Green electronics: ELEC 3202 – 1
System design

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PV system

The sun continues to supply energy via the PV system. At present, less energy is being consumed than generated. The excess electricity is fed into the grid.
PV system

What are the issues?
PV system

What are the issues?

- Power requirements (Domestic)
- Limitation of photo cells
  - Maximum power extraction
- Power conversion
  - Power efficiency
  - Power conversion (DC-DC)
  - Power conversion (AC-DC)
- Storage
1. System design
2. Power requirements
3. Power profile
4. Domestic user profile
5. System constraints
6. Efficiency
7. Sunshine constraints
8. Example
System design

• The Overall Requirements of a system are defined in terms of:
  • Peak Power requirements
  • Average Power Requirements
  • Power Profile
  • Capital Costs
  • Available Area

• Using these elements can provide a pretty good assessment of individual system requirements
Power requirements

• If we consider the three power requirements, they are clearly linked together and need to be considered in the system design
  • Peak Power requirements
  • Average Power Requirements
  • Power Profile

• The overall power consumption profile does give all three aspects, so is worth considering first
Power Profile

• In any installation, there is going to be a power usage profile which can be considered prior to any PV system design

• The installation may be domestic, commercial or industrial in nature, each of which has different needs and usage profiles in general
Domestic user

- Domestic users usually have a very well defined usage profile, and also are very easy to measure, in general, using a simple energy monitoring system.

- Domestic users also tend to follow very fixed patterns of usage, making predictions of usage quite straightforward.
Typical domestic profile

- The domestic loads were estimated from the daily usage of a typical family dwelling, with the power demands from electrical appliances monitored over a 24 hour period.
- There are obvious peaks in demand in the morning and early evening.
- This is averaged data, and will depend on the time of year and prevailing weather and light conditions.
- Different load profiles can be obtained for different family groups and usage patterns.
Analysis of the profile

- If we look at the profile itself, we can make some quantitative judgements about it
  - 1. Maximum power requirements = 9.2kW
  - 2. Average Power requirements ~1kW
  - 3. Profile – predictable peaks in the morning and evening

- We can also make the deduction that the system must be able to deliver up to 24kWh per day, to satisfy this demand 100%
From 2006 to 2014, an eight year span, worldwide average module prices have dropped about 78% from $3.25 per watt to about $.72 per watt.

Back in 2007 there was a world wide polysilicon shortage and prices increased to about $400/kg. Polysilicon suppliers made a lot of money and added tons of capacity so that there was a huge polysilicon capacity oversupply by 2010. Over a three year period from 2008 to 2011, polysilicon prices dropped from $400 per kilogram to $25/kg - a 94% drop. Today it is about ~ $14/kg

http://solarcellcentral.com/cost_page.html
- At the end of 2014 crystalline silicone was at $.75 per watt while cadmium telluride was at $.70.

- Cost reduction race as crystalline silicone's volume is roughly 14 to 1 over cadmium telluride
System Constraints (Levelized Cost Of Energy (LCOE))

Method of comparing the cost of different complex energy technologies. It is the total life cycle cost of electricity for a given technology divided by the total life cycle electricity produced, expressed as cents per kilo-watt hour.

<table>
<thead>
<tr>
<th>Energy Plant Type</th>
<th>Lifetime Cost £ per Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore Wind</td>
<td>£1.32</td>
</tr>
<tr>
<td>Peaker Natural Gas</td>
<td>£1.19</td>
</tr>
<tr>
<td>Coal with CCS</td>
<td>£0.95</td>
</tr>
<tr>
<td>PV Solar</td>
<td>£0.83</td>
</tr>
<tr>
<td>Gas Combined Cycle with CCS</td>
<td>£0.66</td>
</tr>
<tr>
<td>Biomass</td>
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</tr>
<tr>
<td>Advanced Nuclear</td>
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<tr>
<td>Hydro-electric</td>
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<tr>
<td>Natural Gas Combined Cycle</td>
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<td>Land Based Wind</td>
<td>£0.49</td>
</tr>
<tr>
<td>Geothermal</td>
<td>£0.32</td>
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</tbody>
</table>

http://solarcellcentral.com/cost_page.html
System Constraints

- Clearly cost is going to be a significant constraint on the system to be installed.
- It is easy to say, “simply install PV panels across the entire roof area of your house”, say to a value of 100m².
- However, given that the cost of solar panels are of the order of £170-£300/m², this soon becomes very expensive!
System Constraints

~20% efficiency for the most expensive monocrystalline panels or 260£ per panel / ~0.8£ per watt

~15% efficiency for the most expensive monocrystalline panels or 180£ per panel / ~0.67£ per watt

http://www.off-grid-europe.com
System Constraints

• The second obvious constraint on the installation is the available surface area suitable for PV panels to be mounted.

• Roofs have a maximum weight rating, and the construction and installation of frames and panels make this a real constraint.
PV Panel Efficiency

• As has been covered already in this course, the efficiency of commercially available panels is still usually less than 20%, and often much lower than this.

• A good working assumption of a suitable efficiency under everyday conditions would be around 15% for modern high quality PV panels.
Sunshine Figures

- There are extensive records of sunshine hours on a monthly basis, held by the Met Office.
- For example, the graph shows the average monthly figures since 1971 at Eastbourne (south coast of England).
Sunshine Figures Analysis

- Looking at the figures for Eastbourne, we can say that the worst case month will be December, with just over 50 hours of sunshine on average for the whole month, and the best month will be July, with about 240 hours of sunshine per month.

- Assuming 30 days per month, therefore

\[ Hours_{daily} = \frac{Sunshine_{monthly}}{30} \]
## Daily Sunshine

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly Hours of Sunshine</th>
<th>Average Daily Hours of Sunshine</th>
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<tbody>
<tr>
<td>January</td>
<td>70</td>
<td>2.33</td>
</tr>
<tr>
<td>February</td>
<td>80</td>
<td>2.66</td>
</tr>
<tr>
<td>March</td>
<td>130</td>
<td>4.33</td>
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<tr>
<td>April</td>
<td>190</td>
<td>6.33</td>
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<tr>
<td>May</td>
<td>230</td>
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<tr>
<td>June</td>
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<tr>
<td>July</td>
<td>240</td>
<td>8.00</td>
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<tr>
<td>August</td>
<td>235</td>
<td>7.83</td>
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<tr>
<td>September</td>
<td>170</td>
<td>5.66</td>
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<tr>
<td>October</td>
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<tr>
<td>November</td>
<td>80</td>
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</tr>
<tr>
<td>December</td>
<td>55</td>
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</tr>
</tbody>
</table>
Sunshine Figures Analysis

• Given that PV panels are specified with relation to a nominal 1000W/m² irradiance, for a nominal efficiency we can estimate the output power under normal conditions for a given area.

• Assuming that the sunshine is optimally incident on the panel, the output power can be calculated as follows:

\[
\text{Energy/day (Wh)} = \text{Sunshine (hours)} \times \text{Efficiency (\%)} \times \text{area (m}^2) \times 1000(W)
\]
Worked Example

• Given these basic figures it is straightforward to estimate the power generating capability of a PV installation using these basic parameters.

• Consider a 10m² PV array on the roof of a house in Eastbourne, and assume that the orientation is ideal for maximum incidence of the sunlight – what is the expected average power consumption per day?

• Assume that the efficiency of the panels is 15%
Worked Example: Calculating the power generated per hour of sunshine

- We can use the equation previously given for the daily power generation:

\[ \text{Energy/day (Wh)} = \text{Sunshine(hours)} \times \text{Efficiency(\%) \times area(m}^2) \times 1000(W) \]

- Then use the values for efficiency and area:
  - Efficiency = 0.15 (15%)
  - Area = 10m²

- This gives a power generation capability of 1.5kW per hour for this installation
## Worked Example: Daily power generation

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Worked Example: Conclusion

- Using this basic worked example, we can conclude that based on our previous figure of an average daily usage of around 24kWh, the output from our installation of 10m² is simply not nearly enough to cover all the energy needs of this particular house.

- It is also graphically clear that the variability between the summer and winter months is starkly apparent, a particular problem for industrialised nations in Northern Europe.
Worked Example: Minimum installation required?

• Clearly, due to the variation of sunshine across the year in the UK, there is an issue with balancing the generated power across the year.

• If we make the assumption that we can store the generated power, or at least trade it with the utility to make the system essentially neutral across the year, how big an installation would be required?
Worked Example: PV installation area requirements

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- Using the generation data, we can calculate the average generation per day is:
  - 7638.75Wh
- Therefore the average daily generation per meter is
  - 763.88Wh
- Therefore the minimum area required to meet the 24kWh requirement is
  - 31.44m²
Worked Example: Installation Costs

• Based on a typical cost of £~200 per m$^2$, the proposed installation of 32m$^2$ works out to cost £6,400 (panels only).

• Remember, of course, that this is making the assumption that all the energy generated can either be used or stored for use later in the year, or that some arrangement can be agreed with the local utility to trade power.
Worked Example: NRE and Cost Effectiveness

• The decision for a household as to whether to install such a system is based primarily on the time it takes to pay for itself.

• Therefore, based on a typical kWh cost of 7p, the annual energy bill can be estimated to be 24kWh*365*tariff

• For this case, the total energy bill works out at around £613.20 per annum, giving a time to pay for the installation of nearly 10 years.
Worked Example: Grants and Incentives

• In most European countries, incentives exist for the installation of PV modules domestically

• These incentives usually range from 50% to 90%, and clearly this has a major impact on the NRE (Non Recoverable Expense)

• In the case of a 50% grant (UK), the time to pay for the installation drops to around 5 years

• In the case of a 90% grant (Germany), the time to pay for the installation drops to around ~2 years
Worked Example: Conclusion

• With current technology, there is a straightforward calculation of the installation requirements based on local sunshine and area availability

• The costs of the system still make PV an expensive option for most countries

• Balancing the energy profile across the calendar year is a significant problem as yet to be addressed successfully