General Introduction to the training

ECREEE Regional Training of Trainers Workshop: HOMER software for RE project design

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I. Considerations for an hybrid system in this training (I)

Definition of hybrid system
What is an hybrid system in this training?

For a first comprehensive understanding of an *hybrid energy system*, watch the following public video on renewable energy technology for stand-alone grids.

**TO SEE THE VIDEO, CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR**

http://player.vimeo.com/video/52066424?title=0&amp;byline=0&amp;portrait=0&amp;badge=0&amp;color=ffffff&amp;autoplay=1

This video has been developed by the SMA Solar Technology AG

*Source: SMA SOLAR TECHNOLOGY AG*
Definition of Hybrid System for this training

• **Hybrid system**: electricity generation system, based on the integration of various energy sources (such as photovoltaics, wind turbines, small hydro power or diesel generators).

  *Source: ECREEE*

• (...) hybrid configurations can potentially deliver improved performance and better economics for a given electrification situation.

  *Source: ESMAP, 2007*
II. Considerations for an hybrid system in this training (II)

General architecture of an energy system
General architecture of an energy system (simplified)
III. Considerations for an hybrid system in this training (III)

Architectures for hybrid systems based on the control strategy
Architectures for hybrid systems based on the control strategy

• There are several system architectures for hybrid systems. Based on the power electronics’ control strategy, two examples are:
  
  – Alternate Current bus coupling
  
  – Direct Current bus coupling

• Other architectures for hybrid systems may have a mixed combination of the two above.

• These architectures have to be taken into consideration when dimensioning and simulating the hybrid system.
SYSTEM ARCHITECTURE: AC BUS COUPLING

Source: ARE, 2008
AC BUS COUPLING
EXAMPLE OF TECHNICAL SCHEME

Source: TRAMA TECNOAMBIENTAL
SYSTEM ARCHITECTURE: DC BUS COUPLING

Source: ARE, 2008
DC BUS COUPLING
EXAMPLE OF TECHNICAL SCHEME

Source: TRAMA TECNOAMBIENTAL
IV. Considerations for an hybrid system in this training (IV)

Hybrid system’s input units
PV generator  (kW)  Kilowatt
Wind Turbine  (Quantity)  number of units
Hydro  (m) meters of head (L/s) liters per second or flow
Converter  (kW)  Kilowatt
Generator  (kW)  Kilowatt
Battery  (Quantity)  number of units

Source: HOMER ENERGY, 2011
V. Example of an operational energy system in an isolated village of 600 people

Monte Trigo, Cape Verde, West Africa
Monte Trigo’s energy system

Source: BRIGANTI et al, 2012
Technical notes of the system

- In February 2012, entered into service Cape Verde’s first rural micro grid with 100% renewable energy generation. This project was carried out within the framework of the “Energy Facility” ACP-EU program. Permanent electricity access had been strongly requested by the local stakeholders and community of the village to cover basic energy needs such as lighting, communication, community services and ice production for fish conservation.

- The objective of the project was the electrification of the village of Monte Trigo (600 people) in Santo Antão Island, with a Multiuser Solar micro-Grid (MSG).

- The project was implemented in 2011, and is currently in the post commissioning follow-up period. A key aspect of the project has been to ensure the long-term sustainability of the electricity service. In addition to the description of the plant and the operation and management scheme, this article underlines the importance of the Energy Daily Allowance (EDA) concept from social, technical and economic perspectives. In conclusion the article intends to highlight the validity of both the technical solution and management model.

- Among other expert methods of calculation, simulation tools were used to analyze the feasibility and the design of the system.

✔ For further reading (1): CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR

Source: BRIGANTI et al, 2012
VI. Considerations on energy demand (I)

UNITS
UNITS

- **Power** (kW) *Kilowatt*
- **Time** (h) *hour*
- **Energy** (kWh) *Kilowatt*(per)hour

**Generation (generator side):** is the energy produced by the *power* of an energy generator during a certain period of *time*.

\[
\text{Energy} = \text{Power of an energy generator (kW)} \cdot \text{Time (period of hours)}
\]

**Energy Demand (users side):** is the total energy the consumers need, during a certain period of time; and the amount of energy that normally they are charged for (as part of an arbitrary tariff).

Normally, the energy produced by an energy generator has to be higher than the energy demand. This is related to the losses and performance of the system, among other factors, that have to be carefully taken into consideration. **This issue will be out from this training due to the deep level of analysis that it needs.**
VII. Considerations on energy demand (II)

LOAD PROFILE
Example of daily load profile (1)
Example of daily load profile (2)
Example of daily load profile (3)
Aggregated daily Load profile

<table>
<thead>
<tr>
<th>Time</th>
<th>Demand</th>
<th>Losses</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power (kW)</td>
<td>Losses (kW)</td>
<td>TOTAL Generation</td>
</tr>
<tr>
<td></td>
<td>0.99</td>
<td>0.33</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>0.33</td>
<td>0.39</td>
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<tr>
<td></td>
<td>0.33</td>
<td>0.33</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>0.93</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>2.19</td>
<td>3.31</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>3.31</td>
<td>1.69</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>3.31</td>
<td>1.69</td>
<td>3.87</td>
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<tr>
<td></td>
<td>1.69</td>
<td>1.69</td>
<td>1.98</td>
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<tr>
<td></td>
<td>1.69</td>
<td>1.63</td>
<td>1.98</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.63</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.63</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.63</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.63</td>
<td>2.03</td>
</tr>
<tr>
<td></td>
<td>1.63</td>
<td>1.63</td>
<td>2.03</td>
</tr>
<tr>
<td></td>
<td>1.66</td>
<td>1.66</td>
<td>3.66</td>
</tr>
<tr>
<td></td>
<td>9.92</td>
<td>9.92</td>
<td>6.92</td>
</tr>
<tr>
<td></td>
<td>10.28</td>
<td>10.28</td>
<td>11.65</td>
</tr>
<tr>
<td></td>
<td>9.68</td>
<td>9.68</td>
<td>12.03</td>
</tr>
<tr>
<td></td>
<td>7.02</td>
<td>7.02</td>
<td>11.33</td>
</tr>
<tr>
<td></td>
<td>3.81</td>
<td>3.81</td>
<td>8.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.46</td>
</tr>
</tbody>
</table>

TOTAL ENERGY PER DAY

- Demand: 74.95 kWh
- Losses: 12.74 kWh
- Total: 87.69 kWh

Source: ECREEE
Simulation softwares use (aggregated) Load daily Profile

Source: HOMER ENERGY, 2011
Recommendation on sizing and simulating RE hybrid systems with multiple users

- Users should have *dispenser meters* with Energy Daily Allowance (EDA) management according to the contracted tariff (limitations through smart devices that control the kWh of energy consumed).

- (...) The concept of *energy daily allowance* introduces certainty in the most uncertain parameter when sizing and simulating RE hybrid micro grids with multiple users

*Source: GRAILLOT et al, 2012*
Dispenser meter: a key device for dimensioning hybrid systems

• From a technological stance, it enables components like batteries and inverters to operate within their specified range.

• From a financial point of view it reduces load uncertainty and its associated risk regarding collected revenues.

• From a social point of view, it responds to users’ needs more accurately and guides them through the management of energy use and energy budget.

Source: GRAILLOT et al, 2012
VIII. Considerations on costs (I)

Comparison of costs of hybrid systems
## Type of costs related to an hybrid energy system

<table>
<thead>
<tr>
<th>EXPENSES</th>
<th>INCOMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>Tariff</td>
</tr>
<tr>
<td>Replacement costs</td>
<td>Subsidy</td>
</tr>
<tr>
<td>Operation, Maintenance and Management</td>
<td>...</td>
</tr>
<tr>
<td>Fuel</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

### Components

- Energy Generators
- Power Electronics
- System control
- Power storage
- User
- User
- User
- ...
Comparison costs of hybrid solutions

Split of levelized costs at 10% of discount rate and fuel at 0.57 $/liter per energy unit and per user service for different case studies

Source: ESMAP, 2007b
Comparison costs of hybrid solutions

<table>
<thead>
<tr>
<th>Hybrid Type</th>
<th>PV Arrays kWP</th>
<th>Genset kW</th>
<th>Batteries kWh</th>
<th>Rectifier kW</th>
<th>Inverter kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Padre Cocha RAPS (Optimized)(^1)</td>
<td>30</td>
<td>128</td>
<td>0</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>1. Diesel-only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a. Alternative One Stand-by Unit</td>
<td>1 x 36 kW</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1b. Alternative Peak and Off-peak</td>
<td>2 x 18 kW</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. Diesel-battery-hybrid</td>
<td>1 x 36 kW</td>
<td>310</td>
<td>20</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3. Diesel-PV-hybrid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a. Solar PV 25%</td>
<td>25</td>
<td>36 kW</td>
<td>310</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3b. Solar PV 50%</td>
<td>50</td>
<td>36 kW</td>
<td>310</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3c. Solar PV 75%</td>
<td>75</td>
<td>36 kW</td>
<td>524</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>3d. Solar PV 85%</td>
<td>93</td>
<td>36 kW</td>
<td>524</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>4. Solar PV 100%</td>
<td>140</td>
<td>0</td>
<td>765</td>
<td>0</td>
<td>25</td>
</tr>
</tbody>
</table>

\(^1\) Actual figures from Padre Cocha but with improvements to significantly reduce distribution losses.

Source: ESMAP, 2007b
Grid extension costs

The extension of the grid has to be taken into consideration when dimensioning and simulating an isolated multi user hybrid system.

Source: ARE, 2008
IX. Considerations on costs (II)

The levelized Cost of Energy
Simulation softwares give the possibility to analyze economics

- Scenario for a life cycle of 20 years, cash flow evolution as a result of aggregated incomes and expenses.

Source: TRAMA TECNOAMBIENTAL
Levelized cost of Energy (LCOE)

- Cash flow evolution of several possible hybrid systems may differ, specially due to the type of technology chosen: replacement costs are not the same for PV solar panels than for Wind generators, different batteries have different replacement costs, and the costs at the beginning of a life cycle are not “economically” the same as the costs at the end of the life cycle due to the evolution of the value of a currency through the years (among other factors).

- We need a reference value to compare different multi year scenarios.

- LCOE is a constant value ($/kWh) used as a reference to compare (through a life cycle period) different technologies and systems that produce energy.

- It is referred to the minimum energy income per kWh, that equals expenses of the implementation and operation of the system with the incomes generated by the system.

- The LCOE is based on the Net Present Value economical methodology in a multi year scenario.

Source: ECREEE
Simple example: one year scenario

How much has to be the energy income ($ per kWh) to pay back the cost of the system in one year?

Cost of the Hybrid System ($) = Energy generated (kWh) · Energy cost ($ / kWh)

So,

Energy cost ($/kWh) = Cost of the system ($) / Energy generated (kWh)

Note.- When performing a rigorous financial analysis of a system we should consider “energy to sell” (the amount of kWh that can be sold to the consumer) rather than energy generated. Energy generated normally is higher than energy consumed. For example, losses can not be sold to someone and get incomes. So the levelized cost of an energy system is better to be related to the energy potentially being sold, rather than simply to the energy generated.

Source: ECREEE
Understanding LCOE in 3 steps (Net Present Value)

one year scenario

<table>
<thead>
<tr>
<th>INCOMES ($)</th>
<th>EXPENSES ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INCOMES ($)</td>
<td>EXPENSES ($)</td>
</tr>
<tr>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Energy generated (kWh) • Energy cost ($/kWh)</td>
<td>Costs of the Hybrid System ($)</td>
</tr>
</tbody>
</table>

multi year scenario

<table>
<thead>
<tr>
<th>NPV (INCOMES) ($)</th>
<th>NPV (EXPENSES) ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV (INCOMES) ($)</td>
<td>NPV (EXPENSES) ($)</td>
</tr>
<tr>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>NPV (Energy generated • Energy cost)</td>
<td>NPV (Costs of the Hybrid System)</td>
</tr>
</tbody>
</table>

the Levelized Cost of Energy is a constant value through the life cycle -by definition-

<table>
<thead>
<tr>
<th>Life Cycle INCOMES ($)</th>
<th>Life Cycle EXPENSES ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle INCOMES ($)</td>
<td>Life Cycle EXPENSES ($)</td>
</tr>
<tr>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Energy cost • NPV (Energy generated)</td>
<td>NPV (Costs of the Hybrid System)</td>
</tr>
</tbody>
</table>

This Energy cost is the LCOE

\[
LCOE = \frac{\sum_{t=1}^{i} C_t}{(1 + d_{nom})^t} - \frac{\sum_{t=1}^{i} E_t}{(1 + d_{nom})^t}
\]

Source: ECREEE
More about LCOE

Range of forecast costs by type of generating technology.
The LCOE is a way to compare different technologies of electricity generation with different cash-flows.

Source: ESMAP, 2007
X. About the HOMER software

Hybrid Optimization Model for Electric Renewables
About the HOMER software

• HOMER is an energy modeling software.

• It is powerful tool for designing and analyzing hybrid power systems.

• The hybrid power systems contain a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaics, batteries, fuel cells, hydropower, biomass and other inputs.

• It is currently used all over the world by tens of thousands of people.

• ✔ For further reading (2): CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR

Source: HOMER ENERGY, 2011
Examples of the user interface

Source: HOMER ENERGY, 2011
Examples of the user interface

Source: HOMER ENERGY, 2011
Examples of the user interface

Source: HOMER ENERGY, 2011
Examples of the user interface

<table>
<thead>
<tr>
<th>Month</th>
<th>Wind Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.794</td>
</tr>
<tr>
<td>February</td>
<td>5.702</td>
</tr>
<tr>
<td>March</td>
<td>3.338</td>
</tr>
<tr>
<td>April</td>
<td>4.121</td>
</tr>
<tr>
<td>May</td>
<td>4.062</td>
</tr>
<tr>
<td>June</td>
<td>2.664</td>
</tr>
<tr>
<td>July</td>
<td>3.572</td>
</tr>
<tr>
<td>August</td>
<td>3.630</td>
</tr>
<tr>
<td>September</td>
<td>3.594</td>
</tr>
<tr>
<td>October</td>
<td>4.823</td>
</tr>
<tr>
<td>November</td>
<td>6.587</td>
</tr>
<tr>
<td>December</td>
<td>7.195</td>
</tr>
</tbody>
</table>

Annual average: 4.500

Wind Resource

Other parameters:
- Altitude (m above sea level): 0
- Anemometer height (m): 10

Advanced parameters:
- Weibull k: 1.95
- Autocorrelation factor: 0.893
- Diurnal pattern strength: 0.283
- Hour of peak windspeed: 13

Scaled annual average (m/s): 4.5

Source: HOMER ENERGY, 2011
Examples of the user interface

Source: HOMER ENERGY, 2011
Convenience of an energy simulation tool and when?

• The hybrid systems have a high level of complexity related to the possibility of many combinations and solutions.

• Due to the interaction of several energy resources, many industrial technologies and prices, different energy user profiles, constrains and costs, etc... it is very convenient to use a powerful simulation tool to achieve good compromised solutions and to analyze different scenarios.

• Very suitable for analysis and feasibility studies.

• Once the type of solution is targeted, other experienced methodology of calculation and dimensioning may apply.

Source: ECREEE
HOMER compared to other softwares

HOMER simulates the annual performance of each of the system combination possibilities for a specified set of energy sources and calculates also the system and operating costs over the given period.

The outcome of the simulation is a list of the possible systems in order of the arising costs. A graph depicts the various ranges of the most profitable systems over the given operating period, based on the selected criteria.

Detailed results can be output for each of the individual simulated systems (graphs, tables, scatter plot, print-out).

✔ For further reading (3): CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR

Source: IEA, 2011
Simulation models are very useful; one important thing is to set the right questions to them and know how to interpret the given results; always, and in any stage of the project design.

“Computers are useless. They can only give you answers.”

Pablo Picasso
References


References

- **ECREEE**  [http://www.ecreee.org](http://www.ecreee.org)
- **ECOWREX**  [http://www.ecowrex.org](http://www.ecowrex.org)
- **HOMER ENERGY**  [http://www.homenergy.org](http://www.homenergy.org)
Merci! Thank you! Muito obrigado!

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