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INTERNATIONAL JOURNAL


PAPERS COMMUNICATED


## APPENDIX A
### IMPORTANT TERMS RELATED TO DISTRIBUTED ENERGY RESOURCES

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Grid Interconnection</strong></td>
<td>Connecting a distributed power system to the electricity grid has potential impacts on the safety and reliability of the grid. Several countries are developing their own interconnection standards.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Net Metering</strong></td>
<td>Net Metering allows the electric meters of customers with generating facilities to turn backwards when they are feeding power into the grid, so that they receive retail prices for the excess electricity they generate. This encourages customer investment in distributed generation, including renewable energy.</td>
</tr>
<tr>
<td>3</td>
<td><strong>Load Control</strong></td>
<td>Utilities can use energy management control systems to remotely control a customer’s electrical equipment switching it on or off for load levelling purpose.</td>
</tr>
<tr>
<td>4</td>
<td><strong>Islanding</strong></td>
<td>Circuit protection is the biggest technical challenge with adding generation to distribution circuits. Islanding, in which a distributed generator energized a portion of a distribution system when the rest of the system is de-energized. This can create safety hazards and damage equipment.</td>
</tr>
<tr>
<td>5</td>
<td><strong>System Control</strong></td>
<td>Real-time information and system control technologies currently under development will facilitate the integration of distributed power systems into the electricity grid.</td>
</tr>
</tbody>
</table>
## APPENDIX B

### IMPORTANT TERMS RELATED TO HOMER

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Terms</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Annualized Cost</td>
<td>The hypothetical annual cost value that if it occurred each year of the project lifetime would yield a net present cost equivalent to the actual net present cost. HOMER calculates the annualized cost of each system component and of the entire system.</td>
</tr>
<tr>
<td>2</td>
<td>Autonomous</td>
<td>Not connected to a larger power transmission grid. Autonomous power systems are often called off-grid systems. An autonomous system must be controlled carefully to match electrical supply and demand.</td>
</tr>
<tr>
<td>3</td>
<td>Battery Energy Cost</td>
<td>The average cost per kilowatthour of the energy stored in the battery bank.</td>
</tr>
<tr>
<td>4</td>
<td>Battery Wear Cost</td>
<td>The cost per kilowatthour of cycling energy through the battery bank. HOMER can calculate this value because it assumes that a certain amount of energy can cycle through the battery bank before it needs replacement. Every kilowatthour of energy that cycles through the battery bank reduces its life span by a known amount.</td>
</tr>
<tr>
<td>5</td>
<td>Beam Radiation</td>
<td>Solar radiation that travels from the sun to Earth’s surface without any scattering by the atmosphere. Beam radiation is also called direct radiation.</td>
</tr>
<tr>
<td>6</td>
<td>Capacity Shortage</td>
<td>A shortfall that occurs between the required amount of operating capacity (load plus required operating reserve) and the actual operating capacity the system can provide.</td>
</tr>
</tbody>
</table>
| 7       | Clearness Index           | The fraction of the solar radiation striking the top of the atmosphere that makes it though the atmosphere to }
strike the surface of the Earth.

8 **Constraint**

A condition that system configurations must satisfy. HOMER discards systems that do not satisfy the applicable constraints. For example, the HOMER user may impose a constraint that all system configurations must serve at least 99% of the electrical demand over the year.

9 **Decision Variable**

A variable over which the system designer has control, and for which HOMER can consider multiple values in its optimization process. Examples include the number of batteries in the system or the size of the ac–dc converter.

10 **Demand Rate**

The fee the electric utility applies each month to the peak hourly grid demand. If the demand rate is $5/kW per month and the peak hourly demand in January is 75 kW, the demand charge for January will be $375.

11 **Diffuse Radiation**

Solar radiation that has been scattered by the atmosphere.

12 **Dispatch Strategy**

A set of rules that controls how a system charges the battery bank.

13 **Extraterrestrial Radiation**

The solar radiation striking the top of EARTH’s atmosphere. One can calculate the quantity of extraterrestrial radiation precisely for any location on earth at any time.

14 **Feasibility**

The state of being feasible or infeasible. A feasible system configuration is one that satisfies the constraints imposed by the user. An infeasible system is one that violates one or more constraints.

15 **Grid Power Price**

The price the utility charges for power purchased from the grid. In HOMER, this price can vary according to month, day of the week, and time of day.

16 **Levelized Cost of**

The average cost per kilowatthour of electricity
Energy produced by the system.

17 Life Cycle Cost The total cost of installing and operating a component or system over a specified time span, typically many years.

18 Micropower System A system that produces electrical and possibly thermal power to serve a nearby load.

19 Net Load The load minus the renewable power available to serve the load.

20 Net Metering A billing scheme by which the utility charges a micropower system operator for the net grid purchases (purchases minus sales) over the billing period.

21 Operating Capacity The total amount of electrical generation capacity that is operating (and ready to produce electricity) at any one time. A generator that is not operating provides no operating capacity. A 200-kW generator that is operating provides 200 kW of operating capacity.

22 Operating Reserve Surplus electrical generation capacity (above that required to meet the current electric load) that is operating and able to respond instantly to a sudden increase in the electric load or a sudden decrease in the renewable power output.

23 Replacement Cost The cost of replacing a component at the end of its useful lifetime. The replacement cost may differ from the initial capital cost for several reasons: only part of the component may need replacement, a donor organization may cover the initial capital cost but not the replacement cost, fixed costs may be shared among many components initially but not at the time of replacement, and so on.

24 Residual Flow The minimum stream flow that must bypass the hydro turbine for ecological purposes.

25 Search Space The set of all system configurations over which HOMER searches for the optimum during the
optimization process.

<table>
<thead>
<tr>
<th></th>
<th>Sellback Rate</th>
<th>The price the utility pays for power sold to the grid. In HOMER, this value can vary according to month, day of the week, and time of day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Sensitivity</td>
<td>An input variable for which the modeler enters multiple values rather than just one.</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>System</td>
<td>A combination of particular numbers and sizes of components, plus an operating strategy that defines how those components work together.</td>
</tr>
<tr>
<td></td>
<td>Configuration</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Unmet Load</td>
<td>Electrical load that the power system is unable to serve. Unmet load occurs when the electrical demand exceeds the supply.</td>
</tr>
</tbody>
</table>
APPENDIX C
LIST OF SYMBOLS USED

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DESCRIPTION</th>
<th>TYPICAL RANGE/IN UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_1$</td>
<td>One-Hour Autocorrelation Factor</td>
<td>0.80 - 0.95</td>
</tr>
<tr>
<td>$\rho/\rho_0$</td>
<td>Air Density Ratio</td>
<td>0.6-1.0</td>
</tr>
<tr>
<td>$z$</td>
<td>Altitude</td>
<td>0-5000 m</td>
</tr>
<tr>
<td>$z_{anem}$</td>
<td>Anemometer Height</td>
<td>10-25m</td>
</tr>
<tr>
<td>$i'$</td>
<td>Annual Real Interest Rate</td>
<td>2-10%</td>
</tr>
<tr>
<td>$i$</td>
<td>Real Interest Rate</td>
<td>2-10%</td>
</tr>
<tr>
<td>$f$</td>
<td>Annual Inflation Rate</td>
<td>2-10%</td>
</tr>
<tr>
<td>$C_{NPC}$</td>
<td>the net present cost</td>
<td>$</td>
</tr>
<tr>
<td>$R_{proj}$</td>
<td>project lifetime</td>
<td>yr</td>
</tr>
<tr>
<td>CRF</td>
<td>a function returning the capital</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>recovery factor</td>
<td></td>
</tr>
<tr>
<td>$R_{batt}$</td>
<td>Battery bank Life</td>
<td>yr</td>
</tr>
<tr>
<td>$A_{batt}$</td>
<td>Battery Bank Autonomy</td>
<td></td>
</tr>
<tr>
<td>$Q_{lifetime}$</td>
<td>Lifetime Throughput</td>
<td>kWh</td>
</tr>
<tr>
<td>$K_t$</td>
<td>Clearness Index</td>
<td>0-1</td>
</tr>
</tbody>
</table>
APPENDIX D
DATA AND RELATED WEBSITES

Electric Load Data

The only source of hourly load data that we're aware of is the DG Marketplace, which you can visit at www.dgmarketplace.com. This website sells typical residential, commercial, and industrial load data for locations across the US.

Geography


To find your time zone, check www.worldtimezone.com.

Solar Radiation Data

HOMER will accept solar radiation data as monthly averages or as a time series. Time series solar radiation data is most commonly available with an hourly time step, but HOMER can accept any time step down to one minute. One of the best sources of solar radiation data is the TMY2 and TMY3 data sets provided for free by the US National Renewable Energy Laboratory. You can import TMY2 and TMY3 files directly into HOMER's Solar Resource Inputs window.

- NREL provides TMY2 data at: http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/.
- NASA's Surface Solar Energy Data Set provides monthly average solar radiation data for everywhere on earth at http://eosweb.larc.nasa.gov/sse/.
- This help file contains a table of monthly solar data for selected worldwide locations.


The World Radiation Data Center provides worldwide solar data at http://wrdc-mgo.nrel.gov. Note that data from this website need a lot of processing to be useful in HOMER.

## Wind Speed Data

It can be difficult to obtain measured wind speed data. Proper measurement of wind speed is expensive and time consuming, and average wind speeds can vary markedly over short distances because of terrain effects. For these reasons, it is often necessary to synthesize wind data from estimated monthly average wind speeds.

Many countries have published wind atlases:

- Wind maps for many US states are available at www.eere.energy.gov/windpoweringamerica/wpa/wind_maps.asp.
- The Canadian Wind Atlas is available at www.windatlas.ca.

A number of other websites provide wind speed data:

- The website www.weatherbase.com provides monthly average wind speed data for many cities around the world.
- The Windustry website maintains a list of US wind data resources at www.windustry.com/resources/windmaps.htm.
- The US National Climatic Data Center provides monthly average wind speed data for many US cities at
www.ncdc.noaa.gov/ol/climate/online/ccd/avgwind.html. To convert from mph to m/s, divide by 2.23694.

- The Technical University of Denmark maintains a database of wind characteristics at www.winddata.com.

**Renewable Power System Components**

Several retailers sell components for renewable power systems. The website www.ecobusinesslinks.com maintains a list of renewable power retailers around the world. A few have very helpful websites providing cost and performance data for PV panels, wind turbines, hydro turbines, batteries, converters, and other system components. Check out:

- Real Goods at www.realgoods.com
- The Alternative Energy Store at www.altenergystore.com
- SolarEnergy.com at www.solarenergy.com
- The Solar Biz at www.thesolar.biz
- The Energy Development Co-operative at www.unlimited-power.co.uk

Other sources of cost and performance data for renewable power system components include:

- The California Energy Commission, at www.energy.ca.gov/distgen/economics/economics.html
- The Renewable Energy Technology Characterizations, a detailed report on the performance and costs of solar, wind, and biomass power systems, available at www.eere.energy.gov/power/techchar.html. This report even includes predictions of future performance and costs out to the year 2030.
- SolarBuzz, which provides price data for PV modules, inverters, batteries, and charge controllers at www.solarbuzz.com.

**Generators**

• The Distributed Generation Information Center provides summary technical and economic data on reciprocating engine generators, microturbines, and fuel cells, as well as a large library of links, at www.distributed-generation.com.

Emissions

• This help file contains a table of US grid emissions factors.

The US Environmental Protection Agency provides emissions coefficients for CO₂, SO₂, and NOₓ for US locations at their Power Profiler website at www.epa.gov/cleanenergy/powpro/screen1.html.

The EPA’s eGRID website contains even more emissions data, including state-by-state average emissions factors for all the pollutants that HOMER models.


Policies and Incentives

• For information on current net metering policies across the United States, see the US Department of Energy web page on the topic at www.eere.energy.gov/greenpower/markets/netmetering.shtml

• For a list of renewable energy incentives across the United States, see the Database of State Incentives for Renewable Energy at www.dsireusa.org.
APPENDIX E
TERMS RELATED TO ECONOMIC ANALYSIS AND DATA

1. TOTAL NET PRESENT COST

Type: Output Variable
Units: $
Symbol: C_{NPC}$

The total net present cost (NPC) of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

2. Levelized Cost of Energy

Type: Output Variable
Units: $/kWh
Symbol: COE

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{C_{ann,tot} - H_{served} c_{boiler}}{E_{served}}$$

$C_{ann,tot} = $ total annualized cost of the system [$/yr] 
$c_{boiler} = $ boiler marginal cost [$/kWh] 
$H_{served} = $ total thermal load served [kWh/yr] 
$E_{served} = $ total electrical load served [kWh/yr]
The second term in the numerator is the portion of the annualized cost that results from serving the thermal load. In systems that do not serve a thermal load ($H_{thermal}=0$) this term will equal zero.

3. Annualized Cost

The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component.

HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor, as in the following equation

$$C_{ann} = CRF(i, R_{proj})C_{NPC}$$

$C_{NPC}$ = the net present cost [$]

$i$ = the annual real interest rate [%]

$R_{proj}$ = the project lifetime [yr]

$CRF()$ = a function returning the capital recovery factor

4. Renewable Fraction

Type: Output Variable

Units: none

Symbol: $f_{ren}$

The renewable fraction is the fraction of the energy delivered to the load that originated from renewable power sources. HOMER calculates the renewable fraction using the following equation

$$f_{ren} = 1 - \frac{E_{nonren} - E_{grid, sales} + H_{nonren}}{E_{served} + H_{served}}$$

$E_{nonren}$ = nonrenewable electrical production [kWh/yr]

$E_{grid, sales}$ = energy sold to the grid [kWh/yr]

$H_{nonren}$ = nonrenewable thermal production [kWh/yr]
E_{served} = total electrical load served [kWh/yr]

H_{served} = total thermal load served [kWh/yr]

5. Renewable Penetration

Type: Output Variable
Units: None
Symbol: p_{ren}

In every time step, HOMER calculates the renewable penetration using the following equation:

\[ P_{ren} = \frac{P_{ren}}{L_{served}} \]

Where:
\[ P_{ren} = \text{total renewable electrical power output in this time step [kW]} \]
\[ L_{served} = \text{total electrical load served in this time step [kW]} \]

6. One-Hour Autocorrelation Factor

Type: Input Variable
Units: none
Symbol: r_1

Typical Range: 0.80 - 0.95

7. Weibull k Value

Type: Input Variable
Units: none
Symbol: k
Typical Range: 1.5 - 2.5

The Weibull k value, or Weibull shape factor, is a parameter that reflects the breadth of a distribution of wind speeds. HOMER fits a Weibull distribution to the wind speed data, and the k value refers to the shape of that distribution.

8. Diurnal Pattern Strength

Type: Input Variable
Units: none
Symbol: d
Typical Range: 0.0 - 0.4

SOLAR AND WIND DATA FOR THE SELECTED SITE: CHARANKA, KUTCH, GUJARAT, INDIA (Latitude: 23.04° and Longitude: 72.38°)

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Solar Radiation</th>
<th>Clearness Index</th>
<th>Wind Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JANUARY</td>
<td>4.50</td>
<td>0.51</td>
<td>5.9</td>
</tr>
<tr>
<td>FEBRUARY</td>
<td>5.12</td>
<td>0.52</td>
<td>6.1</td>
</tr>
<tr>
<td>MARCH</td>
<td>5.96</td>
<td>0.50</td>
<td>6.5</td>
</tr>
<tr>
<td>APRIL</td>
<td>6.41</td>
<td>0.54</td>
<td>8.0</td>
</tr>
<tr>
<td>MAY</td>
<td>6.59</td>
<td>0.53</td>
<td>9.1</td>
</tr>
<tr>
<td>JUNE</td>
<td>5.93</td>
<td>0.46</td>
<td>8.8</td>
</tr>
<tr>
<td>JULY</td>
<td>4.73</td>
<td>0.45</td>
<td>8.6</td>
</tr>
<tr>
<td>AUGUST</td>
<td>4.49</td>
<td>0.44</td>
<td>7.4</td>
</tr>
<tr>
<td>SEPTEMBER</td>
<td>5.14</td>
<td>0.53</td>
<td>7.1</td>
</tr>
<tr>
<td>OCTOBER</td>
<td>5.12</td>
<td>0.55</td>
<td>5.5</td>
</tr>
<tr>
<td>NOVEMBER</td>
<td>4.55</td>
<td>0.54</td>
<td>5.5</td>
</tr>
<tr>
<td>DECEMBER</td>
<td>4.15</td>
<td>0.51</td>
<td>5.9</td>
</tr>
</tbody>
</table>
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