

Failure Modes and Effect Analysis (FMEA) of Module-Level Power Electronics (MLPE)

Introduction

Module-level power electronics (MLPE) devices such as micro-inverters and DC power optimizers offer advantages over traditional string or central inverters, including lower power handling, module-level maximum-power-point tracking and better system monitoring. However, MLPE devices operate close to photovoltaic (PV) modules and are exposed to wide temperature swings and environmental stresses. Because MLPE technology is relatively young, industry lacked comprehensive reliability assessment methods. Researchers at Arizona State University and Sandia National Laboratories developed a failure modes and effect analysis (FMEA) to identify the weak links in MLPE units and guide accelerated test development. The FMEA formed the basis of the 2015 IEEE Photovoltaic Specialists Conference paper “**Failure modes and effect analysis of module level power electronics**”.

FMEA methodology

FMEA systematically identifies failure modes and evaluates their impact on system reliability. For MLPE products the team used **severity (S)** and **occurrence (O)** factors to rank each failure mode because detectability was less relevant [447316737134393†L2740-L2755] . Occurrence factors came from a survey of major MLPE manufacturers, while severity factors were determined by analyzing MLPE subsystems, their components, and functions, and by examining how component failures affect overall reliability [447316737134393†L2740-L2755] . The risk priority number (RPN) was calculated by multiplying severity and occurrence, and the failure modes with highest RPN values were considered most critical.

Top at-risk components in MLPE

The FMEA identified six MLPE components with the highest combined severity–occurrence rankings [447316737134393†L2754-L2767] :

Rank	Component & failure mechanism	Explanation
1	DC and AC interconnects – intermittent contact due to improper tightening/loose connections [447316737134393†L2754-L2767]	Loose or poorly tightened connectors can lead to intermittent electrical contact, causing arcing, high resistance and potential thermal damage.
2	Electrolytic capacitors – open/short-circuit failures of DC-link capacitors due to wear-out [447316737134393†L2754-	Electrolytic capacitors degrade over time because of electrolyte evaporation and elevated temperatures; open- or short-circuit failure of the

Rank	Component & failure mechanism	Explanation
	L2767】	DC bus capacitor was identified as a serious problem 【447316737134393†L2742-L2753】 .
3	Solder joints – fatigue from temperature cycling 【447316737134393†L2754-L2767】	Repeated thermal cycling causes solder joints to crack or fracture, leading to intermittent or permanent connection failures.
4	Enclosure – moisture ingress and corrosion 【447316737134393†L2754-L2767】	Ingress of moisture through the MLPE enclosure can corrode circuit boards and connections, leading to shorts or open circuits.
5	MOSFET/diode devices – open/short-circuit failures due to semiconductor degradation 【447316737134393†L2754-L2767】	Power semiconductor devices may fail due to overvoltage, overcurrent or thermal stresses, leading to open-circuit or short-circuit conditions.
6	Surge suppression devices – failure due to surge 【447316737134393†L2754-L2767】	Devices such as MOVs or TVS diodes protect against voltage surges; repeated or severe surge events can degrade these components until they fail.

These results indicate that **connectors, capacitors and solder joints** are among the weakest elements in MLPE units. The FMEA also highlighted the importance of environmental protection and surge suppression. Based on the FMEA rankings, researchers recommended designing accelerated tests focused on these failure mechanisms and exploring alternative components, such as metallized thin-film capacitors, which may offer better reliability
【447316737134393†L2754-L2779】 .

Conclusion

The FMEA of MLPE units identified critical components whose failures most strongly impact the reliability of micro-inverters and DC optimizers. By ranking failure modes using severity and occurrence factors, the study pinpointed **loose interconnects, electrolytic capacitor wear-out, solder-joint fatigue, moisture ingress, power semiconductor failures and surge suppression device degradation** as the top issues
【447316737134393†L2754-L2767】 . These insights provide the basis for developing accelerated stress tests and improving MLPE designs to enhance reliability and service life.