Tutorial on

“RELIABILITY ISSUE OF PHOTOVOLTAIC DEVICES AND SYSTEMS”
Part II - PV Devices and Systems

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Part II: Reliability of PV devices and systems

- PHOTOVOLTAIC POWER MANAGEMENT SYSTEM
- DC-AC CONVERTER ARCHITECTURES
- DC-DC CONVERTER TOPOLOGIES
- RELIABILITY THEORY
- RELIABILITY MODEL
- DC-DC CONVERTER RELIABILITY EVALUATION
PHOTOVOLTAIC SYSTEM

Power Management System

Load
PV POWER MANAGEMENT

- DC-DC converter topologies
- MPPT strategies

Power Management System

- DC-DC Converter
- MPPT Controller

- Grid
- Load

DC-AC

- Grid
- Load
PV systems performance depends on the grid interface.

**a. CENTRALIZED INVERTER - PV FIELD MPPT**
Only for uniform irradiation and stable temperature

**b. STRING INVERTER - STRING MPPT**
Energetic efficiency increase

**c. MULTI-STRING INVERTER - MPPT on group of strings**
A DC-DC converter for each string

**d. Distributed MPPT - Module MPPT**
Module energetic efficiency increase
Different types of inverters are used:

- Variable frequency inverter
- Self-commutating fixed frequency inverter
- Line-commutated fixed-frequency inverter

Inverters are classified on the basis of:

- presence/absence of the transformer
- location of the power decoupling capacitors
- number of stages
A DC-DC converter is used to manage the module output power to obtain voltages and currents suitable for network interface or for supplying the load.

**DC-DC CONVERTER TOPOLOGIES**

- **Boost**
  \[ V_{out} = \frac{V_{in}}{1 - D} \]

- **Buck**
  \[ V_{out} = D \times V_{in} \]

- **Buck-boost**
  \[ V_{out} = -\frac{D \times V_{in}}{1 - D} \]

- **BUK**
DC-DC CONVERTER

**BOOST** converts a DC voltage in a higher one

- higher input voltage
- lower currents
- lower losses
- higher efficiency
- lower MOSFET junction temperature
DC-DC CONVERTER

**BUCK** converts a DC voltage in a lower one

- Higher input voltage
- Higher currents
- Higher losses
- Lower efficiency
- Higher junction temperature

\[ V_{\text{out}} = D \times V_{\text{in}} \]
The best topology is a trade off between performance, number of devices and cost. Using a DC-DC converter for each module the energetic efficiency of the whole system increases.
The **MPPT controller** is able to maximize the panel output power during day working also in mismatch condition. Many different strategies are available for MPPT. Analog and digital techniques can be implemented.

**Control Techniques**

- Analog/Digital
- Voltage Mode/Peak Current Mode/Average Current Mode
- Fuzzy logic and neural networks
**Strategies**

- Hill climbing
- Perturb and Observe
- Incremental conductance
- Fractional Open Circuit Voltage
- Fractional Short Circuit Current
Hill climbing and P&O methods can fail under rapidly changing atmospheric conditions.

Other control technique by fuzzy logic and neural networks could improve the MPPT performance sensing variations of:

- irradiance level
- temperature
- PV module short circuit current
- PV module open circuit voltage

The performances are different for:

- reliability
- response time
- cost
- complexity
Between all the MPPT strategies much focus is placed on perturb and observe (P&O) methods.

To track the MPP is needed to modify the duty ratio of converter switching devices perturbing the PV array current and voltage.

- \( V \gg \) & \( P \gg \) - the duty perturbation have to be kept in the same direction
- \( V \gg \) & \( P \ll \) - the duty perturbation direction have to be reversed
RELIABILITY [R(t)] is the PROBABILITY than an item will perform a required function without failure under stated conditions for a stated period of time.

\[ R(t) \equiv \Pr \ T > t \]

R = reliability; Pr = probability
T = random variable = lifetime of the unit
\( t \) = mission time

R is a number in the range \( 0 \leq R \leq 1 \)

- \( R(0) = 1 \) At the beginning the probability of device proper functioning is high
- \( R(t) \) decreases with \( t \)
- \( R(t) \to 0 \) for high mission time the probability of device proper functioning is low
UNRELIABILITY [F(t)] is the PROBABILITY that an item fails before a period of time t

\[ F(t) \equiv \Pr \left[ T \leq t \right] \]

F = unreliability; Pr = probability
T = random variable = lifetime of the unit; t = mission time

F is a number in the range 0 ≤ F ≤ 1

- \( F(0) = 0 \) at the beginning, the probability of device not proper functioning is low
- \( F(t) \) increases with t
- \( F(t) \to 1 \) for high mission time, the probability of device not proper functioning is high
Components working condition can be characterized by two events:

- proper functioning
- not proper functioning

Proper and not proper functioning cover the whole space of elementary outcomes and they are two incompatible events, so:

\[ R(t) + F(t) = 1 \]

Then knowing \( R \), it is possible to calculate \( F \)

\[ F(t) = 1 - R(t) \]
UNRELIABILITY [F(t)] is defined as the probability distribution function of the random variable T

\[ F(t) = \int_{0}^{t} f(\tau) \, d\tau \]

F = unreliability = probability distribution function
T = random variable = device lifetime of the device
f = probability density function

So “f(t)\, dt” is the probability that the device lifetime T is in the range \((t, t + dt)\)

\[ f(t) \, dt = dF(t) \]
The **failure rate** or **hazard function** represents the FREQUENCY with which a component or a system fails.

Since

\[
\Pr\left\{ t \leq T \leq t + \Delta t \right\} \geq \frac{1}{3} F(t + \Delta t) - F(t)
\]

and

\[
\Pr\left\{ T > t \right\} \geq \frac{1}{3} \frac{F(t + \Delta t) - F(t)}{R(t)}
\]

The **failure rate** \( h(t) \) is defined as:

\[
h(t) \equiv \lim_{\Delta t \to 0} \frac{\Pr\left\{ t \leq T \leq t + \Delta t \mid T > t \right\}}{\Delta t} = \frac{1}{R(t)} \lim_{\Delta t \to 0} \frac{F(t + \Delta t) - F(t)}{\Delta t} = \frac{f(t)}{R(t)}
\]

\( f(t) \) and \( R(t) \) are positive functions, then:

\[
h(t) \geq 0
\]
BATHTUB CURVE

- Failure rate varies as a function of time.
- The failure rate is expressed in FIT (Failure In Time - failure per billion of hours).

Infant Mortality Failures: high mortality age and decreasing failure rate trend. Defective products are identified and discarded.

Random Failures: low mortality age and constant failure rate.

Wear out Failures: high mortality age and decreasing failure rate trend. Wear out of products.
Components reliability can be represented by different mathematical models:

- Exponential model
- Weibull model
- Lognormal model
Studies on electronic devices reliability demonstrate that a suitable model is the \textit{exponential} one.

This model is characterized by the constant failure rate $\lambda$

\[
R(t) = e^{-\lambda t}
\]

\[
F(t) = 1 - R(t) = 1 - e^{-\lambda t}
\]

The exponential distribution is memoryless, in fact the following expression demonstrates that the probability to have a device lifetime longer than $(t+t_1)$ depends only on $t_1$ and it doesn’t depend on $t$.

\[
\Pr \left[ R > t+t_1 \mid T > t \right] \leq \frac{\Pr \left[ R > t+t_1 \right]}{\Pr \left[ R > t \right]} = \frac{R(t+t_1)}{R(t)} = \frac{e^{-\lambda(t+t_1)}}{e^{-\lambda t}} = e^{-\lambda t_1}
\]

In case of electronic components this property means that they only break for accidental causes and not for wear.
The Mean Time To Failure (MTTF) is the expected or average time to failure.

\[
MTTF = \int_{0}^{\infty} R \cdot dt = \int_{0}^{\infty} e^{-\lambda t} \cdot dt = \frac{1}{\lambda}
\]

MTTF is a reliability index used for non-reparable devices or systems.
MTBF is a measure of how reliable a product is. It is usually given in units of hours. High MTBF values characterize high reliability products.

\[
MTBF = MTTF + MTTR
\]

where \( MTTR \) is the Mean Time to Repair

If a system is characterized by a very high \( MTTF \) or it is quickly reparable, the MTBF expression becomes:

\[
MTBF = MTTF
\]
A system comprises different components that interact for a proper functioning. For system reliability estimation it is necessary to consider the reliability of each component and how they are connected.

Components can be connected:

→ in series

→ in parallel

→ in series-parallel combination
A series structure system functions only when all of its parts are correctly functioning.

In a series structure the system proper functioning depends on the proper functioning of each part:

\[ S = A_1 \cap A_2 \cap A_3 \ldots \cap A_N \]

where:

- \( A_i \) = “proper functioning event” of the \( i \)th part of a system
- \( S \) = the system proper functioning event
The reliability of a series structure system is smaller than the reliability of each element:

\[ R_s = \Pr \bigg\{ \min \{ \Pr A_i \}_{i=1}^{N} \bigg\} \]
A parallel structure system fails only when everyone of its parts fails.

If $\overline{A_i}$ is the “not proper functioning event” of the i-th part of a system, the system function not correctly events is:

$$\overline{S} = \overline{A_1} \cap \overline{A_2} \cap \overline{A_3} \ldots \cap \overline{A_N}$$
Under the hypothesis of stochastical independence of the event $A_i$, the unreliability of a parallel system ($F_p$) is:

$$F_p = \Pr \left( \bigcup_{i=1}^{N} \bigcap_{i=1}^{N} \Pr A_i \bigcap_{i=1}^{N} F_i \right)$$

The reliability of a parallel structure system is:

$$R_p = \Pr \left( \bigcup_{i=1}^{N} 1 - \bigcap_{i=1}^{N} F_i \right)$$
Two types of analyses are usually available within a reliability prediction model

**PART COUNT ANALYSIS (PCA)**

Used at the design beginning phase when details on devices working conditions are not known. Information about the parts types and quantities, part quality levels and the environment where the equipment is presumed to work.

**PART STRESS ANALYSIS (PSA)**

Applicable only when the design is completed and a detailed part list devices/components is available. The failure rate is predicted considering temperature and electrical stress in the real working conditions.
Reliability Prediction Models are used to evaluate the failure rate of a system. Generally the following are used:

- MIL-HDBK-217F
- TELCORDIA SR-332
- 217 PLUS
- FIDES
RELIABILITY PREDICTION MODELS

- **MIL-HDBK-217F**
  - Telecommunication industry
  - Military applications
    (converters, inverters, aircraft, ecc.)

- **217PLUS**
  - Electronic parts
    (magnetic devices)

- **TELCORDIA SR-332**
  - Electrical/Electronic
  - Electromechanical components
    (avionics control)

- **FIDES**
The “Reliability Prediction of Electronic Equipment” was published by the United States Navy in 1965. It had became a de facto standard also if the United States Department of Defence stopped to update it in 1995 with the latest version MIL-HDBK-217F notice 2.

It includes models for a broad range of part types and supports five environments used in the telecom industry and in military applications.

**Disadvantage:** it doesn’t take into account some factors as burning data, lab testing data, field test data, designer experience or wear-out phenomena.

**PART COUNT ANALYSIS**
- PCA

**PART STRESS ANALYSIS**
- PSA

Both of these analyses are possible.
The equipment failure rate is:

\[ \lambda_{\text{equip}} = \sum_{i=1}^{N} N_i (\lambda_g \pi_Q)_i \]

where:  
- \( \lambda_{\text{equip}} \) is the total equipment failure rate  
- \( \lambda_g \) is the generic failure rate for the i-th generic part  
- \( \pi_Q \) is quality factor for the i-th generic part  
- \( N_i \) is the quantity of the i-th generic part  
- \( N \) is the number of different generic part categories in the equipment
The failure rate of every part of the system is evaluated with the following equation:

$$\lambda_p = \lambda_b \pi_T \pi_A \pi_Q \pi_E$$

where:
- $\lambda_p$ is the part failure rate
- $\lambda_b$ is the base failure rate for the device in standard condition
- $\pi_T$ is temperature factor
- $\pi_A$ is the application factor
- $\pi_Q$ is the quality factor
- $\pi_E$ is the environment factor

It is possible to calculate the SYSTEM failure rate summing all the components failure rates.
The “Reliability Information Analysis Center (RIAC) Handbook 217Plus model” was developed by the United States Department of Defence in 2006 as an official successor of the MIL-HDBK-217 methodology. The failure rate of every part of the system is evaluated with the following equation:

\[
\lambda_p = \lambda_o \pi_o + \lambda_e \pi_e + \lambda_c \pi_c + \lambda_i + \lambda_{sj} \pi_{sj}
\]

where:
- \(\lambda_p\) is the part predicted failure rate
- \(\lambda_o\) is the failure rate from operational stresses
- \(\pi_o\) is the product of failure rates multipliers for operational stresses
- \(\lambda_e\) is the failure from environmental stresses
- \(\pi_e\) is the product of failure rates multipliers for environmental stresses
- \(\lambda_c\) is the failure from power or temperature cycling stresses
- \(\pi_c\) is the product of failure rates multipliers for cycling stresses
- \(\lambda_i\) is the failure from induced stress such as ESD
- \(\lambda_{sj}\) is the failure from solder joint stresses
- \(\pi_{sj}\) is the product of failure rates multipliers for solder joint stresses

This model considers a different base failure rate for each generic class of failure mechanism.
The system failure rate is obtained by the following expression:

\[
\lambda_{\text{sys}} = \lambda_{\text{equipment}} \left( \prod P + \prod D + \prod M + \prod S + \prod I + \prod N + \prod W \right) + \lambda_{\text{software}}
\]

where:

- \( \lambda_{\text{sys}} \) is the predicted failure rate of the entire system
- \( \lambda_{\text{equipment}} \) is the failure rate from operational stresses
- \( \pi_P \) is the part process factor
- \( \pi_D \) is the design process factor
- \( \pi_M \) is the manufacturing process factor
- \( \pi_S \) is the system management process factor
- \( \pi_I \) is the induced process factor
- \( \pi_N \) is the no-defect process factor
- \( \pi_W \) is the wear out process factor
- \( \lambda_{\text{software}} \) is the software failure rate prediction
The “Reliability Prediction Procedure for Electronic Equipment SR-332“ was developed by AT&T Bell Labs in 1997. It modified the MIL-HDBK-217F Prediction Model to better represent the equipment of the telecommunication industry including burn-in, field and laboratory test data.

This Prediction Model assumes a serial model for electronic parts and addresses failure rates at the infant mortality stage and at the steady-state stage with three different methods.
Method I is similar to MIL-HDBK-217. It considers for each part the generic failure rate, the quality factor $\pi_Q$, electrical stress factor $\pi_S$ and temperature stress factor $\pi_T$.

Method II is obtained combining Method I predictions with data from laboratory tests performed in accordance with specific SR-332 criteria.

Method III is a statistical prediction of failure rate based on field tracking data collected in accordance with specific SR-332 criteria. The predicted failure rate is a weighted average of the generic steady-state failure rate and the field failure rate.
The reliability methodology “FIDES Guide 2004” has been developed by FIDES Group, a consortium of French companies as Thales, Airbus France, MBDA, GIAT Industries. This prediction methodology provides models for electrical, electronic and electromechanical components and it considers factors as electrical, mechanical and thermal overstresses.

FIDES is based on the physics of failures supported by the analysis of test data, field returns and existing modeling which makes it somewhat different from traditional prediction methods which are exclusively based on the statistical analysis of historical failure data collected in the field, in-house or from manufacturers.
Methodology steps

Component reliability prediction guide:
Calculation of component failure rates based on component characteristics and application related data (e.g. thermal and electrical stress)

Reliability process control and audit guide:
Evaluates the manufacturing quality of the component and effects of all process during the whole life cycle from the specification and design phase up to maintenance and support activities

\[ \lambda_p = \lambda_{\text{physical}} \prod_{\text{part-manufacturing}} \prod_{\text{process}} \]

where:
\( \lambda_{\text{physical}} \) is subdivided in various contributions. Usually there is a base failure rate \( \lambda_b \) multiplied with acceleration factors indicating the sensitivity to operational and environmental condition of use
\( \prod_{\text{part-manufacturing}} \) represents the component quality by taking into account the manufacturer quality assurance, the component quality assurance and even the experience that the user has with the specific manufacturer
\( \prod_{\text{process}} \) represents the quality and technical control of reliability relevant aspects during the product life cycle
PV System Reliability Evaluation
PV System Reliability Evaluation

FAILURE MODES OF

- PV Modules
- Lenses (PVC)
- DC-DC converter
- MPPT Controller
- Inverter
- Tracker system
- Energy storage devices
Development of a reliable PV module requires an understanding of potential failure mechanisms:

- Broken cells
- Corrosion
- Delamination and/or loss of elastomeric properties
- Encapsulant discoloration
- Solder bond failures
- Broken glass
- Hot Spots
- Ground faults
- Junction box and module connection failures
- Structural failures

We cannot wait for 25 or 30 years to see what failure mechanisms a module might suffer! Therefore we try to develop stress tests that accelerate the same failure mechanisms to estimate degradation rate and lifetime.
ACCELERATED TEST ON PV MODULE

- Thermal cycling
- Damp heat exposure & humidity freeze
- Mechanical load
- UV test
- Dry and wet insulating resistance
- Hail test
- Hot spots
To evaluate the reliability of a PV DC-DC converter it is necessary to calculate the reliability of its each component: MOSFETs, diodes, inductors, capacitors.
**INTRINSIC FAILURES**

Failure mechanisms due to chip or die, such as defects in the substrate, insulation films or metallization.

**EXTRINSIC FAILURES**

Unproper interconnection and packaging of chips may lead to device failure, for instance the stress at solder connections due to a mismatch of thermal properties of the different materials.

**ELECTRICAL STRESS FAILURES**

Excessive electrical stresses and electrostatic discharge may cause the device to fail.
The MOSFET failure rate is evaluated with the equation:

$$\lambda_p = \lambda_b \pi_T \pi_A \pi_Q \pi_E$$

The MOSFET Temperature factor $$\pi_T$$ is evaluated with the next expression and it depends on MOSFET junction temperature $$T_j$$.
The Application factor $\pi_A$ depends on the rated power of the MOSFET.
The environment considered is GB “Ground Benign so the Environment factor $\pi_E$ is 1.

Some environment value are:
- $G_F$=Ground Fixed
- $G_M$=Ground Mobile
- $N_S$=Naval, Sheltered
- $A_{IC}$=Airborne, Inhabited, Cargo
- $S_F$=Space, Flight
- $M_F$=Missile, Launch

The Qualification factor depends on devices type. In PV converters design commercial “plastic” components are used, so the $\pi_Q = 8$
The base failure rate $\lambda_b$ depends on the diode type and application. In PV systems Schottky diodes are used so $\lambda_b$ value is 0.003.

The Temperature factor depends on the specific application considered. In our case diodes are used in switching converters, so we have to use the equation *
The Electrical Stress factor depends on the voltage stress ratio:

\[ \lambda_p = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E \]

\[ V_S = \frac{V_{dc} + V_{ac} - \text{peak}}{V_{rated}} \]

The Contact Construction factor depends on the contacts type. For metallurgically bonded contacts \( \pi_c \) value is 1.

\( \pi_Q \) and \( \pi_E \) are the same as MOSFET ones.
The Capacitor failure rate is evaluated with the equation:

\[ \lambda_p = \lambda_b \pi_T \pi_C \pi_V \pi_{SR} \pi_Q \pi_E \]

\( \lambda_b \) depends on the type of capacitor:
- 0.00051 -> for metalized plastic cap
- 0.00012 -> for aluminum cap

\( \pi_C \) is the quality factor.

\( \pi_V \) is the voltage stress factor.

\( \pi_{SR} \) is the series resistance factor.

\( \pi_T \) is the environment factor.
Magnetic devices are more reliable than other components. Main inductor failure mode are:

- Fail of copper winding insulation
- Short between turns
- High current generation
- Power dissipation and hot spots increase

\[ \lambda_p = \lambda_b \pi_T \pi_Q \pi_E \]
\[ \lambda_p = \lambda_b \pi_T \pi_Q \pi_E \]

Hot Spot temperature can be estimated as follows:

\[ T_{HS} = T_A + 1.1 (\Delta T) \]

where:
- \( T_{HS} \) = Hot Spot Temperature (°C)
- \( T_A \) = Inductive Device Ambient Operating Temperature (°C)
- \( \Delta T \) = Average Temperature Rise Above Ambient (°C)

\( \Delta T \) can either be determined by the appropriate “Temperature Rise” Test Method paragraph in the device base specification (e.g., paragraph 4.8.12 for MIL-T-27E), or by approximation using one of the procedures described below.
MTBFs discussed in the next must be considered only as reference values for comparison among the different DC-DC converters topologies designs using MATLAB©.

They are ONLY QUALITATIVE evaluations (no quantitative).
In the next, a study results on converters reliability trends are presented. The influence of temperature and input voltages on MTBF is analyzed.
Since a film capacitor has a lower failure rate compared with an electrolytic one, MOSFET becomes the largest failure rate component for converter design. Higher input voltage $\rightarrow$ lower currents $\rightarrow$ lower losses $\rightarrow$ lower FET junction temperature $\rightarrow$ lower FET stress $\rightarrow$ higher converter reliability.

MTBF and the reliability are strongly dependent on ambient temperature. The same converter has different MTBF values if it works at different temperatures.
In the next results of a study on converters reliability trends are presented. The influence of temperature and input voltages on MTBF is underlined.
Since a film capacitor has a lower failure rate compared with an electrolytic one, MOSFET becomes the largest failure rate component for converter design. Higher input voltage->higher currents-> higher losses-> higher junction temperature -> higher FET stress -> lower converter reliability.

MTBF and the reliability are strongly dependent on ambient temperature. The same converter has different MTBF values if it works at different temperatures.
**Case study:** MTBF calculation of a PV module converter

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>PART NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOS</td>
<td>Fairchild FDP3682</td>
</tr>
<tr>
<td>Diode</td>
<td>On Semiconductor MBRP3010NTU</td>
</tr>
<tr>
<td>Inductor</td>
<td>Coilcraft PCV-2-184-10</td>
</tr>
<tr>
<td>Input Capacitor</td>
<td>Panasonic EEUFM1H121L</td>
</tr>
<tr>
<td>Output Capacitor</td>
<td>Panasonic EEUFM1H221</td>
</tr>
</tbody>
</table>

After the device choice it is possible to calculate the MTBF of the converter:

\[
MTBF_{boost} = \frac{1}{\lambda_{MOS} + \lambda_{Diode} + \lambda_{Inductor} + \lambda_{InCap} + \lambda_{OutCap}}
\]
\[ \lambda_{MOS} = \lambda_b \pi_T \pi_A \pi_Q \pi_E \]

\( \lambda_b = 0.012 \)
\( \pi_T = 8.6959 \) for \( T_j = 175^\circ C \)
\( \pi_A = 2 \)
\( \pi_Q = 8 \) for “Plastic” components
\( \pi_E = 1 \) for Ground Benign

\[ \lambda_{MOS} = 0.012 \times 8.6959 \times 2 \times 8 \times 1 = 1.6696 \text{ Failures/}10^6 \text{ Hours} \]
\[ \lambda_{Diode} = \lambda_b \pi_T \pi_S \pi_C \pi_Q \pi_E \]

- \( \lambda_b = 0.003 \) for Schottky diodes
- \( \pi_T = 21.4378 \) for \( T_j = 150^\circ C \)
- \( \pi_C = 1 \) for “Metallurgically bonded contacts”
- \( \pi_Q = 8 \) for “Plastic” components
- \( \pi_E = 1 \) for Ground Benign

\[ \pi_S = 0.1079 \text{ for } Vs = \frac{\text{Voltage Applied}}{\text{Voltage Rated}} = \frac{40V}{100V} = 0.4 \rightarrow \pi_s = 0.4^{2.43} = 0.1079 \]

\[ \lambda_{Diode} = 0.003 \times 2.4378 \times 1 \times 8 \times 1 \times 0.1079 = 0.0555 \text{ Failures/10}^6 \text{ Hours} \]
**DC-DC RELIABILITY QUANTITATIVE EVALUATION**

**MIL-HDBK-217F: CAPACITOR**

\[
\lambda_{\text{Cap}} = \lambda_b \pi_T \pi_C \pi_V \pi_{SR} \pi_Q \pi_E
\]

- \( \lambda_b = 0.00012 \) for Aluminium Electrolytic Capacitor
- \( \pi_T = 1 \) for \( T=25^\circ C \)
- \( \pi_{Cin} = 3 \) for \( C_{in}^* = 120\mu F \)
- \( \pi_{Cout} = 3.7954 \) for \( C_{out}^* = 330\mu F \)
- \( \pi_v = 1 \)
- \( \pi_{SR} = 1 \)
- \( \pi_Q = 10 \) for Commercial device
- \( \pi_E = 1 \) for Ground Benign

\[
\lambda_{\text{InCap}} = 0.00012 \times 1 \times 3 \times 1 \times 1 \times 10 \times 1 = 0.0036 \text{ Failures/10}^6 \text{ Hours}
\]

\[
\lambda_{\text{OutCap}} = 0.00012 \times 1 \times 3.7954 \times 1 \times 1 \times 10 \times 1 = 0.0046 \text{ Failures/10}^6 \text{ Hours}
\]

* The capacitor failure rate is calculated considering the equivalent capacitance of capacitor systems.
**Inductor Reliability Evaluation**

**MIL-HDBK-217F: INDUCTOR**

\[ \lambda_{\text{Inductor}} = \lambda_b \pi_T \pi_Q \pi_E \]

- \( \lambda_b = 0.0003 \)
- \( \pi_Q = 3 \) for “lower”
- \( \pi_E = 1 \) for Ground Benign

\( \pi_T = 0.75 \) obtained by

\[ \pi_T = \exp\left(\frac{-0.11}{8.617 \times 10^{-5}} \left( \frac{1}{T_{HS} + 273} - \frac{1}{298} \right)\right) \]

where \( T_{HS} = T_A + 1.1\Delta t = 88.8 \)

\( T_A = 25^\circ C \)

\[ \lambda_{\text{Inductor}} = 0.0003 \times 0.75 \times 3 \times 1 = 0.000675 \text{ Failures/10}^6 \text{ Hours} \]
In conclusion the MTBF value of the PV module boost considered is:

\[
MTBF_{\text{boost}} = \frac{1}{\lambda_{\text{MOS}} + \lambda_{\text{Diode}} + \lambda_{\text{Inductor}} + \lambda_{\text{InCap}} + \lambda_{\text{OutCap}}} = 0.5767 \times 10^6 \text{ Hours}
\]
The investment in a new inverter is required 3-4 times over the life of a PV system.

The inverter reliability can be evaluated calculating the failure rate of its each component by MIL-HDBK-217F.
Thanks for your attention