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Reliability Evaluation of Photo Voltaic Array using Cutsets

Palthur Shashavali, V. Sankar

Abstract*: Electrical power generation resources for green energy revolution have been the present state of the art. Photo Voltaic (PV) systems are of prime concern for solar energy extraction as an alternate source of power systems. Reliability analysis of such PV systems will be significant for future prediction and estimating the failure so as to improve the performance of the system. In this paper, a probabilistic method is used to evaluate reliability performance of solar array of a PV system. The system PV-Array includes cells, Modules, Strings. The cutset method is proposed to analyze real life grid-connected PV systems. Exponential failure rate of PV Cell is considered. For improved performance of the PV System, failure analysis has been done and the range of predicted failure rate of PV Cell is estimated to design for Reliability of the PV System array. Also evaluated, the reliability of the PV System using proposed method by neglecting higher order Cutsets. The computational results for presented by variation in failure rate of cell to designing for reliability of PV system array.

Index Terms*: PV-Cell, Module, Array, Reliability, Cutset approach, Exponential distribution.

I. INTRODUCTION

In recent years, power generation from renewable resources has been counted upon to bring the gap between global demand and supply of power. Solar photovoltaic is widely used as renewable source to provide electricity power to consumers. Solar PV can convert free and unlimited sunlight to electricity without carbon dioxide emission or any other air pollutions. In the literature, a reliability characteristic of inverter configuration [1] that is used in the PV system is discussed. The PV module failure prediction parameters are estimated and analyzed in [2]. The state of the art models of PV systems are presented in [4]. A practical case study of solar PV system is presented in [5] which include failure rates of PV cells with temperature dependence and developed discrete distribution model. Probabilistic analysis of PV system using battery energy storage system is described in [6]. In the literature [3, 7] modeling aspects of networking and evaluation of series-parallel and non-series parallel complex networks using cutset approach are developed. Reliability evaluation of PV systems in the intermittent faults is analyzed in [8]. Reliability and the life time of the Converter considering the PV array sizing has been evaluated in [9]. The performance of various PV configurations which includes shading patterns has been analyzed in [10]. However, in these approaches related to PV arrays, network modeling and failure analysis has not been dealt with. In this paper an attempt has been made to do reliability modeling and expressions and derived independently for generalized configuration of the PV system array.

In this paper, a PV array has been considered with string which consists of modules and each module consists of series/parallel connections of cells. Individual failure probability of each cell is considered. Exponential distributed failure probability of the PV Cell is assumed. In order to design the PV Cell for improved performance, the effect of variation of failure rate has been considered so as to analyze the range of probability failure that can be predicted. Beyond these limits, the reliability improvement cannot be achieved.

II. RESEARCH PROPOSED METHOD

Consider the sample PV system array as shown in Fig.1 which consists of two cells in a row in a panel, two rows in parallel in a module, two such modules in a string and two strings in a array.

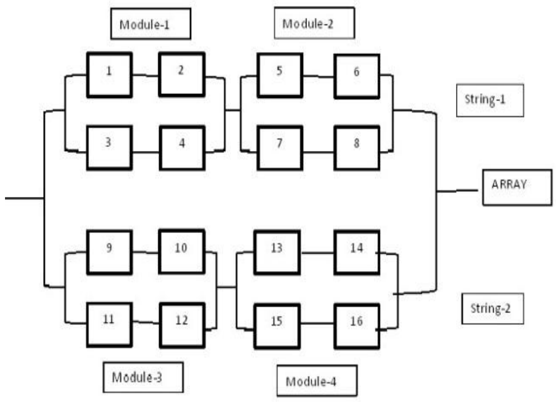

Fig. 1. Simple PV System array.

Let R_i be the probability of success of each cell. Q_i is failure of each cell.

Such that $R_i + Q_i = 1, \ \forall\ i = 1$ to 16.

Although network reduction technique can be used with series-parallel connections, cutset approach is most advantageous in computation of reliability/ unreliability of a network [7, 8].

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* Correspondence Author
Palthur Shashavali*, Department of Electrical and Electronics Engineering, J.N.T.University Anantapur. India. Email: shashavali240@gmail.com
V. Sankar, Department of Electrical and Electronics Engineering, JNTUACE (A), Ananthapuramu, India. Email: vsankar.eee@jntua.ac.in

Hence, in this context, the PV systems array is treated as the interconnections of cells and hence cutset method can be used for this purpose. Accordingly, a cutset of Fig. 1 can be identified with elements 1-3, 1-4, 2-3, and 2-4. And there will be total number of cutsets will be 4. Generalizing, Such a PV system array with N_{rm}, N_{sm}, N_{ms}, and N_{sa}.

Total number of Cutset in module = $[N_{sm}]^{Nrm}$ … (1)

Where the number elements of a cutset in each module will be equal to $[N_{rm}]$. The data required is the probability of failure of each cell. It is assumed that the probability of failure is exponentially distributed with constant hazard rate λ_k for each cell $\forall$ k=1 to Na,

where $N_a = N_{sm} \times N_{rm} \times N_{ms} \times N_{sa}$. … (2)

The unit for λ is in failures/Million hrs.

$$R_K = e^{-\lambda kt} \quad \text{.... (3)}$$

and

$$Q_K = 1- e^{-\lambda kt} \quad \text{.... (4)}$$

where 't' is the time period in years.

It is assumed that cell failure probability independent. Therefore, Q_{CS} can be expressed as:

$$Q_{CS} = [Q_K]^{Nrm} \quad \text{.... (5)}$$

And

$$R_{CS} = 1- Q_{CS} \quad \text{.... (6)}$$

Hence, R_{mi} can be expressed as:

$$R_{mi} = \prod_{i=1}^{N_{cm}} R_{cs} \quad \text{.... (7)}$$

and

$$R_{sj} = \prod_{j=1}^{N_{ms}} R_{mi} \quad \text{.... (8)}$$

$$Qsj = [1- Rsj] \quad \text{.... (9)}$$

and

$$Q_a = [Q_{SJ}]^{Nsa} \quad \text{.... (10)}$$

$$R_a = 1- Q_a \quad \text{.... (11)}$$

The PV system array reliability will be same given in Eqn. (11). Now, for a known/given value of probability of failure of each cell, the PV array reliability can be estimated. In this context, designing for desired reliability of PV system array is of significant importance. Therefore, for the desirable level of reliability of PV system array which can be prefixed, the variation of failure rate of each cell has been considered so that designing for the acceptable range of failure rate of each cell for different configurations have been obtained and the results are analyzed. Further, in the above analysis, all possible cutsets are considered for the reliability analysis. It is well known [6, 8] in the literature that cutsets of higher order (more than third order), can be neglected so as to reduce the number of computations. In such case Eqn. (5). Can be rewritten as:

$$Q_{cs} = \sum_{i=0}^{3} N_{c_r} R^r Q^{n-r} \quad \text{.... (12)}$$

Therefore, reliability analysis is to be carried out with Eqn. (12) with remaining expressing are same. If $R_a > R_{adh}$ or $R_a < R_{adl,}$ the algorithm is terminated in either case.

III. ALGORITHM

Based on the above ideas the algorithm for computation of PV system array using cutset method is presented in the following steps:

The flow chart of the above algorithm is shown in Fig.2.

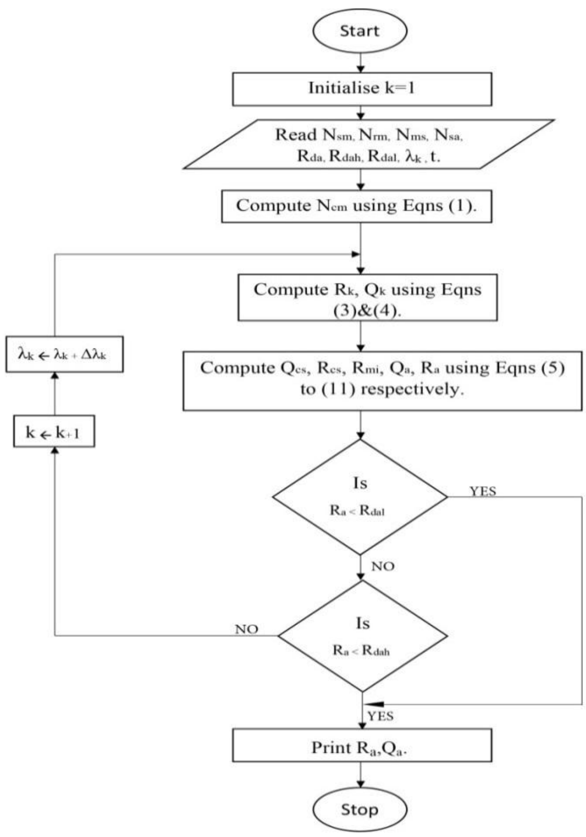

Fig. 2. Flow Chart for designing of failure rate for desired reliability of PV System array.

IV. ILLUSTRATION

Example 1: Consider the network shown in Fig.1.with $\lambda_k = 0.1$ f/Mhr; $N_{rm} = N_{sm} = N_{ms} = N_{sa} = 2$, R_{dah}=0.9999; $\Delta\lambda$=0.1; t=20 years, R_{dal}=0.0001 Therefore, N_{cm} using Eqn. (1) will be 4. R_k= 0.87686 using Eqn. (3). Software has been developed using Turbo C++. Now by varying λ with changes in failure rates assumed with desired level of reliability of array, the results are tabulated in Table 1. From the Table 1, it can be observed that, the optimum value of failure rate for desired value of reliability 0.9999 is 0.2 f/Mhr.

Step 1:	Initialize k=1.
Step 2:	Read λ_k, R_{da}, $\Delta\lambda$, N_{rm}, N_{sm}, N_{ms}, N_{sa}, R_{dah}, R_{dal}, t.
Step 3:	Compute R_k, Q_k using Eqns. (3) and (4).
Step 4:	Compute Number of cutsets in a module using Eqn. (1).
Step 5:	Compute Q_{cs}, R_{cs} using Eqns. (5) and (6).
Step 6:	Compute R_{mi} using Eqn. (7).
Step 7:	Compute Q_{sj} using Eqns.(8) and (9).
Step 8:	Compute Q_a and R_a using Eqns. (10) and (11).
Step 9:	if $R_a < R_{dal}$ then goto step 11
Step 10:	if Ra > R_{dah}, then goto step:11. else, k$\leftarrow$ k+1; $\lambda_k \leftarrow \lambda_k + \Delta\lambda$ then goto Step: 3.
Step 11:	Print R_a and Q_a.
Step 12:	End.

Also, it can be observed that by increasing the failure rate of the cell, the R_a will decrease and λ cannot be increased beyond the value so that reliability will become almost negligible, with failure rate greater than or equal to 10.2 f/Mhr. The graph of R_a Vs. λ_k is shown in Fig.3.

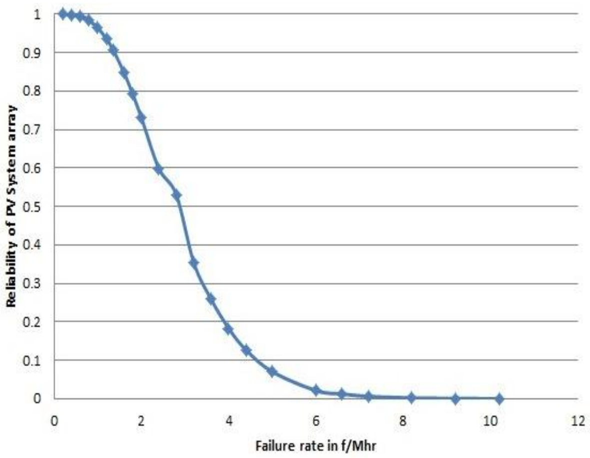

Fig. 3. R_a Vs. λ Characteristics for fig.1.

Example 2: Similarly, consider the PV solar system array with $N_{rm} = N_{sm} = N_{ms} = N_{sa} = 3$. R_{dah}=0.9999; R_{dal}=0.0001, λ_k =0.1 f/Mhrs; $\Delta\lambda$=0.1 f/Mhrs; t=20 years. The results obtained are given Table 2. The graph of R_a Vs. λ_k is shown in Fig.4.

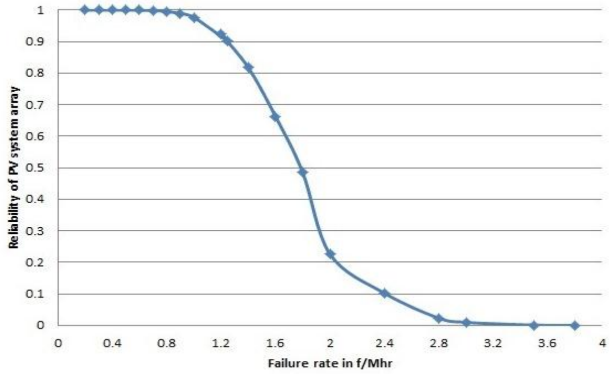

Fig. 4. R_a Vs. λ Characteristics for 3X3 system.

From Table 2, it can be observed that the value of λ for R_a to be negligible is only 3.8 f/Mhr. whereas for fig.3 it is 10.2 f/Mhr.

Table 1

Λ	R_a
0.2	0.99991
0.4	0.99869
0.6	0.99408
0.8	0.98338
1	0.96432
1.2	0.93552
1.35	0.9073
1.6	0.84853
1.8	0.79258
2	0.73085
2.4	0.599
2.8	0.53047
3.2	0.3539
3.6	0.2581
4	0.1829
4.4	0.1266
5	0.0702
6	0.0213
6.6	0.0124
7.2	0.00624
8.2	0.00189
9.2	0.00055
10.2	0.00015

Table 2

λ	R_a
0.2	1
0.3	0.99999
0.4	0.99998
0.5	0.99989
0.6	0.99953
0.7	0.99839
0.8	0.99543
0.9	0.98896
1	0.97659
1.25	0.901
1.2	0.92302
1.4	0.81734
1.6	0.66226
1.8	0.48441
2	0.2257
2.4	0.10215
2.8	0.0229
3	0.00969
3.5	0.00085
3.8	0.00015
0.2	1

Example 3: Consider the PV solar system array with $N_{rm} = N_{sm} = N_{ms} = N_{sa} = 4$. $R_{dah}=0.9999$, $R_{dal}=0.0001$; $\lambda_k=0.1$ f/Mhr; $\Delta\lambda=0.1$ f/Mhr; t=20 years. The results obtained are given Table 3. The graph of R_a Vs. λ_k is shown in Fig.5. It can be observed that the value of λ for R_a to be negligible is only 2.1 f/Mhr.

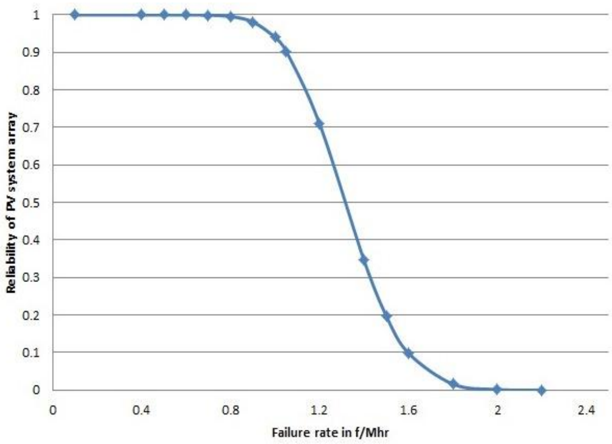

Fig. 5. R_a Vs. λ Characteristics for 4X4 system.

Table 3

λ	R_a
0.1	1
0.4	0.99999
0.5	0.9999
0.6	0.99991
0.7	0.99923
0.8	0.9955
0.9	0.98103
1	0.9399
1.05	0.903
1.2	0.70968
1.4	0.34619
1.5	0.19795
1.6	0.09869
1.8	0.01632
2	0.00156
2.2	0.00008

Table 4

λ	R_a
0.5	0.99999
0.6	0.99994
0.7	0.99845
0.8	0.98153
0.85	0.9508
0.89	0.9046
1	0.64526
1.2	0.10392
1.3	0.02069
1.4	0.00247
1.5	0.00016

Example 4: Consider the PV solar system array with $N_{rm} = N_{sm} = N_{ms} = N_{sa} = 5$. $R_{dah}= 0.9999$, $R_{dal} = 0.0001$, $\lambda_k = 0.1$ f/Mhrs; $\Delta\lambda= 0.1$ f/Mhrs; t=20 years. The results obtained are given Table 4. The graph of R_a Vs. λ_k is shown in Fig.6. it can be observed that the value of λ for R_a to be negligible, the value will be 1.5 f/Mhr. Thus as the configuration increases, the failure rate will be decreases, operating time will be more. The graph of R_a Vs. λ_k is given in Fig.6.

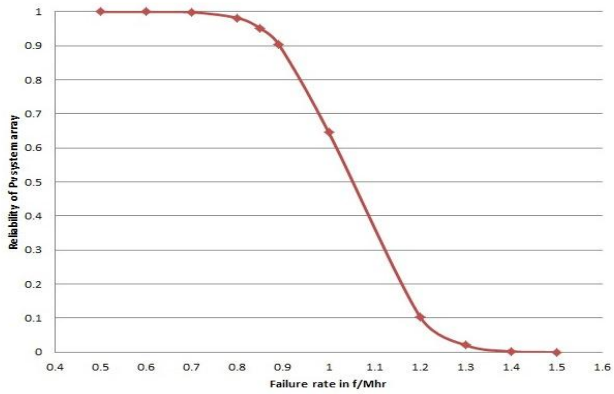

Fig. 6. R_a Vs. λ Characteristics for 5X5 system.

Further, let the reliability of the array to be designed for 0.9, then the value of λ for different configurations can be noted from the graphs of Fig. 3 to Fig. 6 respectively and are tabulated in Table 5.

Table 5: Comparison of failure rates with desired R_a= 0.9

Desired Value of R_a	Failure rate (λ) Values obtained from different configurations			
	Fig. 3	Fig. 4	Fig. 5	Fig. 6
0.9	1.35f/Mhr	1.25f/Mhr	1.05f/Mhr	0.89f/Mhr

From Table 5 it can be observed that for the same desired value of reliability of the system as the configuration increases, the value of λ decreases, indicating that the operating time will be more with higher number of module configurations.

NOTATION

N_{rm}	No. of rows in a module.
N_{ms}	No. of modules in a string.
N_{sa}	No. of strings in an array.
N_a	Total No. of cells in an array.
N_{rm}	No. of elements in a cutset in each Module.
N_{cm}	No. of Cutsets in a module.
λ_k	Failure rate of a cell.
R_k	Reliability of a cell.
Q_k	Unreliability of a cell.
Q_{cs}	Unreliability of series configuration Of the module.
R_{cs}	Reliability of series configuration of the module.
R_{mi}	Reliability of the each module.
R_{sj}	Reliability of the each string.
R_a	Reliability of the array.
$\Delta\lambda$	Change in the failure rate of each Cell.
R_{da}	Desired level of reliability of PV System array.
R_{dah}	Maximum value of desired reliability of array.
R_{dal}	Minimum value of desired reliability of array.
f/Mhr	Number of failures per Million hours.

V. CONCLUSIONS

In this paper, cutset approach has been used for PV system array reliability analysis. An algorithm has been developed for obtaining the reliability of array by choosing minimum and maximum values. This analysis is carried out by assuming variation of failure rate of each cell, so as to design for the required level of reliability, the failure rate cell is estimated. Proper configuration of the PV system is required to design for better reliability.

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AUTHORS PROFILE

Mr. PALTHUR SHASHAVALI Received the B.Tech Degree from J.N.T University Hyderabad. He received Master of Technology degree from G. Pulla Reddy Engineering College Kurnool. Currently he is Pursuing Ph.D degree from J.N.T University Anantapur. Presently, he is working as Lecturer in the Department of Electrical and Electronics Engineering, S.K.University College of Engineering & Technology, S.K.University, Ananthapuramu-515 003, Andhra Pradesh, India. His research area of interest is Reliability concepts in Power Electronic Converters, Renewable Energy Sources and Facts Devices

Dr.V.SANKAR Graduated in Electrical Engineering (1978), M. Tech. (1980), Ph. D. (1994) from IIT Delhi. Presently, he is working as Professsor in Electrical Engineering at JNTUA College of Engineering, Ananthapuramu-515 002, Andhra Pradesh, India. He has guided 13 Ph.D Students and guiding five at present. He is recipient of A.P.State Best Teacher award in 2010. He is Senior Member of IEEE and presently Chair of IEEE Ananthapuramu Sub-Section. He has Published more than one hundred research papers in various International/National Journal/Conferences. His area of interests are Power Systems, Reliability Engineering.