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

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Ageing effects in PV cells and modules

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Introduction to ageing factors and ageing effects

Experiments with PV modules operating in field conditions for 13, 18, 22 years

Ageing effects identified through:
- 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
Ageing Factors

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

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

Partial Shading

Short / Long Term Degradation

Discoloration

Long Term Optical & Physical degradation

Humidity Ingress

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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

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Ageing effects

- Discoloration of the EVA encapsulant
- Delamination of the encapsulant
- Oxidization
- High conductivity paths (shunts)
- Humidity ingress
- Hot spots/ hot areas
- Cracks, tears in the back sealing
- Bubbles
- Corrosion in bus bars and contacts
Experimental Procedure

PV modules
- **BP B 1233**
  - 22 years of field operation, natural weathering
- **SIEMENS M55**
  - 18 years of field operation, natural and induced shading effects
- **SIEMENS SM55**
  - 13 years of field operation, natural weathering

Examined via:
- **Visual Inspection**
  - visual observation/ digital camera
- **IR thermography**
  - TROTEC IC080LV thermocamera (res.384x288 pxls)
- **I-V curve, electrical parameters**
  - I-V curve analyser, pyranometers (global & diffuse radiation), IR thermometer

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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

- **Delamination**
  - Expansion

- **Corrosion of contacts**

- **Bubbles**

- **Tears in the back sealing surface**
EVA Discoloration

BP B 1233
EVA Discoloration – BP B 1233
EVA Discoloration – BP 1233
EVA Discoloration – M55
First signs of ageing – SM55

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AR deterioration – SM55
Delamination – M55
AR deterioration/oxidization – M55
Corrosion of contacts – M55
Damage in the back sealing – BP B 1233
Bubble formation – M55
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
Junction box – M55
Hot spots/ hot areas – M55
Hot spots/ hot areas – M55
Hot zones at bus bars – M55
Experimental results

- Example: BP B 1233 and M55.
- I-V curves obtained in field conditions
- Recording the global and diffuse solar radiation, the cell temperature, and the ambient temperature.
- Converting the electrical characteristics of the modules $I_{sc}$, $V_{oc}$, $P_m$, and $FF$ to STC for comparison with the nominal values.
I-V curve analysis

- BP B 1233

\[ I_T = 482.7 \text{ W/m}^2, T_c = 39.8^\circ\text{C} \]

<table>
<thead>
<tr>
<th>Nominal</th>
<th>BP B 1233</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isc</td>
<td>2.3</td>
</tr>
<tr>
<td>Voc</td>
<td>20</td>
</tr>
<tr>
<td>Pm</td>
<td>33</td>
</tr>
<tr>
<td>Im</td>
<td>2</td>
</tr>
<tr>
<td>Vm</td>
<td>16.5</td>
</tr>
<tr>
<td>FF</td>
<td>0.717</td>
</tr>
</tbody>
</table>
I-V curve analysis

- M55

$I_T = 617 \text{ W/m}^2, T_c = 47.8^\circ \text{C}$
# PV module degradation

A measure of the mean PV module degradation:

\[
\frac{P_m(\text{STC}) - P'_m(\text{STC})}{P_m(\text{STC})} \quad \frac{FF(\text{STC}) - FF'(\text{STC})}{FF(\text{STC})}
\]

<table>
<thead>
<tr>
<th>module</th>
<th>(P_m(\text{STC}))</th>
<th>(P'_m(\text{STC}))</th>
<th>(FF(\text{STC}))</th>
<th>(FF'(\text{STC}))</th>
<th>(\frac{P_m(\text{STC}) - P'_m(\text{STC})}{P_m(\text{STC})})</th>
<th>(\frac{FF(\text{STC}) - FF'(\text{STC})}{FF(\text{STC})})</th>
</tr>
</thead>
<tbody>
<tr>
<td>M55</td>
<td>53</td>
<td>44.56</td>
<td>0.729</td>
<td>0.619</td>
<td>15.9%</td>
<td>15.1%</td>
</tr>
<tr>
<td>BP B1233</td>
<td>33</td>
<td>29.67</td>
<td>0.717</td>
<td>0.666</td>
<td>10.1%</td>
<td>7.1%</td>
</tr>
</tbody>
</table>
Conclusions (1)

- 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.

- The overall power degradation for the naturally aged PV module of 22 years operation was estimated about 0.5% per year. For the naturally and induced aged PV module of 18 years operation was estimated about 0.9 per year.
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 the RES Lab, TEI of Patras


Acknowledgements

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