

# Institute of Aeronautical Engineering (Autonomous)



**Department of Electrical and Electronics Engineering**

**RESEARCH BASED LABORATORY (RBL)**

**DOCUMENTATION  
ON**

**“IMPACT OF SOLAR IRRADIANCE AND AMBIENT TEMPERATURE  
ON PV INVERTER RELIABILITY CONSIDERING GEOGRAPHICAL  
LOCATIONS”**

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## ABSTRACT

Today inverter system is one of the enabling technologies for efficiently harnessing energy from renewable energy sources (Solar, Wind, etc.,) and also for high reliable grid interfacing systems. With the advancements in power electronics, inverter conversion efficiency pushed to 98%, also PV is becoming a major renewable energy source globally. Nevertheless, the reliability performance of PV inverter is of high concern.

Different environmental factors like solar irradiance, ambient temperature (also called Mission Profile) affect the reliability performance of PV inverter. Environmental conditions vary from location to location. Hence to quantify the reliability performance of PV inverter all these factors need to be considered. In this paper reliability performance of PV inverter is evaluated considering environmental factors and geographical locations.

For the reliability evaluation, a 1- $\phi$ , 3-kW grid connected PV system is developed in PLECS. Full bridge PV inverter with 600V/30A IGBT is employed as the interface between grid and PV source. Real time mission profile data of one-year logs at India (Relatively hot climate) and Denmark (Relatively cold climate) to account for environmental factors and geographical locations during the reliability performance evaluation of PV inverter. Monte Carlo simulation is used to generate a population of 20000 samples with 5% variation. Lifetime for 20000 samples is calculated and fitted in Two Parameter Weibull distribution. B10 lifetime is calculated at two locations.

## INTRODUCTION

With the rapid advancement of power electronic technologies, PV inverter systems [1] have been widely applied to harvest energy from solar energy systems, grid connected applications etc. The application of inverter leads to an increase in the utilization of solar energy sources and shares a significant amount in total electricity demand [2]. Nevertheless, researchers reported PV inverter as the most unreliable device in the PV system. The studies [3-7] says that the Grid connected PV inverter is the weakest among all in terms of reliability due to the power semiconductor switches. Factors such as quality control, adequate design, Electrical component failure, and other manufacturing factors influence the reliability of PV inverter. A survey [8] taken from industries concluded that power electronics switches are the critical components. The major failures in power electronic switches are due to thermomechanical failures. Reported wear out, bond wire liftoff, etc., are the most occurring failures in switches [9, 10]. Environmental conditions lead to power cycling and thermal cycling of the switch, which are the major causes for failure. Hence reliability evaluation of power electronic switch is needed. The reliability performance of the PV inverter is affected by environmental factors like solar irradiance, ambient temperature (also called Mission Profile). Environmental condition varies from location to location. Regions near the equator receive relatively high average solar irradiance and average ambient temperature all over the year. Similarly, regions far from the equator receive relatively low average solar irradiance and average ambient temperature all over the year. The yearly month wise heatmap table of solar irradiance and ambient temperature at both India and Denmark locations are tabulated in Table 1 and Table 2 respectively [11]. The heatmap table showcases that solar irradiance and ambient temperature vary from time to time and location to location, thereby the reliability performance of PV inverter also varies. In comparison with Denmark high climatic conditions are recorded at India. High solar irradiance is

recorded at India from March to May. Low solar irradiance is recorded at Denmark from November to February. Similarly, high ambient temperature is recorded at India from March to June. Low ambient temperature is recorded at Denmark from November to April. To account for these factors in the reliability evaluation real time mission profile data for one year at geographical locations of India and Denmark are logged.

In this paper 1- $\phi$ , 3-kW grid connected PV system is considered as a test case and developed in PLECS. Full bridge PV inverter with four 600V/30A IGBT's of Infineon manufacturer [12] is employed as the interface between grid and PV source. First mission profile based reliability evaluation is carried out at individual IGBT (Component Level) then by combining all individual IGBT's to get invert

**Table 1.** Heatmap table of solar irradiance

Country/ Month	Solar Irradiance (Wh/m <sup>2</sup> )	
	India	Denmark
SEP	165053	100054
OCT	186766.1	61622.69
NOV	164028.1	24233.29
DEC	144757.6	10711.25
JAN	165846.2	16247.97
FEB	172830.1	36188.28
MAR	215120.5	71213.96
APR	213292.3	149069.7
MAY	215131.3	176171.3
JUN	145693.6	198472.5
JUL	148344.1	191219.2
AUG	146975.4	152064.2

Red = High, Yellow = Medium, Green = Low

**Table 2.** Heatmap table of ambient temperature

Country/ Month	Ambient Temperature (°C)	
	India	Denmark
SEP	25.81	14.79
OCT	25.44	10.78
NOV	24.51	6.43
DEC	21.75	4.17
JAN	21.14	1.95
FEB	25.08	3.66
MAR	29.84	5.32
APR	32.71	7.95
MAY	34.68	10.5
JUN	30.51	16.77
JUL	27.14	17.34
AUG	25.76	18.03

Red = High, Yellow = Medium, Green = Low

## Reliability Evaluation of PV Inverter

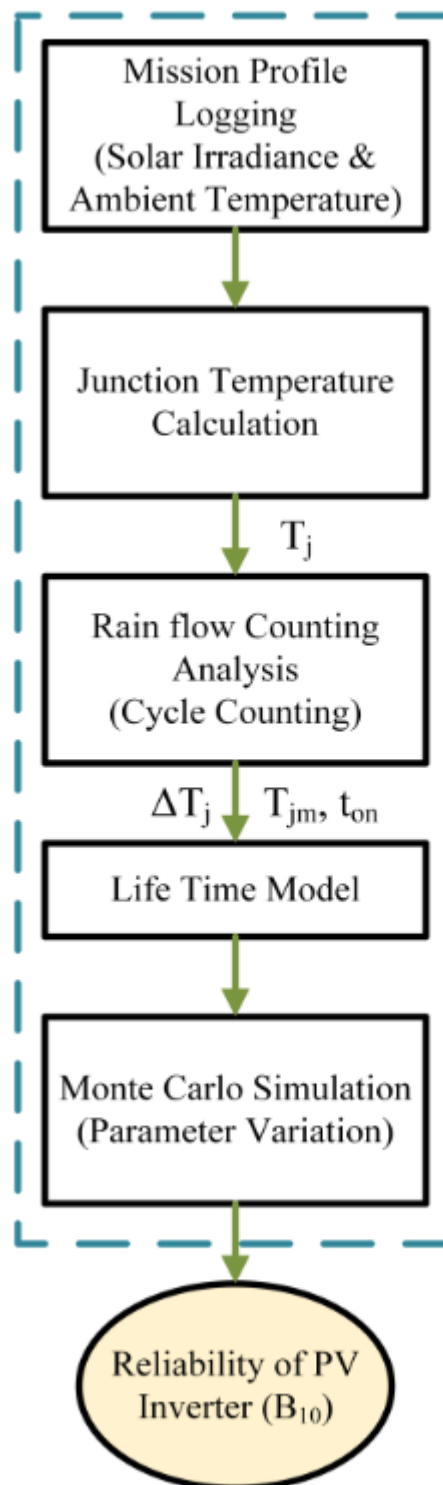


Figure 1. Flow chart for reliability evaluation

## RELIABILITY EVALUATION OF PV INVERTER

The critical component in the PV inverter is power electronic devices i.e., IGBT [13]. Hence the reliability of IGBT needs to be evaluated to get PV inverter reliability. The temperature at the junction layers of the IGBT varies with mission profile variations and leads to failure (bond wire liftoff, wear out, etc.,) [14, 15]. Hence junction temperature needs to be calculated for reliability evaluation. The step wise reliability evaluation of PV inverter flow chart is shown in Figure 1.

First mission profile data for one year needs to be logged. The junction temperature of IGBT corresponds to the mission profile variations it needs to be calculated. Foster Electro thermal model of IGBT based of manufacturer data sheet is developed in PLECS shown in Figure 2 for the calculation of junction temperature [16].

Junction temperature at any instant is given as

$$T_j = Z_{th(j-c)} * P_T + T_C \quad (1)$$

where,

- $Z_{th(j-c)}$  = Junction to case
- $P_T$  = Total Power Loss
- $T_c$  = Case Temperature

Variations in the junction temperature are analyzed by the rainflow counting algorithm [17]. From the rainflow algorithm

No. of Cycles  $n_i$ , Mean Junction Temperature  $T_{jm}$ , Cycle

Amplitude  $\Delta T$  are calculated. The lifetime of IGBT is

calculated by miners rule given as

$$Life\ Time\ (LT) = 1$$

$$Life\ Consumption\ (LC) \quad (2)$$

Life Consumption of IGBT is given as

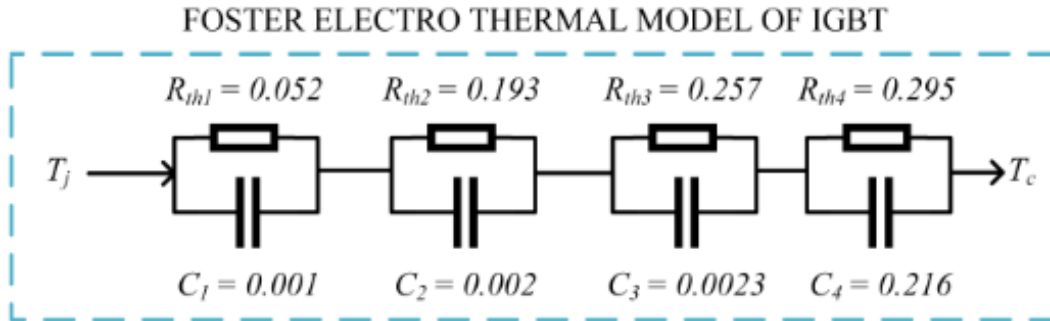
$$Life\ Consumption\ (LC)$$

$$= \sum No.\ of\ Cycles\ (n_i)$$

$$No.\ of\ Cycle\ to\ failure\ (N_{fi})$$

$$(3)$$

where, No. of Cycles  $n_i$  calculated from rainflow counting algorithm. No. of Cycles to failure  $N_{fi}$  can be calculated BY Bayerer's life time model [18] shown below



**Figure 2.** Foster electro thermal model of IGBT

$$N_f = K(\Delta T_j)^{\beta_1} \cdot e^{\beta_2} (T_j + 273K)^{\beta_3} \cdot t_{on}^{\beta_3} \cdot I^{\beta_4} \cdot V^{\beta_5} \cdot D^{\beta_6} \quad (4)$$

where,  $R_i(t)$  individual component reliability.

From the reliability function B10 lifetime i.e., the probability to fail 10% of the population is calculated at both component level and system level can be obtained [21]

The parameter of the above equation is tabulated in Table 3.

**Table 3.** Bayerer's lifetime model parameters

Parameter	Value
Technology Factor (A)	9.34E+14
Coefficient ( $\beta_1$ )	-4.416
Coefficient ( $\beta_2$ )	1285
Coefficient ( $\beta_3$ )	-0.463
Coefficient ( $\beta_4$ )	-0.716
Coefficient ( $\beta_5$ )	-0.761
Coefficient ( $\beta_6$ )	-0.5
Current per bond foot (I)	3-23 A
Voltage class (V)	6-33 V
Bond wire diameter	75-500 $\mu\text{m}$

Monte Carlo simulation is used to generate a population of 20000 samples with 5% variation. Lifetime for 20000 samples are calculated and fitted in two parameter Weibull distribution then reliability function is calculated at as follows [19, 20].

For component level reliability function is given as

$$R(t) = e^{-\left(\frac{t}{\alpha}\right)^\gamma} \quad (5)$$

where,  $\alpha$  is Scale Parameter (2.5 for IGBT)

$\gamma$  is Shape Parameter (characteristic life at 63.2% of population have failed)

For system level

$$R_{total}(t) = \prod_{i=1}^n R_i(t) \quad (6)$$



## RESULTS AND DISCUSSION

A test case of a 1-  $\phi$ , 3-kW grid connected PV system with full bridge inverter is considered and developed in PLECS environment as shown in Figure 3. The parameters of the test case are tabulated in Table 4. Reliability evaluation of PV inverter is implemented on two cases.

1. Reliability (B10) evaluation of PV inverter considering Mission Profile at India.
2. Reliability (B10) evaluation of PV inverter considering Mission Profile at Denmark

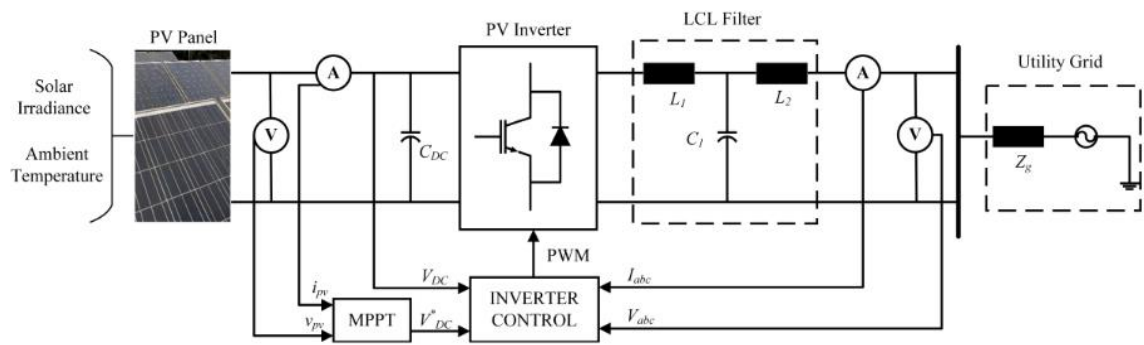
**Table 4.** Proposed 3-KW grid connected PV inverter parameters

Name	Specification
PV panel model	BP365
PV inverter rated power	3-kW
Grid voltage	230 V
Grid frequency	50 Hz
Dc link capacitance	1.5e-3 F
IGBT make	Infineon
IGBT model	IGW30N60H3
IGBT Voltage rating	600 V
IGBT Current rating	30 A
IGBT min $T_j$	25°C
IGBT max $T_j$	175°C

Reliability (B10) evaluation considering mission profile at India

Real time mission profile data.  
The real time mission profile data i.e., solar irradiance and ambient temperature logs for one year (one min sample) at BVRIT Narsapur, India from 2018 September to 2019 August as shown in Figure 7. CMP11 Pyranometer from Kipp & Zonen manufacturer is used to measure solar irradiance as shown in Figure 4, RTD device from Kipp & Zonen manufacturer is used to measure ambient temperature as

shown in Figure 5, CR3000 data logger from Campbell Manufacturer is used to log mission profile shown in Figure 6



**Figure 3.** 1- $\phi$  3-kW grid connected PV system



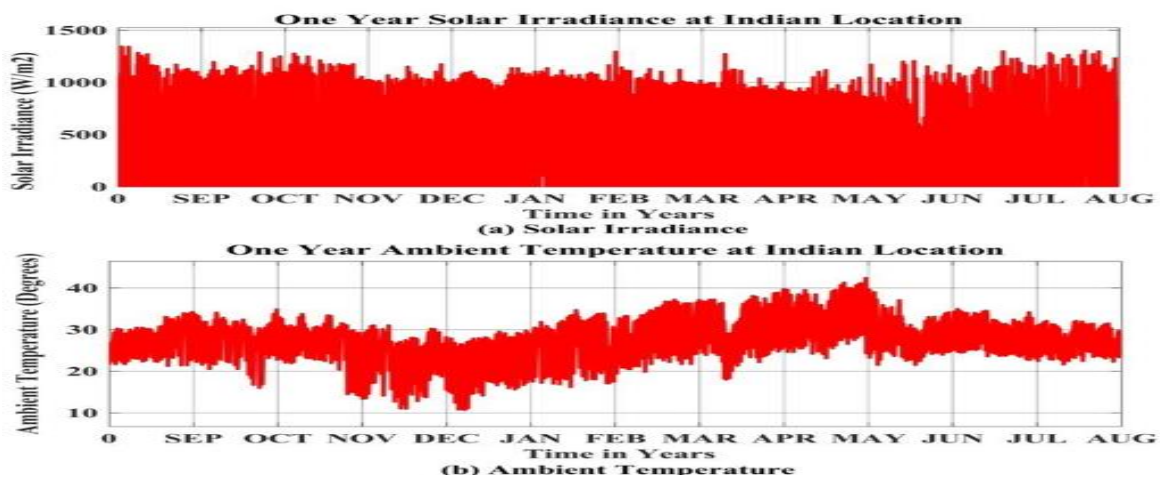
**Figure 4.** Pyranometer



**Figure 5.** RTD device



**Figure 6.** CR3000 data logger



The maximum ambient temperature at India is recorded from March to June similarly low ambient temperature at India is recorded from November to February. Solar irradiance and ambient temperature is continuously varying all over the year.

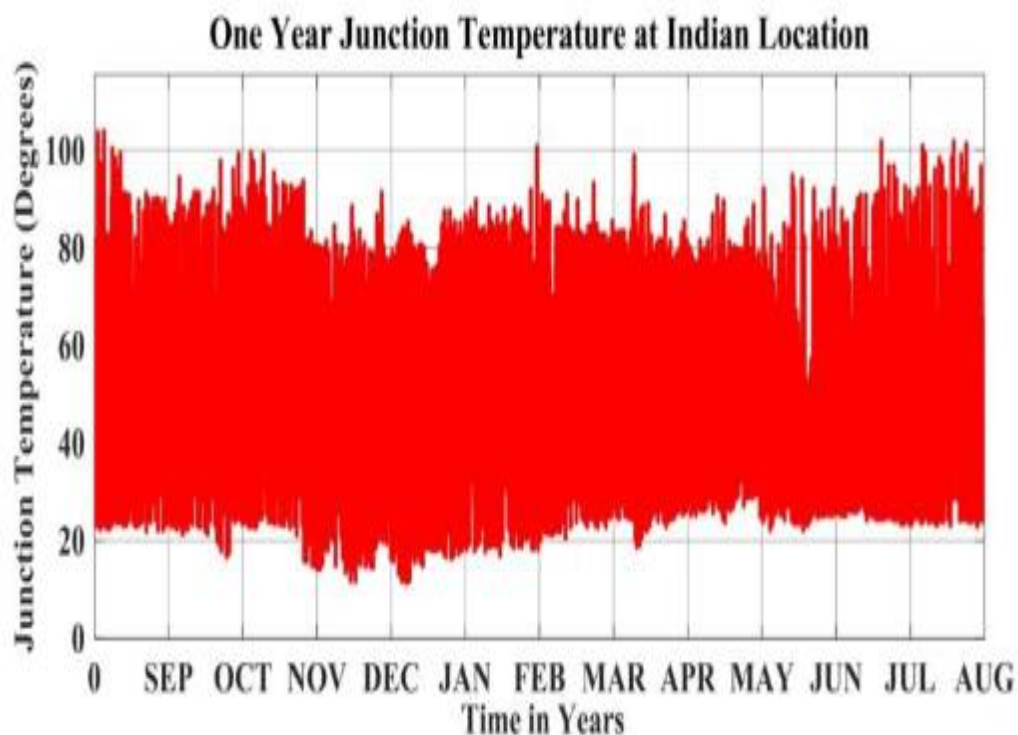
### 3.1.2 Calculation of junction temperature

The junction temperature corresponds to the yearly mission profile is calculated using the foster electro thermal model of IGBT shown in Figure 8. The maximum junction temperature recorded at India is

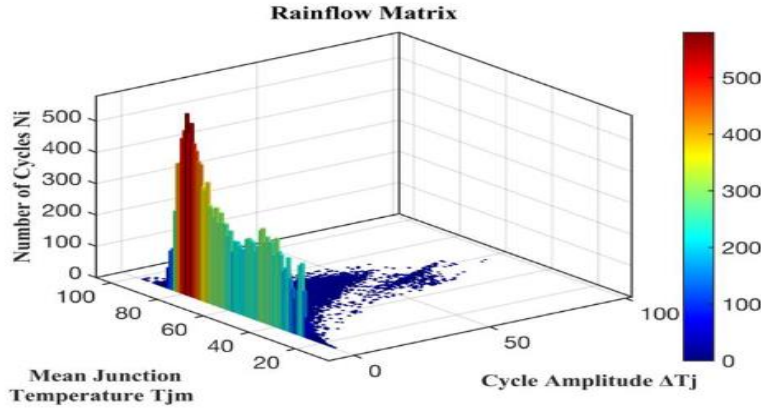
103.88°C. Similarly, the minimum junction temperature recorded at India is 11.41°C. The above calculate junction temperature of IGBT clearly shows that it is varying rapidly in the form of cycles.

#### Rainflow counting algorithm

The junction temperature variations at India are analysed using rainflow counting algorithm



**Figure 8.** Yearly junction temperature at India



**Figure 9.** Rainflow matrix indian location

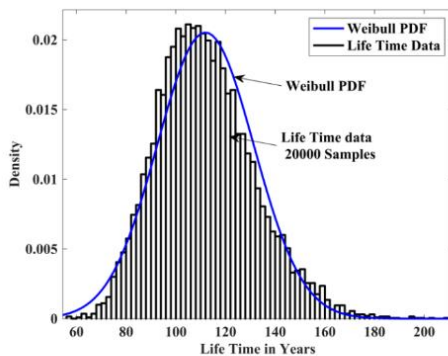
The junction temperature variations i.e., No.of Cycles  $n_i$ , Mean Junction Temperature  $T_{jm}$ , Cycle Amplitude  $\Delta T$  are plotted in Figure 9.

#### 3.1.4 Monte Carlo simulation and B10 lifetime

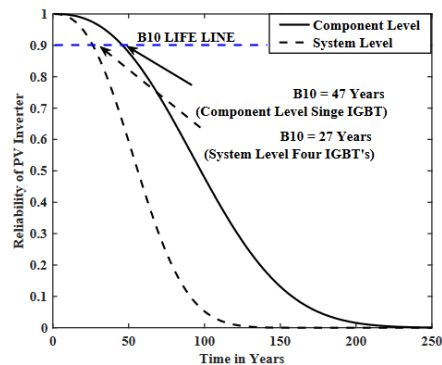
With the help of Monte Carlo simulation population size of 20000 is generated and the lifetime at each sample is calculated with 5% variation using Eq. (2). The 20000 population is fitted with Weibull distribution and is shown in Figure 10.

The B10 lifetime of PV inverter at India with both component level and system level is calculated using Eq. (5) and Eq. (6) shown in Figure 11.

The B10 lifetime at the Indian location at the component level is 47 years whereas at the system level is 27 years. In this paper full bridge i.e., four IGBT are considered hence system level reliability is reduced to 27 years



**Figure 10.** Lifetime distribution

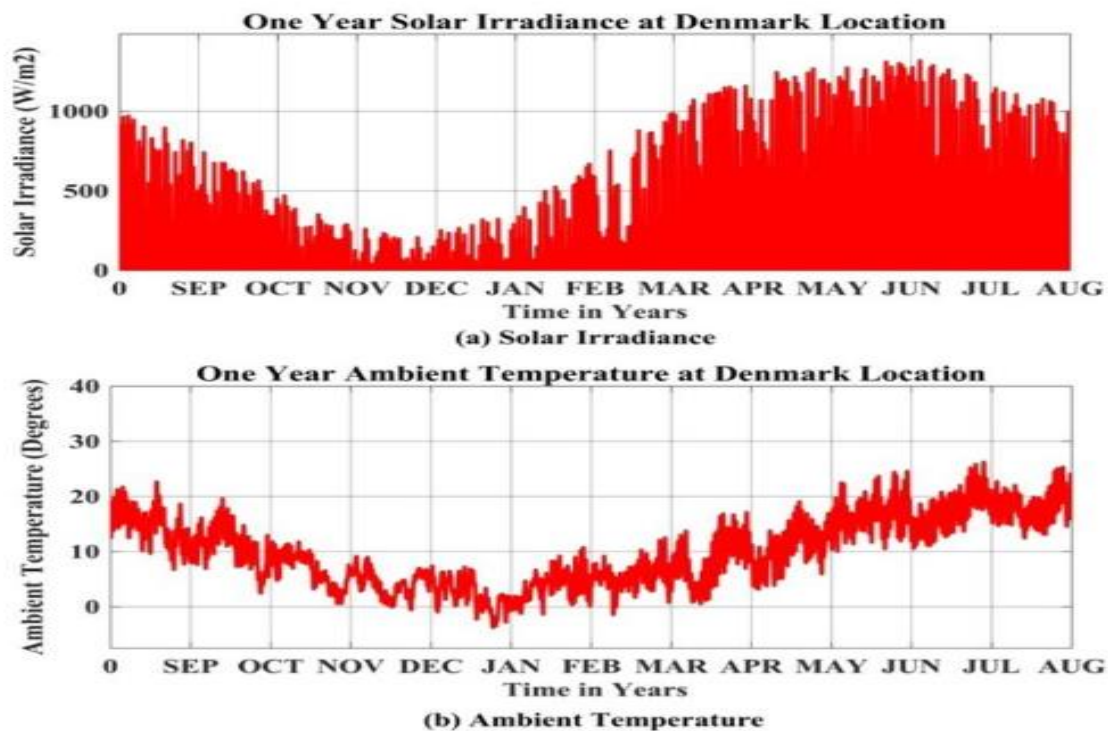


**Figure 11.** B<sub>10</sub> life time at India

Reliability (B10) evaluation considering mission profile at Denmark

### 3.2.1 Real time mission profile data

The real time mission profile data i.e., solar irradiance and ambient temperature logs for one-year (one min sample) form [11] at Alborg, Denmark from 2018 September to 2019 August shown in Figure 12.



**Figure 12.** Yearly mission profile at Denmark a) Solar irradiance, b) Ambient temperature

The maximum ambient temperature at Denmark is recorded from May to August similarly low ambient temperature at Denmark is recorded from November to February. Solar irradiance and ambient temperature is continuously varying all over the year.

### 3.2.2 Calculation of junction temperature

The junction temperature corresponds to the yearly mission profile is calculated using the foster electro thermal model of IGBT shown in Figure 13

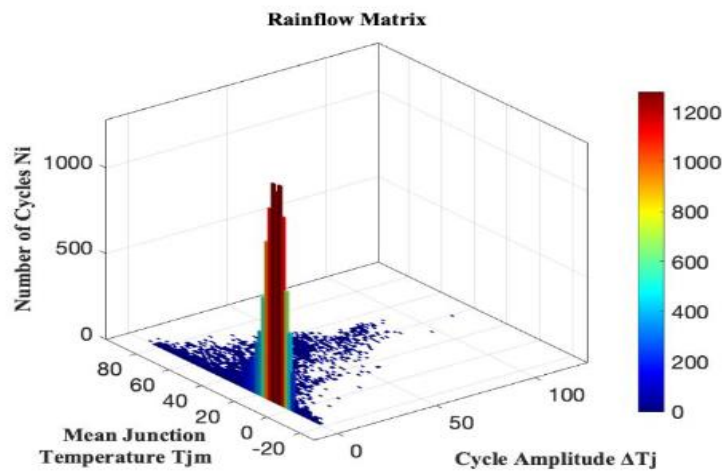


## Rainflow counting algorithm

The junction temperature variations at Denmark are analysed using rainflow counting algorithm.

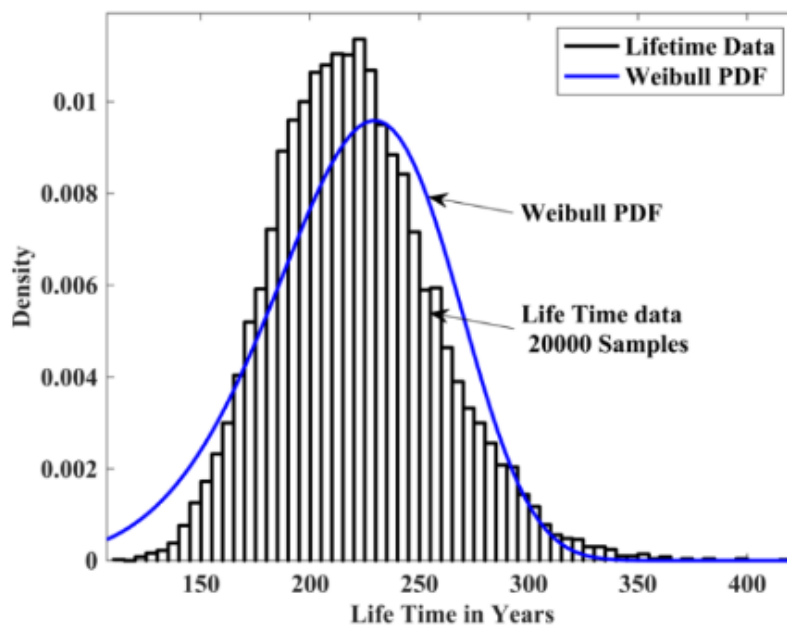
Figure 14. Rainflow matrix denmark location

The junction temperature variations i.e., No. of Cycles  $n_i$ , Mean Junction Temperature  $T_{jm}$ , Cycle Amplitude  $\Delta T$  are plotted in Figure 14

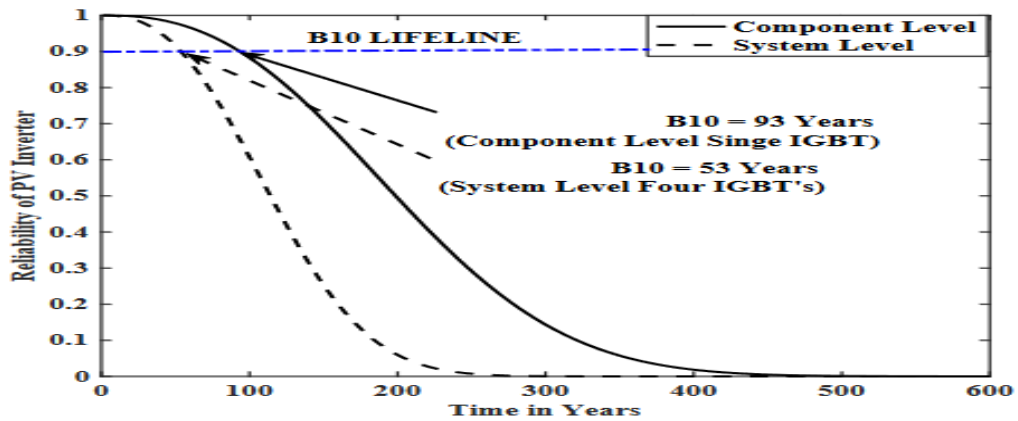


**Figure 14.** Rainflow matrix denmark location

### 3.2.4 Monte Carlo simulation and $B_{10}$ lifetime



**Figure 15.** Lifetime distribution

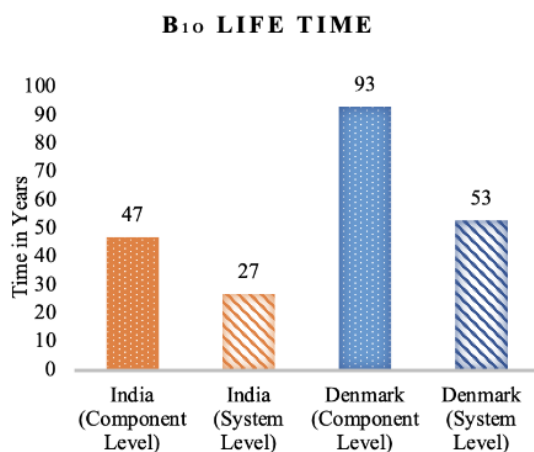


**Figure 16.** B<sub>10</sub> life time at Denmark

With the help of Monte Carlo simulation population size of 20000 is generated and the lifetime at each sample is calculated with 5% variation using Eq. (2). The 20000 population are fitted with Weibull distribution and shown in Figure 15.

The B10 lifetime of PV inverter at Denmark with both component level and system level is calculated using Eq. (5) and Eq. (6) shown in Figure 16.

The B10 lifetime at Denmark location at the component level is 93 years whereas at the system level is 53 years. In this paper full bridge i.e., four IGBT are considered hence system level reliability is reduced to 27 years.



**Figure 17.** B<sub>10</sub> lifetime comparison chart

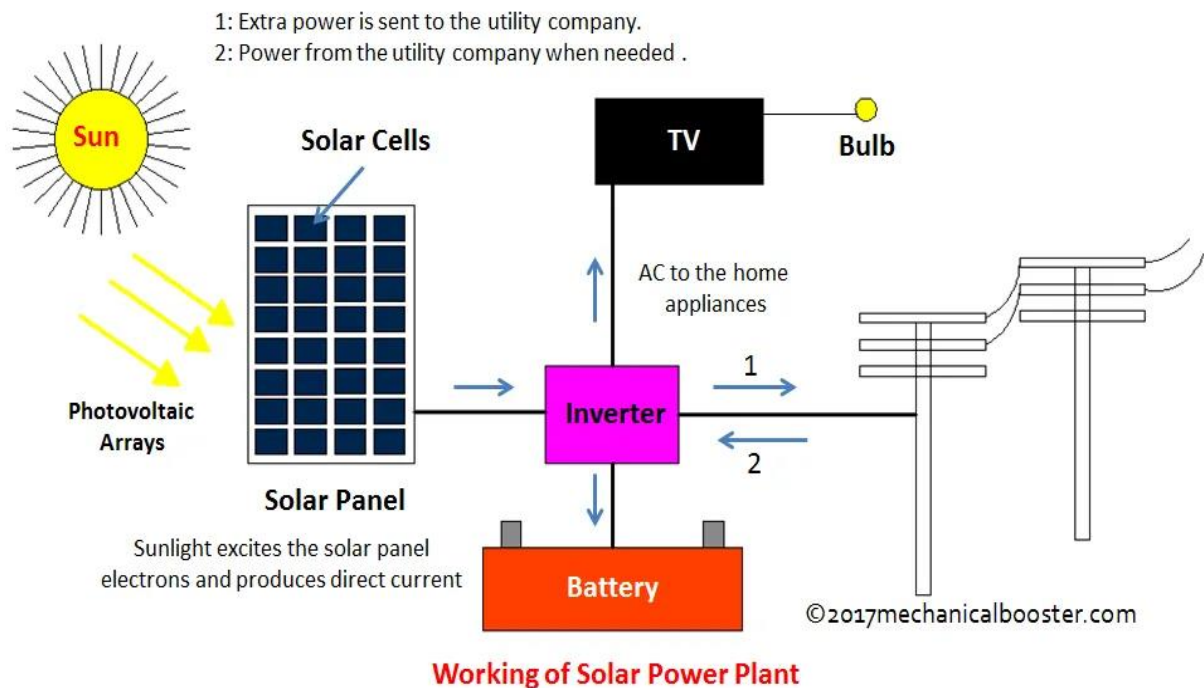
B10

lifetime

comparison

India and Denmark are two different climatic zones. In India, the highest ambient temperature and solar irradiance are recorded from March to June and the overall mean junction temperature at the Indian location is  $55.66^{\circ}\text{C}$ . In Denmark highest ambient temperature and solar irradiance are recorded from June to July and the overall mean junction temperature at the Denmark location is  $16.37^{\circ}\text{C}$ . The mean temperature difference between both locations is  $39.29^{\circ}\text{C}$  and this leads to the variation in reliability performance. The B10 lifetime recorded at India where climatic conditions are relatively hot is 47 years (Component Level) and 27 years (System Level). Similarly, B10 lifetime recorded at Denmark where climatic conditions are relatively cold is 93 years (Component Level) and 53 years (System Level). B10 lifetime comparison bar chart is shown in Figure 17. This scenario clearly shows that B10 lifetime varies with respect to the geographical locations and environmental conditions.

### Working of Solar Power Plant





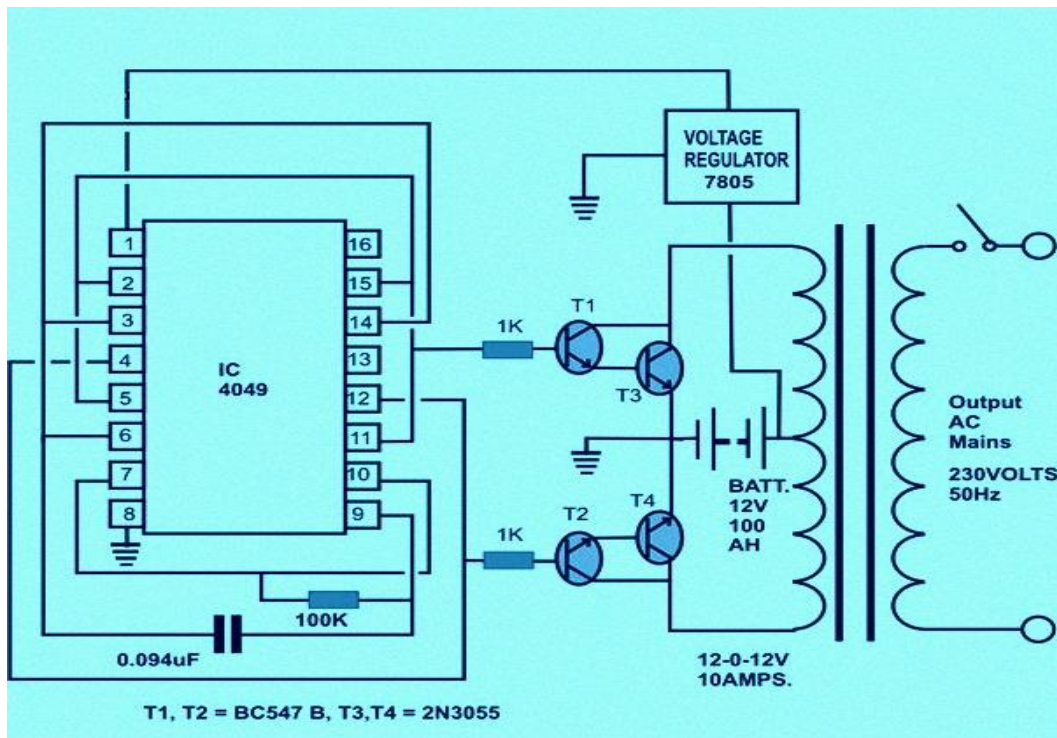
As sunlight falls over a solar cells, a large number of photons strike the p-type region of silicon. Electron and hole pair will get separated after absorbing the energy of photon. The electron travels from p-type region to n-type region due to the action of electric field at p-n junction. Further the diode is reversed biased to increase this electric field. So this current starts flowing in the circuit for individual solar cell. We combine the current of all the solar cells of a solar panel, to get a significant output. Solar power plant have a large number of solar panels connected to each other to get a large voltage output. The electrical energy coming from the combined effort of solar panels is stored in the Lithium ion batteries to be supplied at night time, when there is no sunlight

### **Introduction to Solar Inverter:**

We see many people using Solar inverters these days which proves that its necessity has been increased in the current years. A Solar inverter is similar to a normal electric inverter but uses the energy of the Sun i.e. Solar energy.

A solar inverter helps in converting the direct current into alternate current with the help of solar power. Direct power is that power which runs in one direction inside the circuit and helps in supplying current when there is no electricity. Direct currents are used for small appliance like mobile e phones, MP3 players, IPod etc. where there is power stored in the form of battery. In case of alternative current it is the power that runs back and forth inside the circuit. The alternate power is generally used for house hold appliances. A solar inverter helps devices that run on DC power to run in AC power so that the user makes use of the AC power. If you are thinking why to use solar inverter instead of the normal electric one then it is because the solar one makes use of the solar energy which is available in abundant from the Sun and is clean and pollution free.

## Working of Solar Inverter:



Now after knowing what a solar inverter is, let's talk about its working. **Solar panels** produce direct electricity with the help of electrons that are moving from negative to positive direction. Most of the appliances that we use at home work on alternative current. This AC is created by the constant back and forth of the electrons from negative to positive. In AC electricity the voltage can be adjusted according to the use of the appliance. As **solar panels** only produce Direct current the solar inverter is used to convert the DC to AC.

An inverter produces square waves or a sine wave which can be used for running lights, televisions, lights, motors etc. However these inverters also produce harmonic distortion. Expensive inverters make use of lots of steps to produce a sine wave and thus are found in residential solar inverters. Basically inverters should be a large one so that it supplies enough power to all the necessary appliances.

An inverter is easy to buy but choosing the right solar inverter for your appliance is more important. Thus you must always consult a solar professional before buying one. We know that the energy derived

from sun is solar energy which is one of the cleanest sources of energy. Also it can be used to provide lighting to houses.

You can make use of the photovoltaic tiles that attract energy from Sun and convert it into a clean form of electricity which can be used to light, houses, industries and companies. The cells of photovoltaic consist of positive and negative silicon that is placed underneath a slice of glass. When the photons of the Sunlight hit the PV cells they knock the electrons present in the silicon. Now the negative charged electrons get attracted to the silicon but then are held inside a magnetic field. The wires attached on the silicon catch hold of these electrons and while connecting to the circuit, current is formed. This then gives space for direct electricity and for converting that into alternate electricity an inverter is used so that the house appliances can run. As mentioned before major of the house appliances work on alternate current hence an inverter is used to convert DC to AC.

### **Solar Inverter Advantages:**

After knowing in detail what a solar inverter is and how different useful it is to make appliances work at residential and industrial levels we must discuss about the many advantages of the device.

- Solar energy has always helped in reducing global warming and green house effect.
- Also use of solar energy helps in saving money many people have started using solar based devices
- A solar inverter helps in converting the Direct current into batteries or alternative current. This helps people who use limited amount of electricity.
- There is this synchronous solar inverter that helps small homeowners and power companies as they are large in size
- Then there is this multifunction solar inverter which is the best among all and works efficiently. It converts the DC power to AC very carefully which is perfect for commercial establishments

- This inverter is cost effective i.e. less expensive than generators
- Apart from solar inverters there are other devices too that make use of solar energy namely, solar cooker, heater.
- Solar inverters are the best way and they are better than the normal electric ones. Also their maintenance does not cost much money

## CONCLUSION

This paper presents the impact of solar irradiance and ambient temperature on PV inverter reliability considering geographical locations. In this paper reliability performance of PV inverter is evaluated at both component level and system level. Environmental factors like solar irradiance, ambient temperature, geographical locations are considered during the reliability evaluation. Real time mission profile data of one-year logs at India (Relatively hot climate) and Denmark (Relatively cold climate). Foster electro thermal model is implemented in PLECS for the calculation of junction temperature. Junction temperature variations of IGBT are analyzed using rainflow counting algorithm. Monte Carlo simulation is used to generate a population of 20000 and fitted with Weibull distribution. From the reliability function of Weibull distribution B10 lifetime is calculated at both India and Denmark. The results reveal that B10 lifetime calculated at India i.e. hot climate condition is less than the B10 lifetime calculated at Denmark i.e. cold climate condition. This paper concludes that B10 lifetime varies with respect to the geographical locations and environmental condition.

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# IMPACT OF SOLAR IRRADIANCE AND AMBIENT TEMPERATURE ON PV INVERTER RELIABILITY CONSIDERING GEOGRAPHICAL LOCATIONS

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