FMECA Analysis for Photovoltaic Inverters

Author: Eng. Abdulla Al Abbasi Sr. Electrical Engineer – EWA

Presented by: Eng. Khalid Al Mujadami Electrical Engineer – EWA

Contents

Introduction

In a grid-connected PV plant, inverter represents an expensive and complex key component, and PV inverter (PVI) is the considered most mature compared to inverters of other renewable sources

- (Maish et al.1997) carried out an investigation on 126 system that provided 190 failure events, and results shows that PVI dominates the outage causes of PV plants by 76%.
- (Golnas, A. 2003) carried out a survey, which stated that PVIs are the leading cause of PV systems failures.
- (Dhere, N.G. 2005) stated that 65 % of outages of 213 events for 103 PV systems were assigned to PVI.
- A study conducted by (FOES. 2003) has depicted that the mean time to first failure of the PVI is five years.
- According to (Navigant Consulting. 2006), the Mean Time Between Failures (MTBF) is reported to be between 5- 10 years.

Issue

PVIs fauilers are due to:-

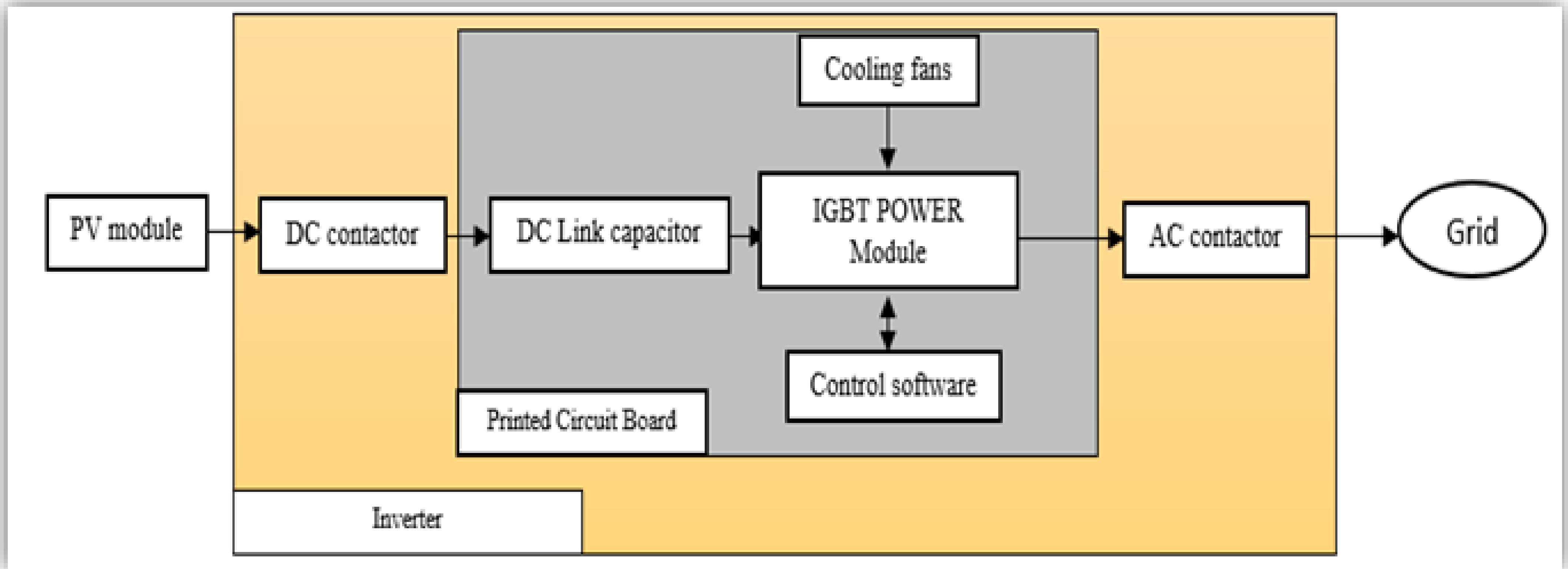
- Their operation in inhospitable environments
- Extreme temperatures and frequent thermal cycling
- load stress.

(R Brock et al. 2012) stated that “the reasons behind the high failure rates can be traced into manufacturing quality, inadequate design, and defective components”.

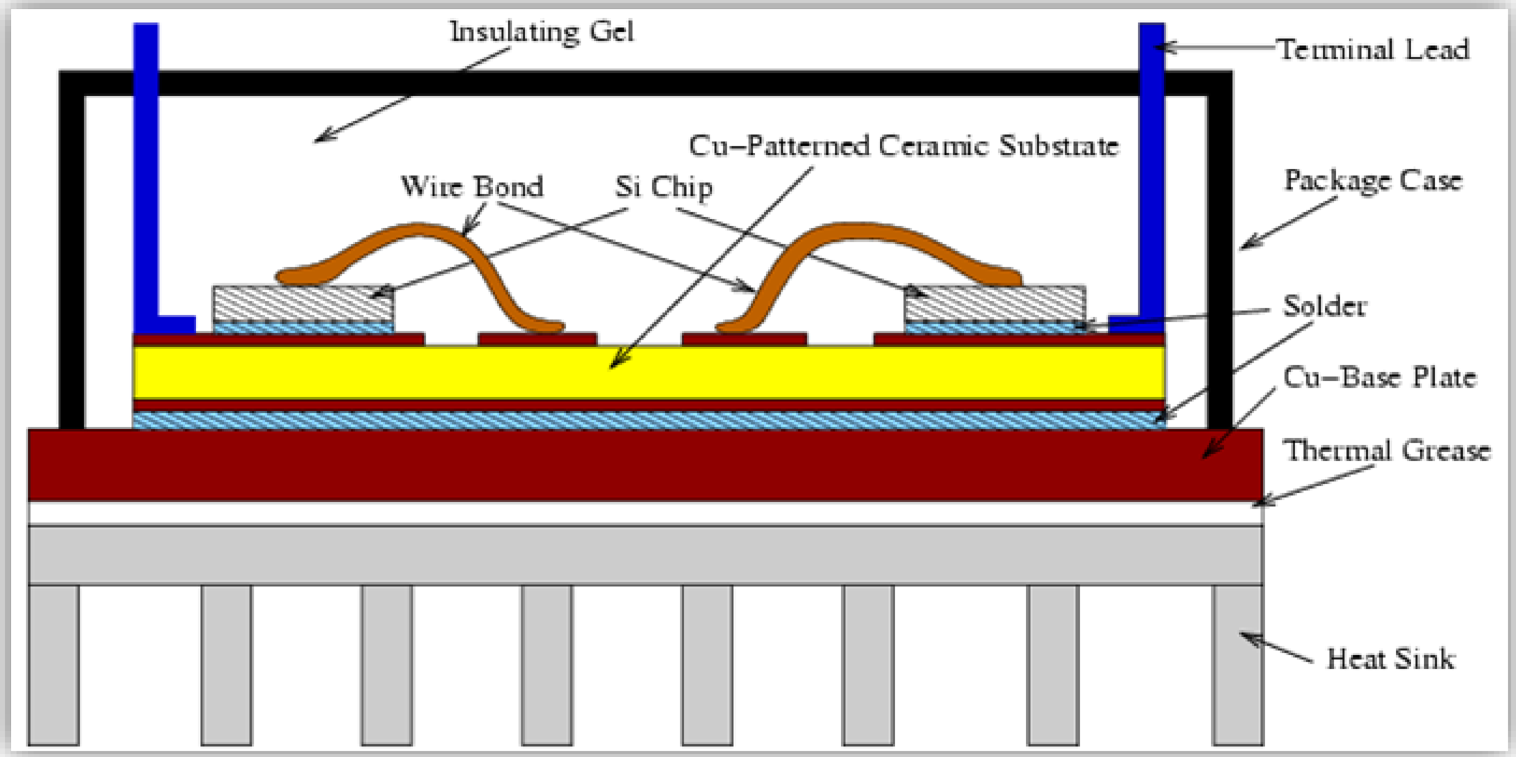
Aim

This work aims to identify all the possible PVI failure modes of greatest concern, list the causes of these failure modes, consider the consequences of each failure modes, and finally determine the recommended actions to limit these failures.

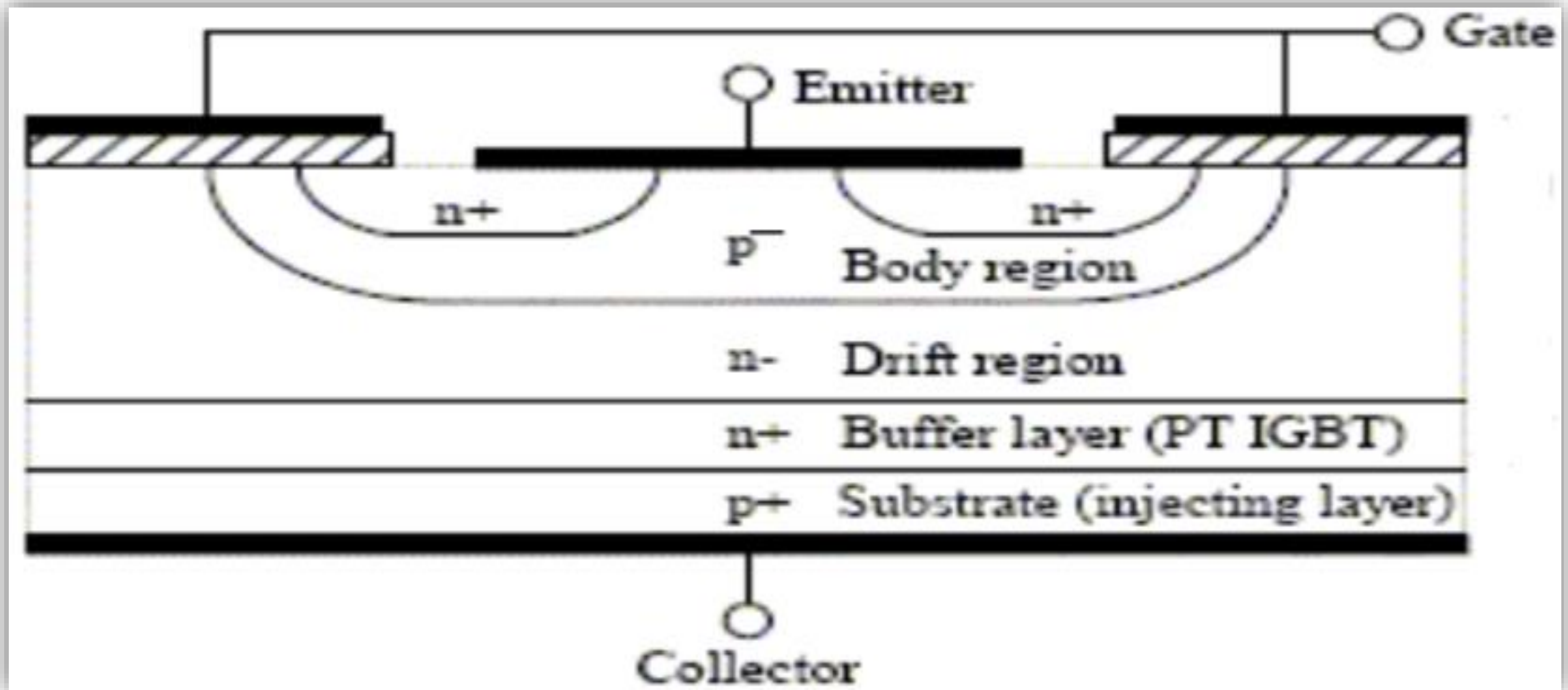
Components failure causes



IGBT Power module



IGBT


Gate
Emitter
n+
n+
p⁻
Body region
n-
Drift region
n+
Buffer layer (PT IGBT)
p+
Substrate (injecting layer)
Collector

IGBT failure causes

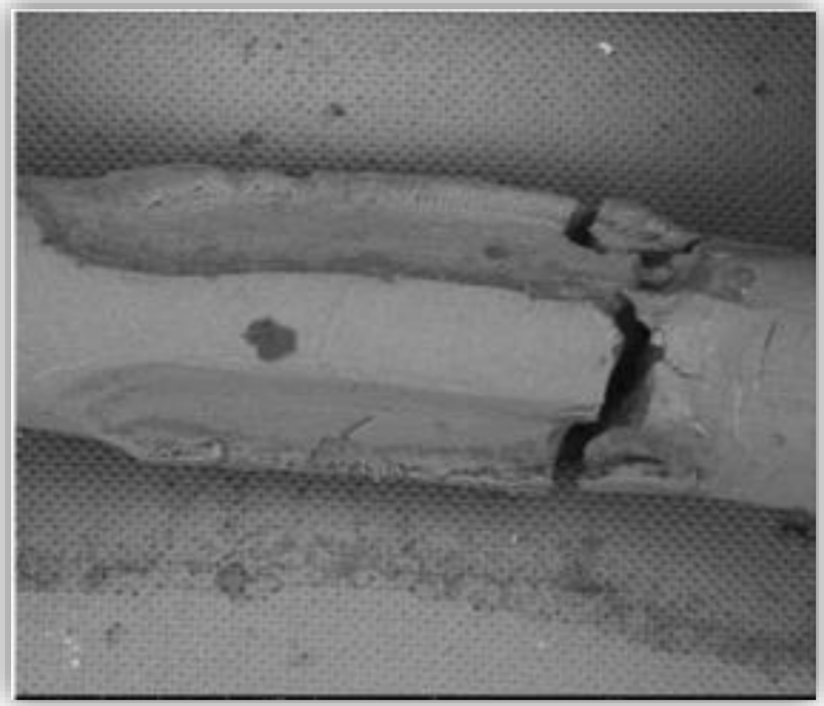
Thermal runway

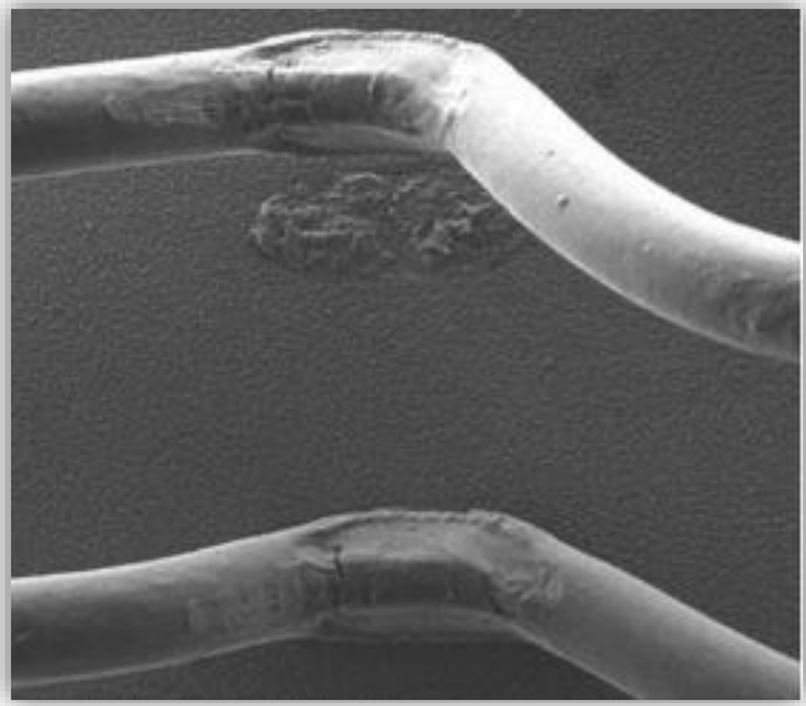
Ceramic substrate to base plate solder fatigue,

Emitter wire bond fatigue

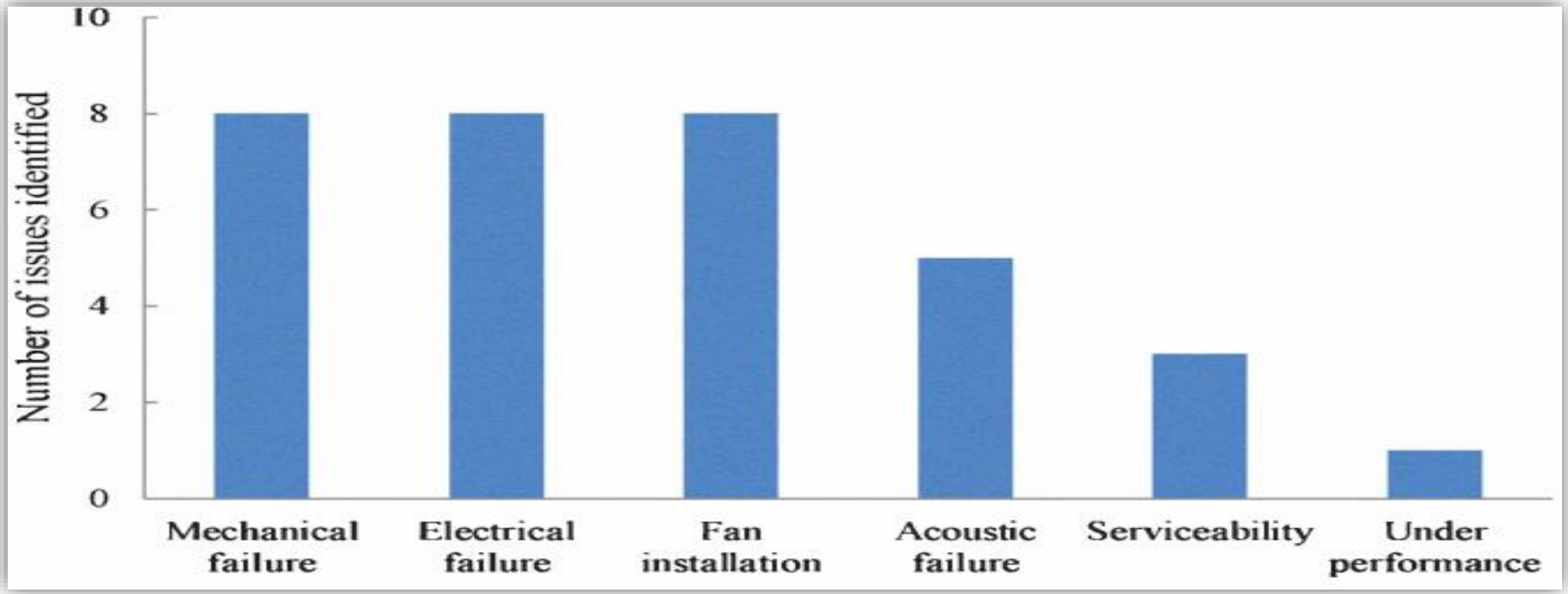
Partial discharge in insulating gel

Wire bond fatigue

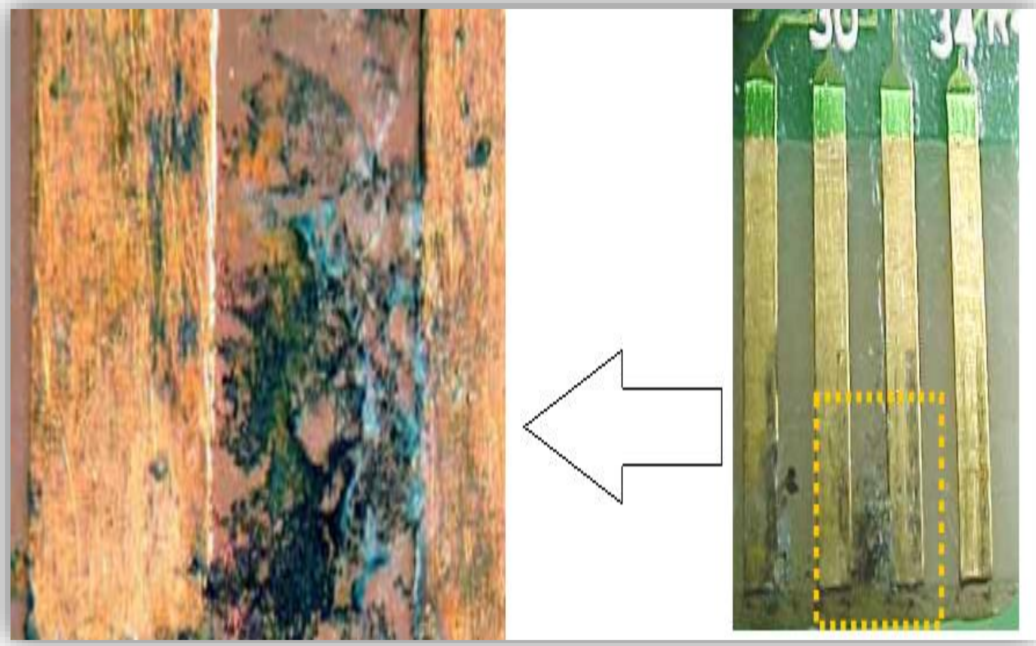




Cooling fans failure causes



PCB failures



Failure Mode and Effects Analysis (FMEA)

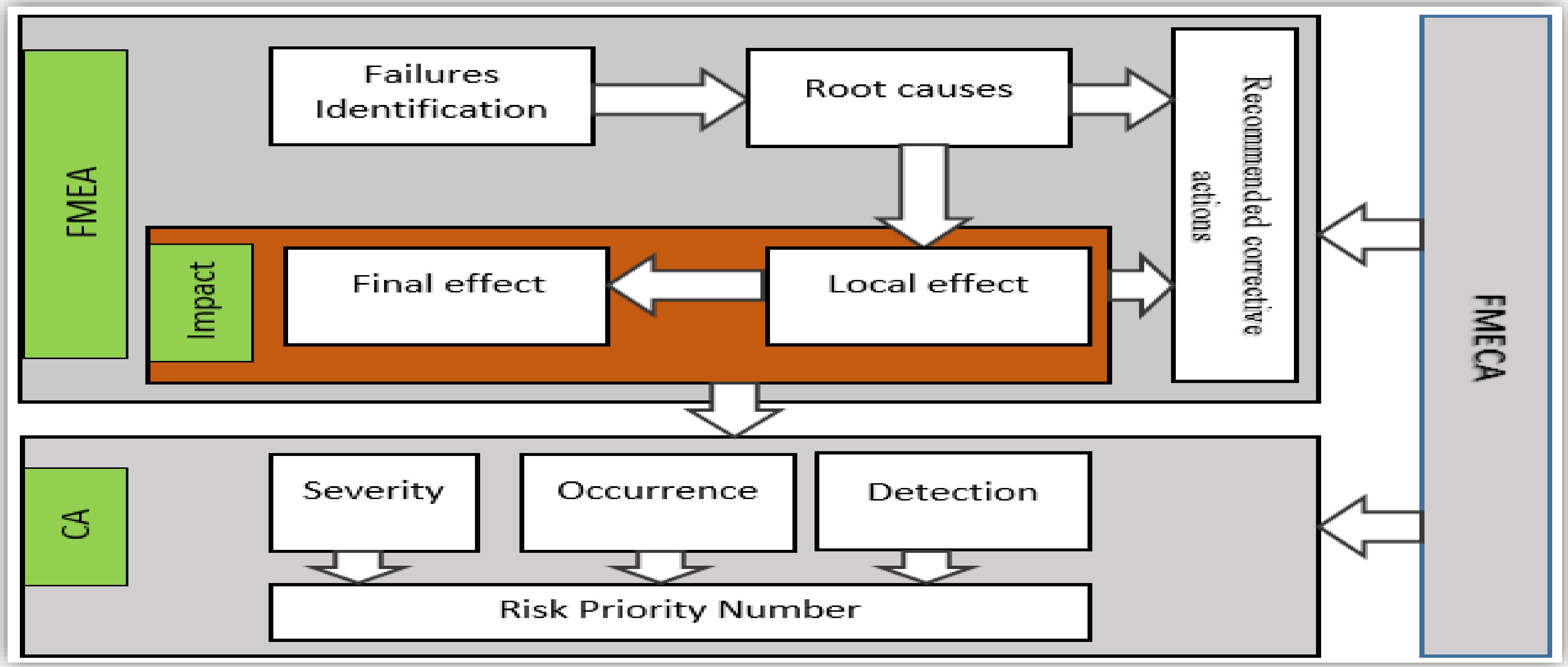
FMECA is composed of two separate analyses, the Failure Mode and Effects Analysis (FMEA) and the Criticality Analysis (CA).

IEC-60182 defines FMEA as a systematic procedure for the analysis of a system which target is the identification of the potential failure modes, their causes and effects on system performance.

CA is necessary to plan and focus the efforts according to set of priorities in order to reduce the risk of failures and give to failures with the highest risk the highest priority.

Risk Priority Number (RPN) to each failure mode: $RPN=S \times O \times D$, Where S (Severity) represents the severity on the base of the assessment of the worst potential consequences resulting from an item failure, O (Occurrence) denotes the probability of failure mode occurrence and D (Detection) represents the chance to identify and eliminate the failure before the system or customer is affected.

Schematic Diagram of FMECA



IEC-60182 evaluation criteria for occurrence, severity and detection

Occurrence (O)	Severity (S)	Detection (D)	Ranking
Failure is unlikely	No discernible effect	Almost certain	1
Low: **Relatively few failures**	Very minor	Very high	2
	Minor	High	3
Moderate: **Occasional failures**	Very low	Moderately high	4
	Low	Moderate	5
	Moderate	Low	6
High: **Repeated Failures**	High	Very low	7
	Very high	Remote	8
Very high: **Failure is almost unavoidable**	Hazardous with warning	Very remote	9
	Hazardous without warning	Absolutely uncertain	10

PVI FMECA analysis

Considering CA, quantitative CA approach is followed up in this paper based on a survey carried out by SunEdison Company that operates more than 600 PV systems in four continents with 1500 in-service inverters from 16 vendors and more than 2.2 million PV modules from 35 manufacturers

Frequency of tickets and associated energy loss for each PVI failure mode

Specific failure Area	Percentage of tickets	Percentage of KWh lost
Control software	28%	15%
PCB board	13%	22%
AC contactors	12%	13%
DC contactor	4%	1%
Fans	6%	5%
IGBT modules	6%	5%
Capacitors	3%	7%

Component failure	S	O	D	RPN	outage mode	Possible outage cause	Local effect	Final effect	Compensating provision against failure
IGBT Power Module	3	3	7	63	Thermal runway	High operating Temperature	Cracks formation and delamination formation in solder layers.	Damage of IGBT power module and power interruption	Lowering thermal resistance between IGBT and heat sink,
DC link Capacitor	3	2	5	30	Capacitor open circuit.	Capacitor open circuit.	Moisture absorption.	-Replacing DC link capacitor & PVI power interruption	A proper overload protection scheme.
AC/DC contactors	6	5	5	150	Fails to open or open late.	Bad system configuration	During ON-state: high power losses & degradation of contactor.	Overheating, arcs, and fire	Periodic visual inspection
Cooling fans	4	3	4	48	Mechanical mode	Cage damage.	Reversed Air flow.	Excessive heat.	A careful design.
PCB	7	4	6	168	Delaminated layers	Overheating & moisture between wafer layers	Board integrity is reduced	Inverter Replacement & interruption of power	Proper board design
Control software	6	7	3	126	Poor PVI	Improper setting parameters.	Unreliable MPPT scheme	Inefficient operation of inverter	Improving inverter data acquisition level.

Conclusion

Reliability of inverters is still inadequate, but improvements are being in progress.

A 5-year warranty has currently become a norm in the industry, whereas 2-year warranties were most common just a few years ago. Unfortunately, these longer warranties are still controversial.

The main objective of this work is to provide the manufacturers and decision-makers in utilities a guide, through FMEA, for the reason and impact of feasible hazards that could interrupt PVI operation and result in losses of power in addition to the prioritizing of these hazards, through CA, for a better maintenance strategies.

THANK YOU

For further questions:

Eng. Abdulla Al Abbasi

Sr. Electrical Engineer –EWA

Email: Abdullai.Ahmed@ewa.bh

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