Innovation Week on “PV Systems Engineering and the other Renewable Energy Systems”.

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Outline

- Introduction to ageing factors and ageing effects
- Ageing effects in sc-Si PV modules operating in field conditions for 13, 18, 22 years
- Identification of degradation effects:
  - Visual Inspection/digital image
  - IR thermography
- Performance degradation
  - I-V curves, electrical characteristics, Power output
- Conclusions
PV cell and module Ageing

Appears due to:
- Natural weathering
- Induced ageing by external agents

Stages:
- Initial degradation
- First signs of ageing
- Gradual/ Accelerated ageing (cause & effect)
  - Arithmetic or geometric progression

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Ageing Factors

External factors:
- Vegetation / nearby objects
- Dirt or Dust
- Bird droppings

Weather conditions
- High ambient Temperatures
- High solar irradiation
- Lower UV wavelengths
- Rain/ wind

Partial Shading

Discoloration

Humidity

Ingress

Short / Long Term Degradation

Long Term Optical & Physical degradation

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Ageing Factors

Internal factors
- Crystal defects or impurities
- Manufacturing micro-cracks, micro-defects

Combination of factors (cause & effect)
- UV stabilizer degradation => EVA yellowing => formation of acetic acid => EVA browning

Defects lead to mismatch effects => defected cells operate in reverse bias conditions => power dissipation => high temperatures => hot spot formation
Ageing effects

- Discoloration of the EVA encapsulant
- Degradation of the AR coating
- Degradation of the cell-encapsulant interface
- High conductivity paths (shunts)
- Humidity ingress
- Hot spots/ hot areas
- Cracks, tears in the back sealing
- Bubbles
- Corrosion in bus bars and contacts
Identification of cell and module degradation

- **Visual Inspection**
  - visual observation/ digital image
- **IR thermography**
  - Identification of hot spots and hot cells
- **I-V curve analysis & electrical characteristics, Isc, Voc, Pm**

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Visual Inspection

- **EVA Discoloration**
  - Location => central region of the cell
  - Shape => circular, square, patches, other shapes
  - Severity of Browning
    - Different degrees, from golden brown to dark brown
    - Differs between cells of the same module, and between modules
    - Acceleration of browning in surface domain and degree

- **Degradation in the cell-encapsulant interface**
  - Expansion

- **Corrosion of contacts and busbars**

- **Bubbles**

- **Tears in the back sealing surface**
First signs of natural ageing in 13 year old PV module
Degradation of the AR coating
Natural degradation in 22 year old PV module
EVA Discoloration
Induced degradation of PV module
EVA Discoloration

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Degradation of the cell-encapsulant interface
Degradation of the AR coating
Corrosion of busbars and contacts

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Damage in the back sealing
Bubble formation
IR Thermography

- Temperature distribution on cells and modules
- Front and back of the module
- Hot spots/hot areas
  - Junction box
  - Discolored cell areas
  - Bus bars
Increased temperature at junction box

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Hot spots/ areas in PV modules

Induced ageing

Natural ageing
Hot spots/ hot areas/ hot zones at busbars
Performance Degradation

- Electrical characteristics. Isc, Voc, Pm, and FF converted to STC for comparison with the nominal values.
- I-V curve analysis. I-V obtained in field conditions
- Performance comparison for PV modules with different type and degree of ageing.
I-V curve analysis

Normalized I-V curves of modules with different ageing effects (induced and natural)


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A measure of PV module degradation

Indicative Results:

Relative change in Pm and FF:

<table>
<thead>
<tr>
<th>ageing</th>
<th>Relative change in Pm %</th>
<th>Relative change in FF %</th>
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</thead>
<tbody>
<tr>
<td>natural 22 years</td>
<td>18-24</td>
<td>12</td>
</tr>
<tr>
<td>induced 18 years</td>
<td>24-42</td>
<td>17-38</td>
</tr>
</tbody>
</table>
PV ageing is a complex process being the result of independent and interrelated factors.

Different ageing effects are observed between cells and modules, of different severity, and different stage of development.

The ageing process seems to follow a geometric progression after the first stage of ageing.

Milder degradation effects in naturally aged PV modules than that of younger modules subjected to induced ageing.
Conclusions (2)

- The I-V curve analysis assists in the identification of the existence of critical defects in cell(s) in a module. It also provides an estimate of the performance degradation of the PV module $\delta P_m/P_m$, $\delta FF/FF$, $R_s$, $R_{sh}$.

- The IR thermography assists in the identification of the exact location and type of defect.

- Current work is involved in the identification of defects through digital image processing.
Related Work in R.E.S. Laboratory


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