Design and Simulation of Micro-Power System of Renewables

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4. Micropower System Modeling using HOMER – part 1

TVET Program

Charles Kim, Ph.D.
Howard University, Washington, DC USA

January 21-25, 2012
Course Contents and Schedule

- **Day 3**
  - HOMER Simulation 1
    - Input Requirements
    - Component Data Determination - Diesel, Solar, Wind, and Battery
    - Simulation Details
  - Micro-Power System Design
    - Off-grid system design --- Isolated System
    - Combination of Renewable sources

- **Day 4**
  - HOMER Simulation 2
    - Grid Data Details
    - Grid-Connected System Design
  - Team Practice
    - Isolated or Grid-Connected Power System Design

- **Day 5**
  - Team Presentation
  - Summary and Conclusions
HOMER

- Homer (Hybrid Optimization Model for Electric Renewables)

- Simulation
- Optimization
- Sensitivity Analysis
Homer – a tool

A tool for designing micropower systems
- Village power systems
- Stand-alone applications and Hybrid Systems
- Micro grid

- Wind turbines
- PV
- Batteries
- Diesels
- Microturbines
- Fuel cells
- Small hydro
- Small modular biomass
- Grid connection
Homer - capabilities

- Finds combination components that can service a load the lowest cost with answering the following questions:
  - Should I buy a wind turbine, PV array, or both?
  - Will my design meet growing demand?
  - How big should my battery bank be?
  - What if the fuel price changes?
  - How should I operate my system?
  - And many others...
Homer - Features

- Simulation—Estimate the cost and determine the feasibility of a system design over the 8760 hours in a year
- Optimization—Simulate each system configuration and display list of systems sorted by net present cost (NPC)
  - Life-Cycle Cost:
    - Initial cost – purchases and installation
    - Cost of owning and O&M and replacement
  - NPC: Life-cycle cost expressed as a lump sum in “today’s dollars”
- Sensitivity Analysis—Perform an optimization for each sensitivity variable
Features

- Homer can accept max 3 generators
  - Fossil Fuels
  - Biofuels
  - Cogeneration

- Renewable Technologies
  - Solar PV
  - Wind
  - Biomass and biofuels
  - Hydro

- Emerging Technologies
  - Fuel Cells
  - Microturbines
  - Small Modular biomass

- Grid Connected System
  - Rate Schedule, Net metering, and Demand Charges

- Grid Extension
  - Breakeven grid extension distance: minimum distance between system and grid that is economically feasible
Features

Loads
- Electrical
- Thermal
- Hydrogen

Resources
- Wind speed (m/s)
- Solar radiation (kWh/m²/day)
- Stream Flow (L/s)
- Fuel price ($/L)
1. Collect Information
   - Electric demand (load)
   - Energy resources

2. Define Options (Gen, Grid, etc)

3. Enter Load Data

4. Enter Resource Data

5. Enter Component Sizes and Costs

6. Enter Sensitivity Variable Values

7. Calculate Results

8. Examine Results

Caveat: HOMER is only a model. HOMER does not provide "the right answer" to questions. It does help you consider important factors, and evaluate and compare options.
HOMER Users

- **System designers:**
  - evaluate technology options

- **Project managers:**
  - evaluate costs of different options

- **Program managers:**
  - explore factors that affect system design (resource availability, fuel price, load size, carbon emissions, etc.)

- **Educators:**
  - teach and learn about renewable energy technologies
HOMER software

¿NREL → Homer Energy

New Distribution Process for NREL's HOMER Model

Note! HOMER is now distributed and supported by Homer Energy (www.homerenergy.com)

To meet the renewable energy industry’s needs, NREL started developing HOMER in 1997. It is now charged by more than 30,000 individuals and universities worldwide.

HOMER is a computer model that simplifies both off-grid and grid-connected power generation and distributed generation (DG) applications. Its optimization and sensitivity analysis algorithms allow the user to evaluate the number of technology options and to account for variations in technology costs and energy resource availability. Originally...
HOMER download

- Get the “LEGACY” version free
  - Registration required
- Or, get the installation file from me.

Try HOMER

HOMER 2 is the supported version of the HOMER software for modeling and optimizing microgrids.

HOMER 2 is available at no cost and no obligation for a 2 week trial period. No credit card or payment information is required to try the software. The trial version is fully functional.

If you wish to license HOMER 2 for an additional 6 months at the end of your trial, you may do so for $99.99.

(You will be asked to log in or create an account in order to download, but no payment information will be requested.)

Are you looking for HOMER Legacy? HOMER Legacy is an unsupported, never updated, no-cost version of HOMER. You may obtain a 6-month license for HOMER Legacy, which is renewable indefinitely. We ask only that you share some basic information about how you are using the software. Download HOMER Legacy here. (You will be asked to log in or create an account in order to download HOMER Legacy.)
HOMER legacy for free

Download HOMER software

HOMER: The Hybrid Optimization Model for Electric Renewables

Try HOMER free for 14 days Free

Purchase a 6-month HOMER license $99 - $49 previous user discount

*Download and install the trial before purchasing.

Resources for HOMER Users, Sample Files, etc.

Sample data files for HOMER All Sample Files

Resource Files TMY2 Solar data

Legacy Software

HOMER Legacy Free

Renew HOMER Legacy (was HOMER 2.68) Free

VIPOR* Free

* VIPOR optimizes the layout of wires and transformers within a mini-grid. We offer it for free because it is not fully documented or supported but you are welcome to use it.
HOMER - Intro

HOMER (Hybrid Optimization Model for Electric Renewables): Micropower Optimization computer model developed by NREL.

“Micropower system”: a system that generates electricity, and possibly heat, to serve a nearby load.

Micro Grid

- A solar–battery system serving a remote load
- A wind–diesel system serving an isolated village
- A grid-connected natural gas micro-turbine providing electricity and heat to a factory.

Models power system’s physical behavior and its life-cycle cost [installation cost + O&M cost]

Design options on technical and economic merit
HOMER – Principal 3 tasks

- **Simulation**: HOMER models the performance of a particular micropower system configuration each hour of the year to determine
  - its technical feasibility (i.e., it can adequately serve the electric and thermal loads and satisfy other constraints) and
  - life-cycle cost.

- **Optimization**: HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost.
  - Optimization determines the optimal value of the variables such as the mix of components that make up the system and the size or quantity of each.

- **Sensitivity Analysis**: HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs such as average wind speed or future fuel price
The simulation process determines how a particular **system configuration** and an **operating strategy** that defines how those components work together, would behave in a given setting over a **long period of time**.

- Home can simulate variety of micropower system configuration
- **1-hour time step** to model the behavior of the sources involving intermittent renewable power sources with **acceptable accuracy**
A system with **battery bank** and **generator** requires dispatch strategy.

Dispatch strategy: A set of rules governing how the system **charges** the battery bank.

- **(LF) Load-following dispatch**: Renewable power sources charge the battery but the generators do not.

- **(CC) Cycle-charging dispatch**: Whenever the generators operate, they produce more power than required to serve the load with surplus electricity going to charge the battery bank.

Life Cycle Cost of the system is represented by total net present cost (NPC):

- NPC includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present.

- Any revenue from the sale of power to the grid reduces the total NPC.

- NPC is the negative of NPV (Net Present Value).
NPV & “Time value of money”

- Compare money today with money in the future
- Relationship between $1 today and $1 tomorrow
- $1 (time t) → $ ? (time t+1)
- Case: Invest in a piece of land that costs $85,000 with certainty that the next year the land will be worth $91,000 [a sure $6,000 gain], given that the guaranteed interest in the bank is 10%?

- Future Value (If invested in the bank) perspective

\[ FV = C_0 \times (1 + r) \]

\[ $85,000 \times (1 + 0.1) = $93,500 \]

- Present Value (PV) perspective

\[ PV \times (1 + 0.1) = $91,000 \]

\[ PV = \frac{$91,000}{1.1} = $82,727.27 \]

- \[ PV = \frac{C_1}{1 + r} \], where \( C_1 \) is cash flow at date 1

Do not to buy the land.
**NPV (Net Present Value)**

- **Net Present Value (NPV):**
  - Present value of future cash flows minus the present value of the cost

  \[
  NPV = PV - Cost.
  \]

  \[
  NPV = \frac{91,000}{1.1} - 85,000 = -2,273
  \]

- **Formula:**

  \[
  NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}
  \]

  \[
  NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}.
  \]
A company is determining whether they should invest in a new project. The company will expect to invest $500,000 for the development of their new product. The company estimates that the first year cash flow will be $200,000, the second year cash flow will be $300,000, and the third year cash flow to be $200,000. The expected return of 10% is used as the discount rate.

\[
NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1 + r)^i}.
\]

<table>
<thead>
<tr>
<th>Year</th>
<th>Cash Flow</th>
<th>Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-$500,000</td>
<td>-$500,000</td>
</tr>
<tr>
<td>1</td>
<td>$200,000</td>
<td>$181,818.18</td>
</tr>
<tr>
<td>2</td>
<td>$300,000</td>
<td>$247,933.88</td>
</tr>
<tr>
<td>3</td>
<td>$200,000</td>
<td>$150,262.96</td>
</tr>
</tbody>
</table>

Net Present Value = $80,015.02
**Optimization**

- Best possible system configuration that satisfies the user-specified constraints at the **lowest total net present cost**.
- Decide on the mix of components that the system should contain, the **size** or **quantity** of each component, and the **dispatch strategy** (LF or CC) the system should use.
- Ranks the feasible ones according to total net present cost.
- Presents the feasible one with the lowest total net present cost as the optimal system configuration.
Optimization Example

- Configuration and 140 (5x1x7x4=140) search spaces

- Overall Optimization results

<table>
<thead>
<tr>
<th>FL30 (Quantity)</th>
<th>Gen (kW)</th>
<th>Batteries (Quantity)</th>
<th>Converter (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>32</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>48</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Categorized optimization result

<table>
<thead>
<tr>
<th>FL30</th>
<th>Gen (kW)</th>
<th>Batt. (kW)</th>
<th>Conv. (kW)</th>
<th>Initial Capital</th>
<th>Total NPC</th>
<th>COE ($/kWh)</th>
<th>Diesel (L)</th>
<th>Gen (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$216,500</td>
<td>$849,905</td>
<td>0.273</td>
<td>75,107</td>
<td>4,528</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>48</td>
<td>30</td>
<td>$200,500</td>
<td>$855,733</td>
<td>0.275</td>
<td>78,061</td>
<td>4,910</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$216,500</td>
<td>$849,905</td>
<td>0.273</td>
<td>75,107</td>
<td>4,528</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$86,500</td>
<td>$885,175</td>
<td>0.284</td>
<td>101,290</td>
<td>5,528</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$86,500</td>
<td>$885,175</td>
<td>0.284</td>
<td>101,290</td>
<td>5,528</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>64</td>
<td>30</td>
<td>$86,500</td>
<td>$885,175</td>
<td>0.284</td>
<td>101,290</td>
<td>5,528</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>48</td>
<td>30</td>
<td>$330,500</td>
<td>$856,335</td>
<td>0.275</td>
<td>57,654</td>
<td>3,685</td>
</tr>
</tbody>
</table>
Sensitivity Analysis

- Optimization: best configuration under a particular set of input assumptions
- Sensitivity Analysis: Multiple optimizations each using a different set of input assumptions
- "How sensitive the outputs are to changes in the inputs" – results in various tabular and graphic formats
- User enters a range of values for a single input variable:
  - Grid power price
  - Fuel price,
  - Interest rate
  - Lifetime of PV array
  - Solar Radiation
  - Wind Speed
Why Sensitivity Analysis? Uncertainty!

- When unsure of a particular variable, enter several values covering the likely range and see how the results vary across the range.
- Diesel Generator – Wind Configuration: Uncertainty in diesel fuel price with $0.6 per liter in the planning stage and 30 year generator lifetime
- Example: Spider Graph Tabular Format

---

**Spider Graph**

- Diesel Price
- FL30 Life
- Gen O&M Multiplier

**Tabular Format**

<table>
<thead>
<tr>
<th>Diesel Price ($/L)</th>
<th>FL30 Gen (kW)</th>
<th>Batt. (kW)</th>
<th>Conv. (kW)</th>
<th>Total NPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.420</td>
<td>1</td>
<td>30</td>
<td>$688,679</td>
<td></td>
</tr>
<tr>
<td>0.450</td>
<td>1</td>
<td>30</td>
<td>$721,987</td>
<td></td>
</tr>
<tr>
<td>0.480</td>
<td>1</td>
<td>30</td>
<td>$753,695</td>
<td></td>
</tr>
<tr>
<td>0.510</td>
<td>1</td>
<td>30</td>
<td>$777,748</td>
<td></td>
</tr>
<tr>
<td>0.540</td>
<td>1</td>
<td>30</td>
<td>$801,800</td>
<td></td>
</tr>
<tr>
<td>0.570</td>
<td>1</td>
<td>30</td>
<td>$825,852</td>
<td></td>
</tr>
<tr>
<td>0.600</td>
<td>1</td>
<td>30</td>
<td>$849,905</td>
<td></td>
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<tr>
<td>0.630</td>
<td>2</td>
<td>30</td>
<td>$872,093</td>
<td></td>
</tr>
<tr>
<td>0.660</td>
<td>2</td>
<td>30</td>
<td>$889,525</td>
<td></td>
</tr>
<tr>
<td>0.690</td>
<td>2</td>
<td>30</td>
<td>$906,957</td>
<td></td>
</tr>
<tr>
<td>0.720</td>
<td>2</td>
<td>30</td>
<td>$924,389</td>
<td></td>
</tr>
</tbody>
</table>
Sensitivity Analysis on Hourly Data Sets

- Sensitivity analysis on hourly data sets such as primary electric load, solar/wind resource
- 8760 values that have a certain average value with scaling variables
- Example: Graphical Illustration
  - Hourly primary load data with an annual average of 22 kWh/day with average wind speed of 4 m/s
  - Primary load scaling variables of 20, 40, ---, 120 kWh/day & 3, 4, ---, 7 m/s wind speeds.
Physical Modeling - Loads

Load: a demand for electric or thermal energy
3 types of loads

- **Primary load**: electric demand that must be served according to a particular schedule
  - When a customer switches on, the system must supply electricity
  - kW for each hour of the load
  - Lights, radio, TV, appliances, computers,

- **Deferrable load**: electric demand that can be served at any time within a certain time span
  - Tank – drain concept
  - Water pumps, ice makers, battery-charging station

- **Thermal load**: demand for heat
  - Supply from boiler or waste heat recovered from a generator
  - Resistive heating using excess electricity
Physical Modeling - Resources

- **Solar Resources**: average global solar radiation on horizontal surface (kWh/m² or kWh/m²-day) or monthly average clearness index (atmosphere vs. earth surface). Inputs – solar radiation values and the latitude and the longitude. Output – 8760 hour data set.

- **Wind Resources**: Hourly or 12 monthly average wind speeds. Anemometer height. Wind turbine hub height. Elevation of the site.

- **Hydro Resources**: Run-of-river hydro turbine. Hourly (or monthly average) stream flow data.

- **Biomass Resources**: wood waste, agricultural residue, animal waste, energy crops. Liquid or gaseous fuel.

- **Fuel**: density, lower heating value, carbon content, sulfur content. **Price and consumption limits**
HOMER models 10 types of part that generates, delivers, converts, or stores energy:

- 3 intermittent renewable resources:
  - PV modules (dc)
  - wind turbines (dc or ac)
  - run-of-river hydro turbines (dc or ac)

- 3 dispatchable energy sources: [control them as needed]
  - Generators
  - the grid
  - boilers

- 2 energy converters:
  - Converters (dc $\rightarrow$ ac)
  - Electrolyzers (ac,dc $\rightarrow$ electrolysis $\rightarrow$ Hydrogen)

- 2 types of energy storage:
  - batteries (dc)
  - hydrogen storage tanks
Components- PV, Wind, and Hydro

**PV Array**
- $f_{PV}$: PV derating factor
- $Y_{PV}$: Rated Capacity [kW]
- $I_T$: Global Solar Radiation incidence on the surface of the PV array [kW/m²]
- $I_S$: Standard amount of radiation, 1 kW/m².

**Wind Turbine**
- Wind turbine power curve

**Hydro Turbine**
- Power Output Eqn = Turbine efficiency, density of water, gravitational acceleration, net head, flow rate through the turbine

$$P_{hyd} = \eta_{hyd} \rho_{water} g h_{\text{net}} Q_{\text{turbine}}$$
Generators

Principal properties: max and min electrical power output, expected lifetime, type of fuel, fuel curve

Fuel curve: quantity of fuel consumed to produce certain amount of electrical power. Straight line is assumed.

Fuel Consumption \((F)\) \([L/h]\), \([m^3/h]\), or \([kg/h]\):

\[
F = F_0 Y_{gen} + F_1 P_{gen}
\]
Components - Generator

- Generator costs: initial capital cost, replacement cost, and annual O&M cost per operating hour (not including fuel cost)

- **Fixed cost:** cost per hour of simply running the generator without producing any electricity

\[
c_{\text{gen, fixed}} = c_{\text{om, gen}} + \frac{C_{\text{rep, gen}}}{R_{\text{gen}}} + F_{0} Y_{\text{gen}} c_{\text{fuel, eff}}
\]

- \(c_{\text{om, gen}}\) is the O&M cost per hour,
- \(C_{\text{rep, gen}}\) the replacement cost
- \(R_{\text{gen}}\) the generator lifetime in hours.
- \(F_{0}\) the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt
- \(Y_{\text{gen}}\) the capacity of the generator (kW),
- \(c_{\text{fuel, eff}}\) the effective price of fuel in dollars per quantity of fuel.

- **Marginal cost:** additional cost per kWh of producing electricity from the generator

\[
c_{\text{gen, mar}} = F_{1} c_{\text{fuel, eff}}
\]

- \(F_{1}\) is the fuel curve slope in quantity of fuel per hour per kilowatthour
Battery Bank

Principal properties:
- nominal voltage
- **capacity curve**: discharge capacity in Ah vs. discharge current in A
- **lifetime curve**: number of discharge-charge cycles vs. cycle depth
- **minimum state of charge**: State of charge below which must not be discharged to avoid permanent damage
- **round-trip efficiency**: percentage of energy going in to that can be drawn back out

Example capacity curve for a deep-cycle US-250 battery (Left)
Components - Battery

Battery Lifetime Curve and Example for US-250

\[
R_{\text{batt}} = \min \left( \frac{N_{\text{batt}} Q_{\text{life}}}{Q_{\text{thrt}}}, R_{\text{batt},f} \right)
\]

- \(R_{\text{batt}}\): life of the battery bank
- \(N_{\text{batt}}\): the number of batteries in the battery bank
- \(Q_{\text{life}}\): the lifetime throughput of a single battery
- \(Q_{\text{thrt}}\): the annual throughput (the total amount of energy that cycles through the battery bank in one year)
- \(R_{\text{batt},f}\): the float life of the battery (the maximum life regardless of throughput)

Battery Fixed cost = $0

Battery Marginal Cost = Battery Wear Cost + Battery Energy Cost

- **Battery Wear Cost**: the cost per kWh of cycling energy through the battery bank
- **Battery energy cost**: the average cost of the energy stored in the battery bank
Components - Battery

- **Battery energy cost** each hour: dividing the **total year-to-date cost of charging the battery bank** by the **total year-to-date amount of energy put into the battery bank**
  - Load-following dispatch strategy: since charged only by surplus electricity, charging cost of battery is always zero
  - Cycle-charging strategy: charging cost is not zero.

- **Battery wear cost**:

\[
c_{bw} = \frac{C_{\text{rep,batt}}}{N_{\text{batt}} Q_{\text{lifetime}} \sqrt{\eta_{rt}}}
\]

- \( C_{\text{rep,batt}} \) is the replacement cost of the battery bank (dollars)
- \( N_{\text{batt}} \) is the number of batteries in the battery bank.
- \( Q_{\text{lifetime}} \) is the lifetime throughput of a single battery (kWh)
- \( \eta_{rt} \) is the round-trip efficiency.
Components - Grid

- Grid and Grid Power Cost
  - Grid power price [$/kWh]: charges for energy purchase from grid
  - Demand rate [$/kW/month]: peak grid demand
  - Sellback rate [$/kWh]: price the utility pays for the power sold to grid

- Net Metering: a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period.
  - Purchase > sales: consumer pays the utility an amount equal to the net grid purchases times the grid power cost.
  - sales > purchases: the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is typically less than the grid power price, and often zero.

- Grid fixed cost: $0

- Grid marginal cost: current grid power price plus any cost resulting from emissions penalties.
Example of Grid Rate for Medium General Service

- Year 2007 example
- Medium General Service:
  - Monthly Use: > 3500kWh
  - Summer Peak: <300kW
- Rate:
  - Customer charge: $25.42/month
  - Energy Charge: $0.062533/kWh [summer], $0.069533/kWh [winter]
  - Demand charge: $22.69535/kW [summer], $14.7419/kW [winter]
- A Restaurant (a summer month: Jun - Sep) 24000 kWh, 150kW demand
  - Customer charge: $25.42
  - Energy charge: $1500.79
  - Demand charge: $3404.02
Example of a residential customer

Welcome to Manage Your Account

<table>
<thead>
<tr>
<th>Last Payment Received On</th>
<th>December 17, 2012</th>
<th>$51.82</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Charges Billed On</td>
<td>January 04, 2013</td>
<td>$64.12</td>
</tr>
<tr>
<td>Total Amount Due Will Be Drafted On Or After</td>
<td>January 15, 2013</td>
<td>$64.12</td>
</tr>
<tr>
<td>Next Bill Date</td>
<td>February 04, 2013</td>
<td></td>
</tr>
</tbody>
</table>

South Korea

<table>
<thead>
<tr>
<th>Energy Efficiency/CO2(^1) Indicators</th>
<th>Units</th>
<th>1980</th>
<th>1990</th>
<th>2000</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential, service and agriculture sectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average electricity consumption of households per capita</td>
<td>kWh/cap</td>
<td>139</td>
<td>414</td>
<td>789</td>
<td>1130</td>
</tr>
<tr>
<td>Average electricity consumption per household</td>
<td>kWh/hh</td>
<td>728</td>
<td>1716</td>
<td>2412</td>
<td>3822</td>
</tr>
<tr>
<td>Average electricity consumption of electrified households</td>
<td>kWh/hh</td>
<td>728</td>
<td>1716</td>
<td>2412</td>
<td>3822</td>
</tr>
<tr>
<td>Households consumption for electrical appliances and lighting</td>
<td>kWh/hh</td>
<td>0</td>
<td>1541</td>
<td>1980</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
Boiler

- Assumed to provide unlimited amount of thermal energy on demand
- Input: type of fuel, boiler efficiency, emission
- Fixed cost: $0
- Marginal cost:

\[ c_{\text{boiler,mar}} = \frac{3.6c_{\text{fuel,eff}}}{\eta_{\text{boiler}} LHV_{\text{fuel}}} \]

- \( c_{\text{fuel,eff}} \) is the effective price of the fuel (including the cost of any penalties on emissions) in dollars per kilogram
- \( \eta_{\text{boiler}} \) is the boiler efficiency
- \( LHV_{\text{fuel}} \) is the lower heating value of the fuel in MJ/kg
Heating Value of Fuel

**Higher Heating Value (HHV)**
- The Higher Heating Value (HHV) is the total amount of heat in a sample of fuel - including the energy in the water vapor that is created during the combustion process.

**Lower Heating Value (LHV)**
- The Lower Heating Value (LHV) is the amount of heat in a sample of fuel minus the energy in the combustion water vapor. The Lower Heating Value is always less than the Higher Heating Value for a fuel.

### Typical Higher and Lower Heat Values for Fuels

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Higher Heat Value (kJ/kg)</th>
<th>Lower Heat Value (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood, Dry</td>
<td>21</td>
<td>19.7</td>
</tr>
<tr>
<td>Grass, Dry</td>
<td>18.5</td>
<td>17.4</td>
</tr>
<tr>
<td>Dairy Manure, Dry</td>
<td>20.5</td>
<td>19.3</td>
</tr>
<tr>
<td>Coal, Bituminous</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>42.5</td>
<td>38.1</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>45.9</td>
<td>43</td>
</tr>
<tr>
<td>Gasoline</td>
<td>47.9</td>
<td>43.8</td>
</tr>
<tr>
<td>Ethanol</td>
<td>29.8</td>
<td>26.9</td>
</tr>
</tbody>
</table>
Components – Converter & Fuel Cell

Converter
- Inversion and Rectification
- Size: max amount of power it delivers
- Synchronization ability: parallel run with grid
- Efficiency
- Cost: capital, replacement, o&m, lifetime

Electrolyzer:
- Size: max electrical input
- Min load ratio: the minimum power input at which it can operate, expressed as a percentage of its maximum power input.
- Cost: capital, replacement, o&m, lifetime

Hydrogen Tank
- Size: mass of hydrogen it can contain
- Cost: capital, replacement, o&m, lifetime
Operating Reserve

Operating Reserve

Safety margin for reliable electricity supply despite variability in load and renewable power supply

Required amount of reserve: Fraction of load at an hour + fraction of the annual peak primary load + fraction of PV power output at that hour + fraction of the wind power output at that hour.

Example for a wind-diesel system

User defines operating reserve as 10% of the hourly load + 50% of the wind power output

Load = 140kW; Wind power output = 80kW

Required Operating Reserve = 140kW*0.1 + 80kW*0.5=54 kW

Diesel Generator should provide 60 kW (140 – 80) + 54 = 114 kW

So, the capacity of the diesel gen must be at least 114 kW
System Dispatch

- Dispatchable and non-dispatchable power sources

- Dispatchable source: provides operating capacity in an amount equal to the maximum amount of power it could produce at a moment’s notice.
  - **Generator**
    - In operation: dispatchable opr capacity = rated capacity
    - non-operation: dispatchable opr capacity = 0
  - **Grid:** dispatchable opr capacity = max grid demand
  - **Battery:** dispatchable opr capacity = current max discharge power

- Non-dispatchable source
  - Operating capacity (PV, Wind, or Hydro) = the amount the source is currently producing (Not the max amount it can produce)

- **NOTE:** If a system is ever unable to supply the required amount of load plus operating reserve, HOMER records the shortfall as “capacity shortage”.
  - HOMER calculates the total amount of such shortages over the year and divides the total annual capacity shortage by the total annual electric load.
Dispatch Strategy for a system with Gen and Battery

**Dispatch Strategy**

- **Whether and how the generator should charge the battery bank?**
- **There is no deterministic way to calculate the value of charging the battery bank** – the value of charging in one hour depends on what happens in future hours. [enter Wind power which can provide enough power the next hour – then the diesel power into battery would be wasted]

- **HOMER provides 2 simple strategies** and lets user model them both to see which is better in any particular situation.
  - **Load-following**: a generator produces only enough power to serve the load, and does not charge the battery bank.
  - **Cycle-Charging**: whenever a generator operates, it runs at its maximum rated capacity and charges the battery bank with the excess
  - It was found that over a wide range of conditions, **the better of these two simple strategies** is virtually as cost-effective as the ideal predictive strategy.

- **“Set-point state charge”**: in the cycle-charging strategy, generator charges until the battery reaches the set-point state of charge.
Control of Dispatchable System Components

- Fundamental principle: cost minimization – fixed cost and marginal cost
- Example: Hydro-Diesel-Battery System

- Dispatchable sources: diesel generator [80kW] and battery [40kW]
- If net load is negative: excess power charges battery
- If net load is positive: operate diesel OR discharge battery
Dispatch Control Example

Hydro-Diesel-Battery System

- Net load < 20kW: Discharge the battery
- Net load > 20kW: Operate the diesel generator
Load Priority

- Decisions on allocating electricity
- Presence of ac and dc buses
- Electricity produced on one bus will serve
  - First, primary load on the same bus
  - Then, primary load on the opposite bus
  - Then, deferrable load on the same bus
  - Then, charge battery bank
  - Then, sells to grid
  - Then, electrolyzer
  - Then, dump load
Economic Modeling

- Conventional sources: low capital and high operating costs
- Renewable sources: high initial capital and low operating costs
- Life-cycle costs = capital + operating costs
- HOMER uses NPC for life-cycle cost
  - NPC is the opposite of NPV (Net present value)
- NPC includes: initial construction, component replacements, maintenance, fuel, cost of buying grid, penalties, and revenues (selling power to grid + salvage value at the end of the project lifetime)

\[
S = C_{\text{rep}} \frac{R_{\text{rem}}}{R_{\text{comp}}}
\]

- \(S\) is the salvage value.
- \(C_{\text{rep}}\) the replacement cost of the component
- \(R_{\text{rem}}\) the remaining life
- \(R_{\text{comp}}\) the lifetime of the component.
Real Cost

- All price escalates at the same rate over the lifetime
- Inflation can be factored out of analysis by using the real (inflation-adjusted) interest rate (rather than nominal interest rate) when discounting the future cash flows to the present
- Real interest rate = nominal interest rate – inflation rate
- Real cost → in terms of constant dollars
NPC and COE

Total NPC

\[ C_{NPC} = \frac{C_{ann,tot}}{CRF(i, N)} \]

- \( C_{ann,tot} \) is the total annualized cost.
- \( i \) is the annual real interest rate (the discount rate).
- \( N \) is the project lifetime.
- \( CRF(\cdot) \) is the capital recovery factor.

\[ CRF(i, N) = \frac{i(1 + i)^N}{(1 + i)^N - 1} \]

Levelized Cost of Energy (COE): average cost/kWh

\[ COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \]

- \( C_{ann,tot} \) is the total annualized cost.
- \( E_{prim} \) total amounts of primary load.
- \( E_{def} \) total amounts of deferrable load.
- \( E_{grid,sales} \) is the amount of energy sold to the grid.
Example Case – Micro Grid in Sri Lanka

- **Load profile:**
  - Base load of 5W, small peaks of 20 W, peak load of 40W; total daily average load = 350 Wh
  - Sensitivity analysis range: [0.3kW/h, 16kWh/d]

- **Solar Resource**
  - 7.30’ Latitude & 81.30 longitude
  - NASA Surface Meteorology and Solar Energy Web: average solar radiation = 5.43 kWh/m²/d.

- **Diesel Fuel Price**
  - $0.4/L – $0.7/L
  - Sensitivity analysis range: [$0.3, 0.8] with increment of $0.1/L

- **Economics:**
  - Real annual interest rate at 6%

- **Reliability Constraints**
  - 0% annual capacity shortage
  - Sensitivity Analysis range: [0.5 – 5]%
Example Case – Micro Grid in Sri Lanka

- PV: de-rating factor at 90%
- Battery: T-105 or L-16
- Converters: efficiency at 90% for inversion and 85% for rectification
- Generator: not allowed to operate at less than 30% capacity

<table>
<thead>
<tr>
<th>Component</th>
<th>Size</th>
<th>Capital Cost ($/kW)</th>
<th>Replacement Cost ($/kW)</th>
<th>O&amp;M Cost ($/year)</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Panels</td>
<td>0.05 – 5.0 kW</td>
<td>$7,500</td>
<td>$7,500</td>
<td>0.00</td>
<td>20 years</td>
</tr>
<tr>
<td>Trojan T-105 Batteries</td>
<td>225 Ah / 6 volt (bank size: 1 – 54 batteries)</td>
<td>$75/battery</td>
<td>$75/battery</td>
<td>$2.00/year</td>
<td>845 kWh of throughput per battery</td>
</tr>
<tr>
<td>Converter</td>
<td>0.1 – 4.0 kW</td>
<td>$1,000</td>
<td>$1,000</td>
<td>$100/year</td>
<td>15 years</td>
</tr>
<tr>
<td>Generator</td>
<td>4.25 kW</td>
<td>$2,550</td>
<td>$2,550</td>
<td>$0.15/hour</td>
<td>5000 hours</td>
</tr>
</tbody>
</table>
Analysis Result

- **Diesel price $0.3/L**

- **Diesel Price $0.8/L**
HOMER: Getting Started – with existing file

2. Download {save as } “ExampleProject.hmr”
3. Open the Example Project File: ExampleProject.hmr
4. Click the Primary Load
5. Exit out of HOMER – We have things to do
Find the Site [Location]

- Latitude and Longitude
- 36.76 & 127.28 ??
Solar and Wind Data

- Click “Homer”, input latitude and longitude, then click “Get Homer Data”
Solar Radiation and Wind Speed Data

- Monthly Solar Radiation [kW/m²-day] and Wind Speed [m/s]

```xml
<data>
  <monthly>
    <monthly_average_radiation>
      <float> 2.82 </float> Jan
      <float> 3.69 </float> Feb
      <float> 4.49 </float> Mar
      <float> 5.40 </float> Apr
      <float> 5.57 </float> May
      <float> 4.99 </float> Jun
      <float> 4.17 </float> Jul
      <float> 4.19 </float> Aug
      <float> 3.95 </float> Sep
      <float> 3.55 </float> Oct
      <float> 2.76 </float> Nov
      <float> 2.55 </float> Dec
    </monthly_average_radiation>
  </monthly>
  <monthly_average_wind_speed>
    <float> 3.46 </float>
    <float> 3.66 </float>
    <float> 3.81 </float>
    <float> 3.91 </float>
    <float> 3.43 </float>
    <float> 3.03 </float>
    <float> 3.02 </float>
    <float> 2.88 </float>
    <float> 2.68 </float>
    <float> 2.73 </float>
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    <float> 3.34 </float>
  </monthly_average_wind_speed>
</data>

<scaled_annual_average>
  <values>
    <float> 4.01 </float> Annual Average
    <float> 3.27 </float>
  </values>
</scaled_annual_average>
```

- <anemometer_height>
  - <values>
    <float> 50 </float>
  </values>
</anemometer_height>
Wind Finder

Windfinder - Wind & weather statistic Cheonan

<table>
<thead>
<tr>
<th>Month of year</th>
<th>Jan 01</th>
<th>Feb 02</th>
<th>Mar 03</th>
<th>Apr 04</th>
<th>May 05</th>
<th>Jun 06</th>
<th>Jul 07</th>
<th>Aug 08</th>
<th>Sep 09</th>
<th>Oct 10</th>
<th>Nov 11</th>
<th>Dec 12</th>
<th>SUM 1-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Wind dir.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind probability &gt;= 4 Beaufort (%)</td>
<td>27</td>
<td>28</td>
<td>37</td>
<td>44</td>
<td>17</td>
<td>20</td>
<td>10</td>
<td>15</td>
<td>16</td>
<td>18</td>
<td>26</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Average Wind speed (Knots)</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Average air temp. (°C)</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>22</td>
<td>26</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>23</td>
<td>16</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Wind dir. distribution Cheonan December

1 mph = 0.44704 m s⁻¹
1 knot = 0.5144444444 meters / second

www.windfinder.com
HOMER: Open the file again

- Click the generator

- 25 kW $10,000

- Minimum running at 30%
Click Wind Turbine

From the drop down list click through the wind turbines and look at the power curve. Try to find a Wind Turbine that would best maximize Average Wind Speed (m/s) :3.27
Equipment

Click PV

Lifetime, De-rating factor, slope, No-tracking
**Resource Information**

- Select Solar Resources, Wind Resources, and Diesel
- Type in Solar Radiation
- Type in Wind Speed
- Diesel Fuel Price

**Baseline data**

<table>
<thead>
<tr>
<th>Month</th>
<th>Wind Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3.460</td>
</tr>
<tr>
<td>February</td>
<td>3.660</td>
</tr>
<tr>
<td>March</td>
<td>3.810</td>
</tr>
<tr>
<td>April</td>
<td>3.920</td>
</tr>
<tr>
<td>May</td>
<td>3.480</td>
</tr>
<tr>
<td>June</td>
<td>3.030</td>
</tr>
<tr>
<td>July</td>
<td>3.020</td>
</tr>
<tr>
<td>August</td>
<td>2.990</td>
</tr>
<tr>
<td>September</td>
<td>2.680</td>
</tr>
<tr>
<td>October</td>
<td>2.730</td>
</tr>
</tbody>
</table>

Annual average: 3.264
Equipment

**Click Converter icon**

**5kW $4,000**

A converter is required for systems in which DC components serve an AC load or vice versa. A converter can be an Inverter (DC to AC), rectifier (AC to DC), or both.

Enter at least one size and capital cost value in the Costs table. Include all costs associated with the converter, such as hardware and labor. As it searches for the optimal system, HOMER considers each converter capacity in the Sizes to Consider table. Note that all references to converter size or capacity refer to inverter capacity.

The pointer over an element or click Help for more information.

**Costs**

<table>
<thead>
<tr>
<th>Size (kW)</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.000</td>
<td>4000</td>
<td>4000</td>
<td>0</td>
</tr>
</tbody>
</table>

**Sizes to consider**

<table>
<thead>
<tr>
<th>Size (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
</tr>
<tr>
<td>5.000</td>
</tr>
<tr>
<td>10.000</td>
</tr>
<tr>
<td>15.000</td>
</tr>
</tbody>
</table>

**Inverter inputs**

- Lifetime (years): 15
- Efficiency (%): 90

**Rectifier inputs**

- Capacity relative to inverter (%): 100
- Efficiency (%): 85
**Economics**
- Real interest 6%
- Lifetime 25 years

**System Control**
- Cycle-charging
Other Information

- Emission: all 0

- Constraints
  - Operating reserve 10%
  - Capacity shortage 0%
Analysis of the System

1. Click “Calculate” to start the analysis

Click Overall: view all possible combinations
Analysis of the System

- Click “Categorized”

- Now back to “Overall”, and choose any system of interest by clicking/ double clicking
**Analysis**

**Simulation Results**

- **System Architecture:**
  - 10 kW PV
  - 10 kW Rectifier
  - 25 kW Generator 1
  - 10 kW Inverter

- **Total NPC:** $365,558
- **Levelized COE:** $0.521/kWh
- **Operating Cost:** $24,450/yr

### Cash Flow Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>Capital ($)</th>
<th>Replacement ($)</th>
<th>O&amp;M ($)</th>
<th>Fuel ($)</th>
<th>Salvage ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>38,000</td>
<td>7,795</td>
<td>0</td>
<td>0</td>
<td>-4,369</td>
<td>38,426</td>
</tr>
<tr>
<td>Generator 1</td>
<td>10,000</td>
<td>64,532</td>
<td>95,953</td>
<td>186,790</td>
<td>-863</td>
<td>516,415</td>
</tr>
<tr>
<td>Converter</td>
<td>8,000</td>
<td>3,003</td>
<td>0</td>
<td>0</td>
<td>-621</td>
<td>10,717</td>
</tr>
<tr>
<td>System</td>
<td>50,000</td>
<td>75,085</td>
<td>55,953</td>
<td>186,790</td>
<td>-5,950</td>
<td>365,558</td>
</tr>
</tbody>
</table>
## PV Output

**Simulation Results**

<table>
<thead>
<tr>
<th>System Architecture</th>
<th>Electrical</th>
<th>PV</th>
<th>Converter</th>
<th>Emissions</th>
<th>Hourly Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 kW PV</td>
<td>10 kW Rectifier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 kW Generator 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 kW Inverter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Summary</th>
<th>Cash Flow</th>
<th>Electrical</th>
<th>PV</th>
<th>Gen1</th>
<th>Converter</th>
<th>Emissions</th>
<th>Hourly Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Value</td>
<td>Units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated capacity</td>
<td>10.0 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean output</td>
<td>1.13 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean output</td>
<td>27.2 kWh/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity factor</td>
<td>11.3 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total production</td>
<td>9.911 kWh/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum output</td>
<td>0.00 kW</td>
<td></td>
</tr>
<tr>
<td>Maximum output</td>
<td>5.86 kW</td>
<td></td>
</tr>
<tr>
<td>PV penetration</td>
<td>16.0 %</td>
<td></td>
</tr>
<tr>
<td>Hours of operation</td>
<td>4,390 h/yr</td>
<td></td>
</tr>
<tr>
<td>Levelized cost</td>
<td>0.303 $/kWh</td>
<td></td>
</tr>
</tbody>
</table>

- Total NPC: $363,550
- Levelized COE: $0.521/kWh
- Operating Cost: $24,460/yr

![PV Output Graph]
## Electrical Output

### Simulation Results

<table>
<thead>
<tr>
<th>System Architecture</th>
<th>10 kW PV</th>
<th>10 kW Refrigerator</th>
<th>Total NPC: $365,558</th>
<th>Operating Cost: $24,450/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 kW Generator 1</td>
<td>10 kW Inverter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Summary</th>
<th>Cash Flow</th>
<th>Electrical</th>
<th>PV</th>
<th>Gen1</th>
<th>Converter</th>
<th>Emissions</th>
<th>Hourly Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>kW/h/yr</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV array</td>
<td>9.911</td>
<td>12</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Generator 1</td>
<td>76.037</td>
<td>88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>85.948</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Consumption  | kW/h/yr   | %          |    |      |           |            |             |
|---------------|-----------|------------|    |      |           |            |             |
| AC primary load | 54,333    | 100        |    |      |           |            |             |
| Total         | 54,333    | 100        |    |      |           |            |             |

| Quantity       | kW/h/yr   | %          |    |      |           |            |             |
|----------------|-----------|------------|    |      |           |            |             |
| Excess electricity | 30,254    | 55.2       |    |      |           |            |             |
| Unused electric load | 0.000535 | 0.0        |    |      |           |            |             |
| Capacity shortage    | 0.442    | 0.0        |    |      |           |            |             |

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable fraction</td>
<td>0.115</td>
</tr>
</tbody>
</table>

### Monthly Average Electric Production

![Monthly Average Electric Production](Image)

- **PV**
- **Generator 1**
Sensitivity Analysis on Wind Power

- Click Wind resource
- Click “Edit Sensitivity Values” >> Do so for Load, Solar, and Diesel
- Wind Resources
- Primary Load
- Solar Resources
- Diesel Fuel
Sensitivity Analysis

- Save and Calculate
- New we see the tab for “Sensitivity Results”
HOMER – Input Summary Report

- HOMER Produces An Input Summary Report:
  - Click HTML Input Summary from the File menu, or click the toolbar button:
  - HOMER will create an HTML-format report summarizing all the relevant inputs, and display it in a browser. From the browser, you can save or print the report, or copy it to the clipboard so that you can paste it into a word processor or spreadsheet program.
HOMER – Simulation Result Report

- HOMER Produces A Report Summarizing The Simulation Results
  - Just click the HTML Report button in the Simulation Results window:
What is this message for?

Those messages mean that:

- You need to expand your search space to be sure you have found the cheapest system configuration.
- If the total net present cost varied with the PV size in this way, and you simulated 10, 20, 30, and 40 kW sizes, HOMER would notice that the optimal number of turbines is 40 kW, but since that was as far as you let it look, it would give you the "search space may be insufficient" warning because 50 kW may be better yet.
- It doesn't know that until you let it try 50kW and 60kW.
- If you expanded the search space, HOMER would no longer give you that warning, since the price started to go up so you have probably identified the true least-cost point.