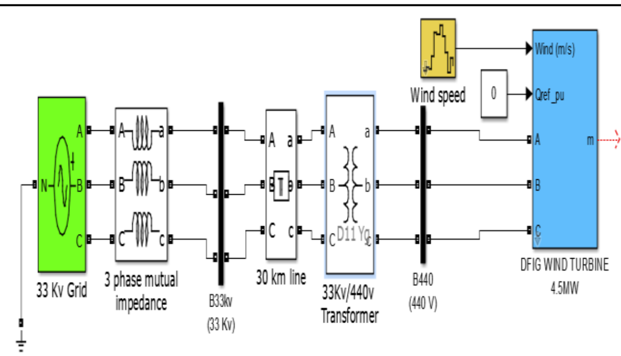

Fig. 4. Matlab Simulink Model for GCWPP

4 RESULTS AND DISCUSSIONS

4.1 performance analysis results for GCSPVP: Results from SAM

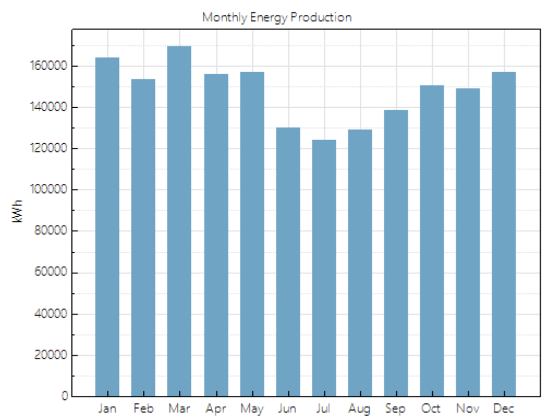

Fig. 5. Monthly Energy Production

4.2 EENS calculated results for GCSPVP

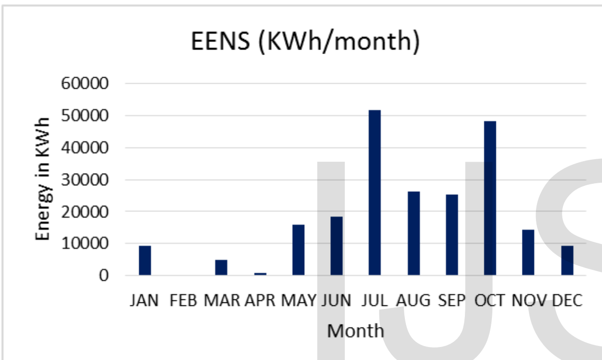

Fig.6. EENS in KWh/month for GCSPVP

TABLE 6
CALCULATION OF EENS FOR 1MW GCSPVP AND MONTHLY WIND ENERGY

Month	EENS in kwh/month for 1MW GCSPVP	Monthly wind energy from 1MW GCWPP
JAN	9297.47	75555.56
FEB	0	77777.78
MAR	4838.25	75555.56
APR	912.496	84444.44
MAY	15870.2	137777.78
JUN	18402.2	244444.44
JULY	51762	291111.11
AUG	26317.7	291111.11
SEP	25340.5	177777.78
OCT	48116.7	97777.78
NOV	14322.7	153333.33

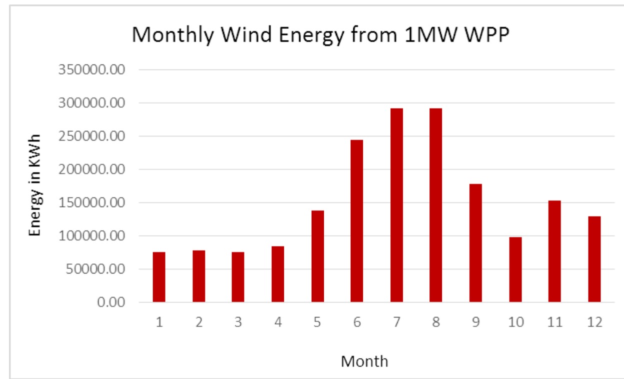

Fig.7. Monthly Harvestable Energy from 1MW GWPP

4.3 MATLAB Results for GCWPP

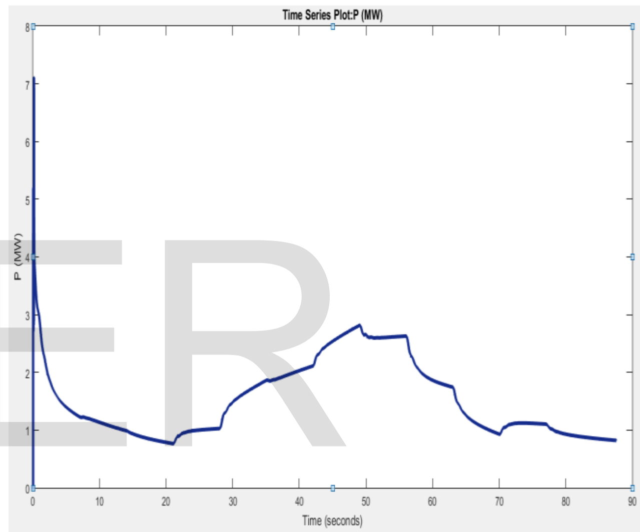

Fig.8. Power output

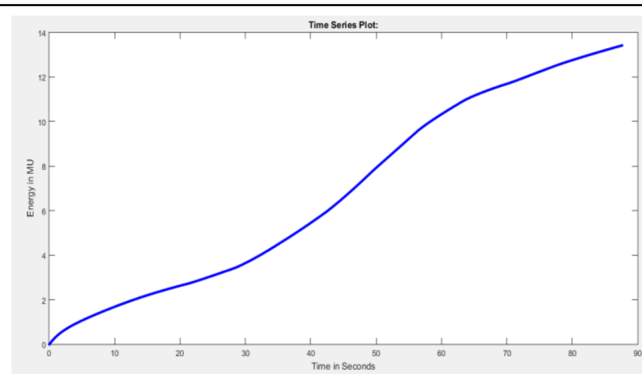

Fig.9. Energy output

5 Conclusion

The Performance analysis of a real time GCSPVP is done using SAM software and different performance indices are obtained. Modeling of GCWPP for the monthly average wind speed collected from the concerned authorities for the wind farm is done using MATLAB SIMULINK and harvestable energy is obtained and the energy harvested from real time GCSPVP is collected from the competent authorities and one of the reliability indices EENS is calculated analytically and enery not served for each month tabulated and plotted. Months with highest value of EENS are identified. It is also noted that in few months especially in the monsoon seasons the EENS is high. From the output of wind power plant it is observed that the wind power stations produces excessive energy during these month. Hence a properly coordinated operation of GCSPVP and GWPP can effectively reduce the EENS.

FUTURE SCOPE

The effective coordination of GCSPVP and GCWPP for reducing EENS can be made possible by,

- Development of algorithm for the integration of GCSPVP and GCWPP for the enhancement of reliability in terms of EENS reduction.
- Simulation of integration of the two systems using MATLAB.
- Exploring the possibilities of calculating other relevant reliability indices.

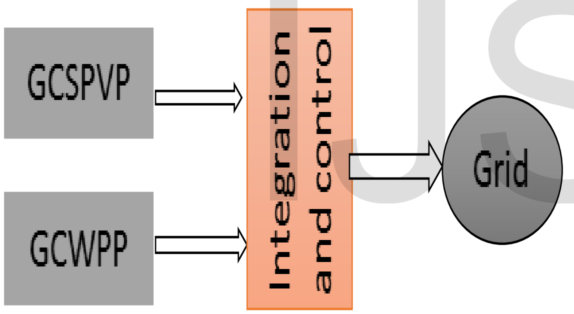

Fig.10. Propsed Combined System

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