U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

A Multi-Perspective Approach to PV Module * Reliability and Degradation *

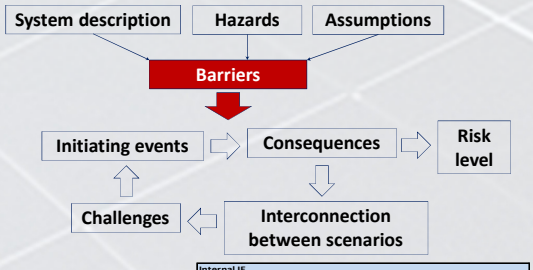
Alessandra Colli*, John P. Looney C

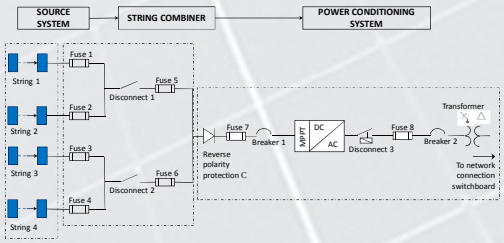
*Tel: +1-631-344-2666, E-mail: acolli@bnl.govC

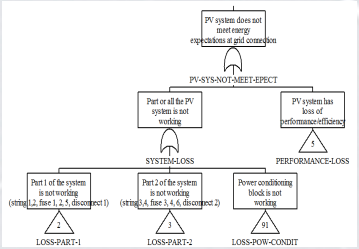
PV modules use different energy conversion materials that vary in composition, properties and structure. The module macro-structure is a complex system where mechanical, electro-chemical, electrical and structural interactions are taking place at micro- and nano-scale level. These effects can lead the PV technology to undergo unexpected changes in behavior not predictable by material studies under standard test conditions. Based on the methodological discussions in the area of system engineering and risk analysis, complex systems are approached by using a practical philosophy called holism, where the system is a working concert of all its part and the environment where it is located. Using such an approach to study degradation and reliability of PV modules means understanding that the synergy of different accelerating factors has a more powerful impact than the sum of the single factors if considered alone. Reliability and degradation studies have the main purpose to outline the acceptable level of defects in PV modules so to define marginal costs for O&M and reduce the lifelong costs of PV plants. The analysis should differentiate diverse failures (intrinsic, extrinsic) and different stages of the module lifetime: early life (pay-back), useful life, and wear-out. To achieve this purpose it is important to adopt proven as well as innovative reliability modeling approaches, and to understand those mechanisms of failure still not clear concerning behavior, cause, activating energy and accelerating factors.

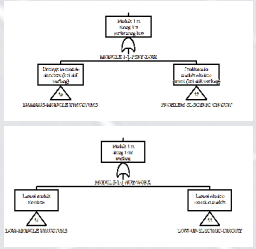
The use of probabilistic risk analysis (PRA) for photovoltaic systems

PRA groups various tasks: design modeling, system analysis, identification of basic events and initiating events, event sequence analysis conducted on the basis of fault trees (FTs) and event trees (ETs), and finally the evaluation of the consequences and the quantification of risk. The main PRA analysis flow is shown at the right. To simulate the correct interactions leading to the fault propagation, the appropriate knowledge of failure modes, causes and effects for each system component is achieved through FMEA. Below, the considered PV system scheme, some example fault trees, and the initiating events (IEs). FTs support failure propagation analysis.





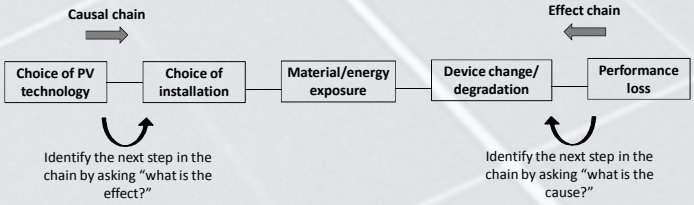




Internal IE	
Loss of grid electricity (AC)	IE_INT_LOSSGRD
Grid electricity transient fluctuations	IE_INT_GRDFLCT
Overvoltage	IE_INT_OVERVLT
Loss of electrical connection of module strings (DC)	IE_INT_LOSSDC
Structural damage to rack	IE_INT_DMGRACK
Leakage (of transformer coolant)	IE_INT_LEAKOIL
Internal fire	IE_INT_FIRE
External IE	
Flood	IE_EXT_FLOOD
Earthquake	IE_EXT_ERTQUAKE
Extreme wind load	IE_EXT_EXRMWIND
Extreme snow load	IE_EXT_EXRMSNOW
Sand storm	IE_EXT_SNDSTRM
Animals	IE_EXT_ANIMAL
Lightning	IE_EXT_LIGHTN
Sabotage (terrorism)	IE_EXT_SABOTG
Adversary action (vandalism)	IE_EXT_ADVACT
Airplane crash	IE_EXT_AIRCRSH
Explosion (considered for transformer, inverter)	IE_EXT_EXPLSN
External fire	IE_EXT_FIRE
Mechanical shock	IE_EXT_MECHSHCK
High humidity	IE_EXT_HUMID
High chemical air contamination	IE_EXT_CHEM
Soil/dust/pollen	IE_EXT_DUST
Shadows on modules	IE_EXT_SHADOW

Investigating reliability from the system to the cell material

- Integration of bottom-up and top-down approach.
- A causal/effect chain (right), with the support of appropriate indicators, can guide the initial steps of the investigation.
- Need of reliability models capable to link the effects at system level with construction defects, impurities and atomic/molecular interactions into the PV device material.
- Models and investigations based on holistic system considerations.



Understanding failure mechanisms

The packaging structure of PV modules and their working environment (geographical location, meteorological conditions and system integration) create a multivariate operational framework. Once degradation effects and failures are identified in modules and cells, the next step leads to decode their physics and mechanisms. Innovative techniques associated with tests to simulate more realistically the degradation and the environmental conditions are introduced to study cell and module reliability, along with ex-situ, in-situ and in-operando analysis using enhanced material investigation techniques (such as those soon available at BNL's NSLS II). Reliability and degradation data (failure rates, frequencies, probability distributions) are needed, along with the knowledge of the associated causes leading to faults and degradation.
Understanding failure mechanisms is not only based on material analysis under single or multivariate conditions, but also requires the introduction of new visions, models and investigations approaches, as so far adopted to investigate complex systems in the nuclear, space, aviation, chemical process and semiconductor manufacturing industry.

Outdoor operation
NSERC grid-connected operation, and degradation of different modules, prototypes and small sample structures in the Northeast environment.

PV devices laboratory to characterize cells/samples and detect small defect areas (QE, IV measurements, LBIC)

NSERC laboratory *

Indoor accelerated tests and module characterization *

Ex-situ, in-situ, and in-operando material investigations involving CFN and NSLS

Analysis of material composition, defects, electro-chemical, electrical and structural interactions to understand degradation mechanisms.

BNL is managed for the U.S. Department of Energy by Brookhaven Science Associates, a company founded by Stony Brook University and Battelle *