

Hybrid Opportunities in SPUG Areas using Homer

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Outline

- Introduction to NPC-SPUG
- PV-Diesel Hybrid Options for SPUG Areas
- Modeling SPUG areas with HOMER Pro
- Hybrid Implementation Arrangements
- Challenges in Hybrid Implementation
- Conclusion

About SPUG

The National Power Corporation Small Power Utilities Group (NPC-SPUG) is mandated by law (Philippines) to undertake the electrification of areas not connected to the main transmission grid, also referred to as Missionary Areas.

SPUG OPERATIONS as of December 2012

- NPC-SPUG operates 529 generating units with a total rated capacity of 283.06 MW in 233 areas. This nationwide operation is composed of 291 land-based power plants, 1 hydroelectric plant, 1 hybrid wind turbine farm and 11 barge-mounted power plants. It serves 233 island customers consisting of 41 electric cooperatives and 10 local government units.
- NPC-SPUG generated a total of 466,569,073.77 kWh with aggregate energy sales of 443,075,715.91 kWh.

Objectives

Use Homer Pro to explore hybrid options to:

- provide 24hours power to the Islands
- reduce energy production costs and subsidy requirement from the Universal Charge for Missionary Electrification (UCME)
- promote renewable energy generation and integration without compromising grid stability and generation cost

Target Operating Hours

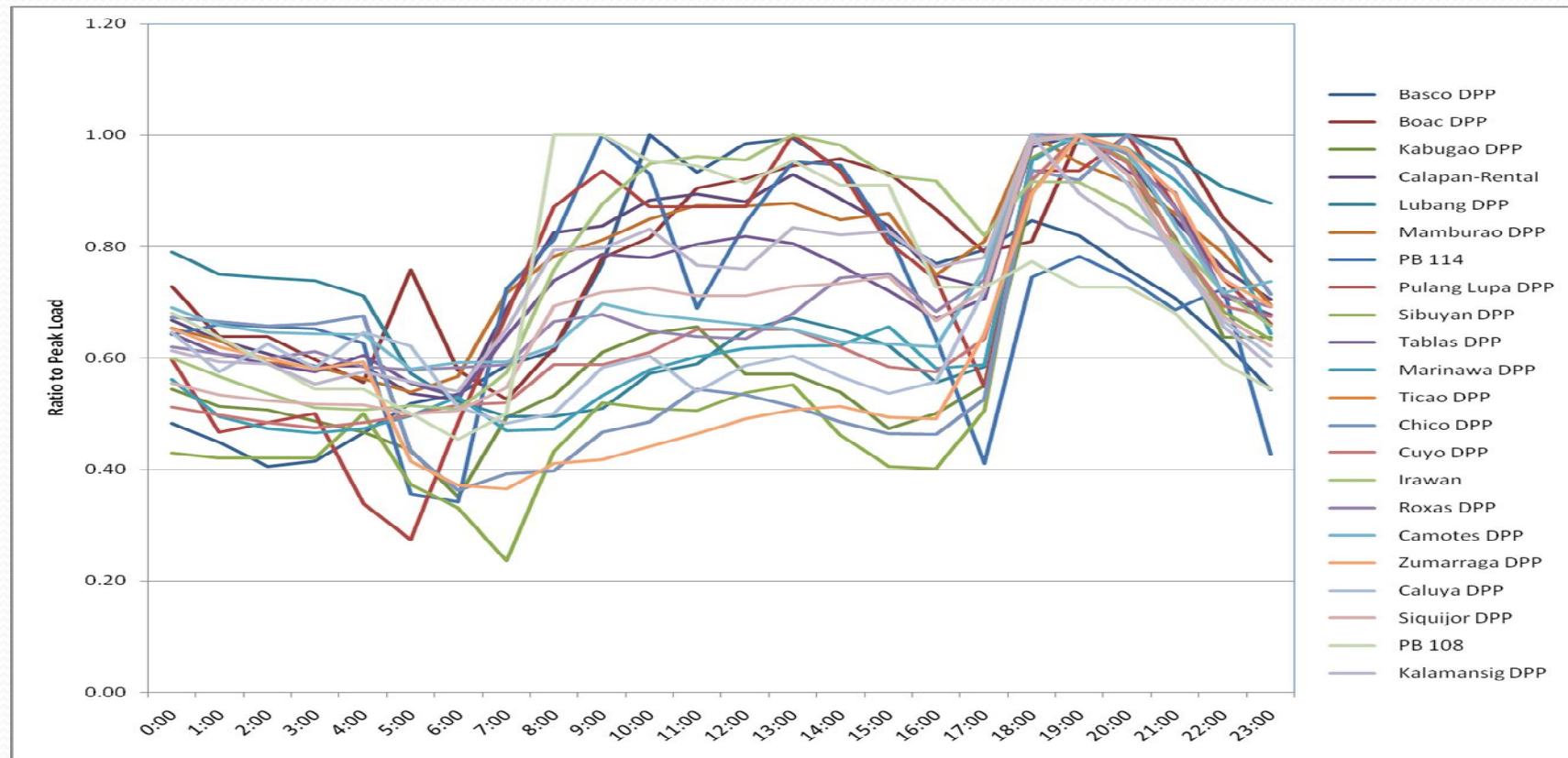
| Year | 2010 | 2012 | 2013 | 2014 | 2015 | 2016 |
|------------------------------|-------|-------|-------|-------|-------|-------|
| 24H | 31% | 35% | 39% | 37% | 44% | 44% |
| 18-20H | 9% | 8% | 4% | 5% | 8% | 12% |
| 12-16H | 21% | 30% | 33% | 41% | 42% | 42% |
| 8-10H | 28% | 20% | 20% | 15% | 6% | 3% |
| 6H | 12% | 8% | 5% | 1% | 0% | 0% |
| Average Running Hours | 13.50 | 16.00 | 16.40 | 16.70 | 18.40 | 18.90 |

Source: NPC-SPUG 2016

Homer Data Requirements

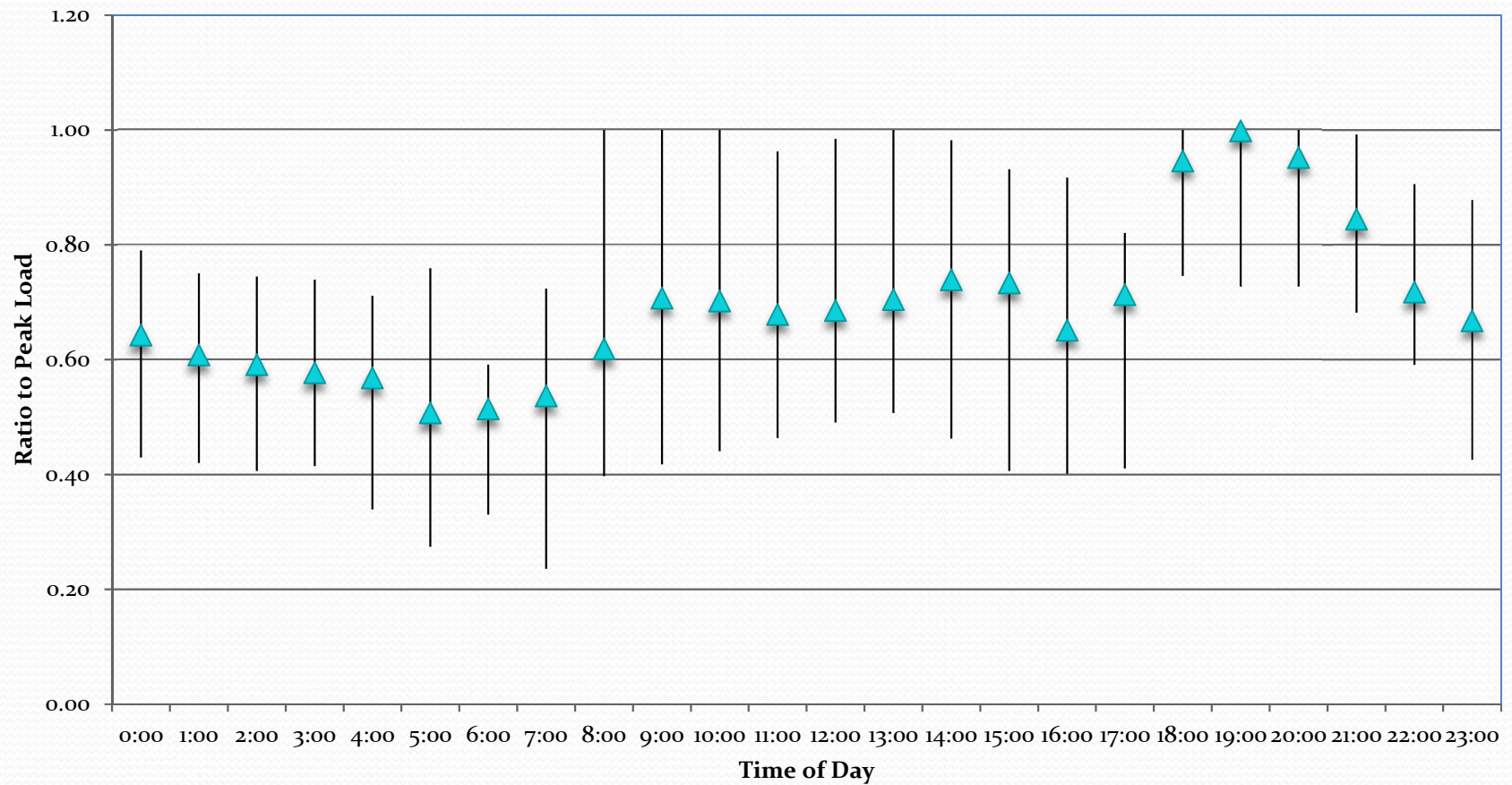
- Load Curve (Load profile – hourly demand data/24H)
- Technical configuration of existing power system
- Delivered cost of Diesel fuel
- Renewable Energy Source Data (solar, wind)
- Capacities and costs of renewable energy components

Load Curve

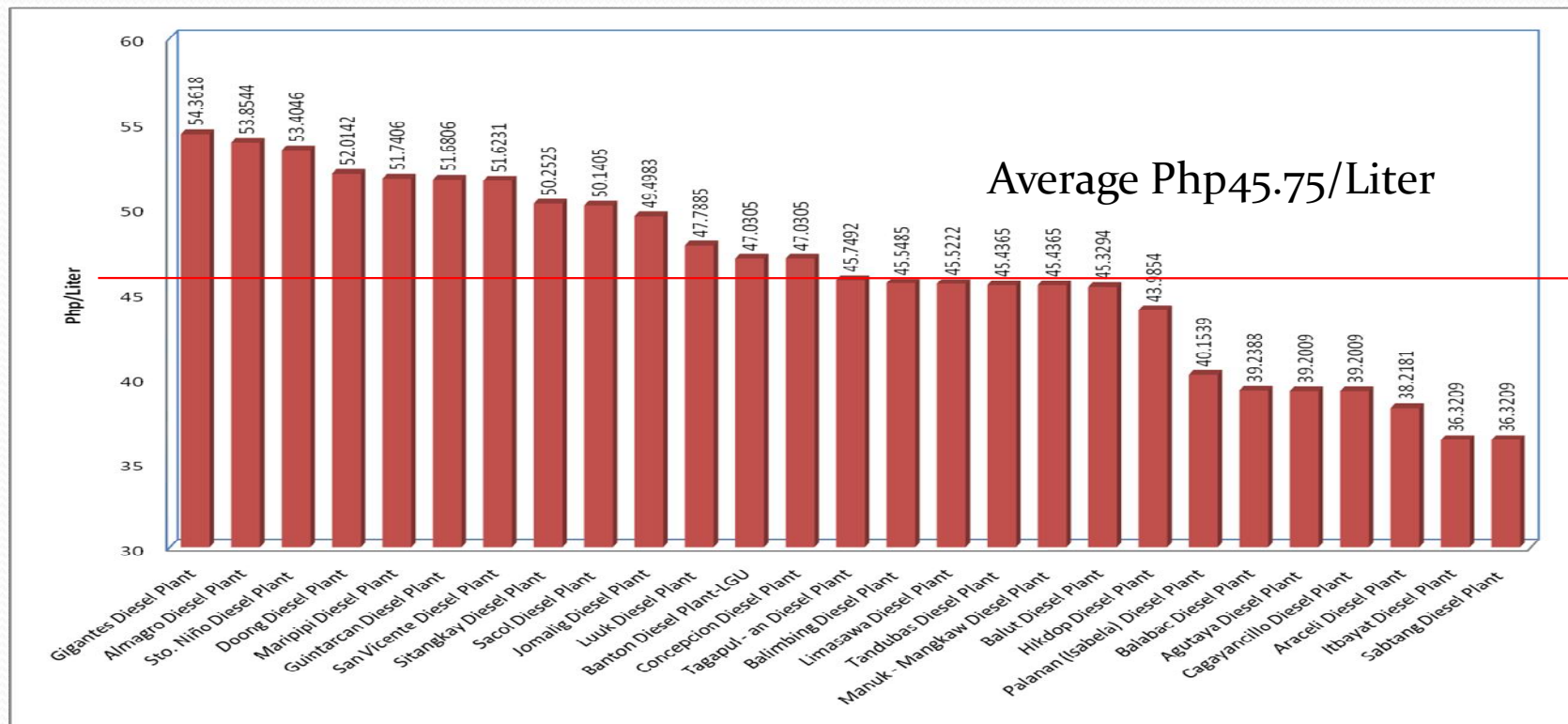


Source: SPUG.PH

Load Curve Model



Delivered Fuel Cost



Source: NPC-SPUG 2016

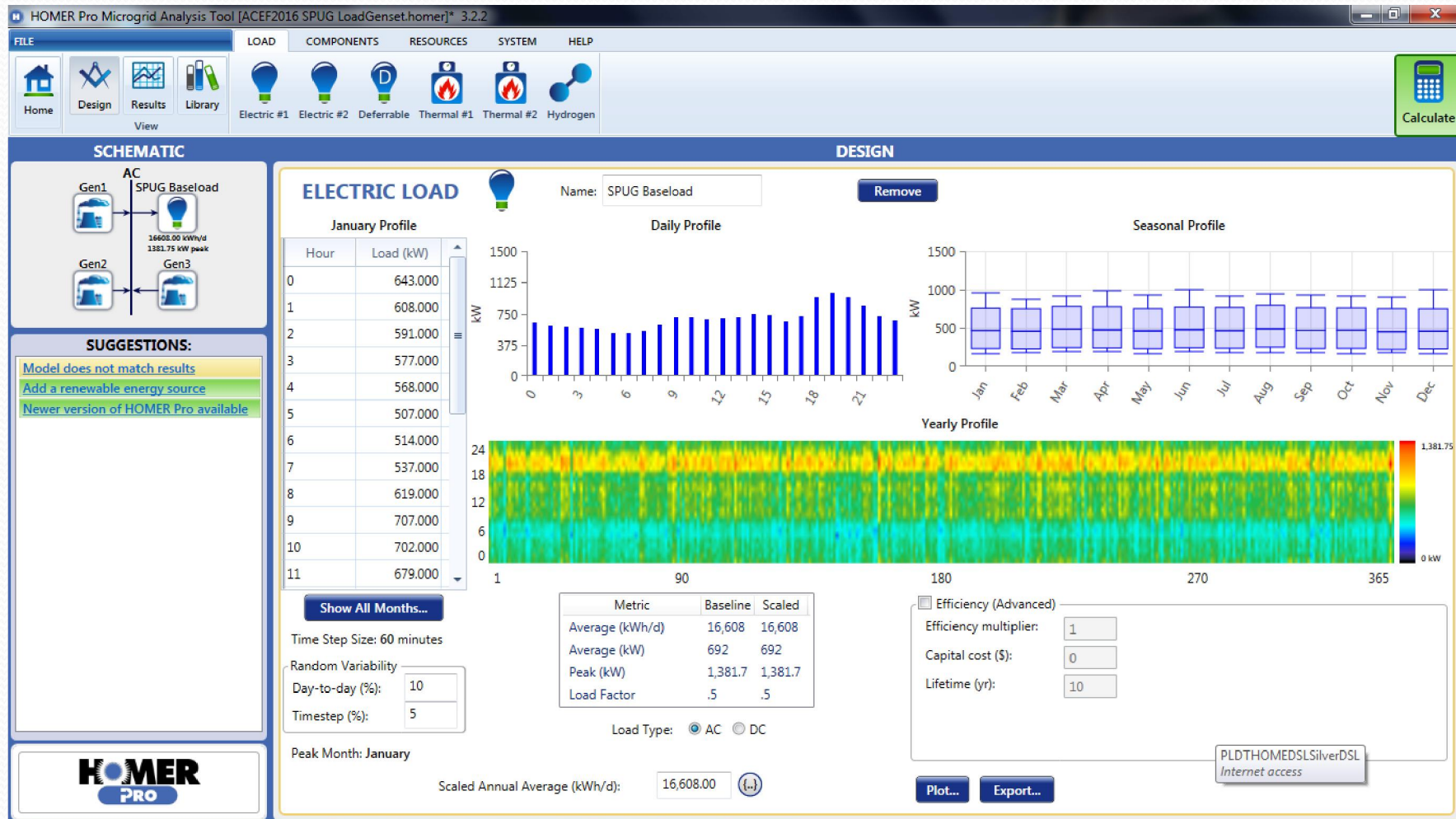
Fuel Conversion Rate Profile

| Gross MWh (2011) | Plant Count | Fuel Rate (L/kWh) | | Plant Use and Losses | |
|------------------|-------------|-------------------|------------------|----------------------|------------------|
| | | Group Average | Weighted Average | Group Average | Weighted Average |
| <120 | 192 | 0.508 | 0.450 | 0.69% | 3.16% |
| 120 to 600 | 45 | 0.324 | 0.321 | 3.24% | 3.56% |
| 600 to 1,200 | 12 | 0.311 | 0.310 | 6.34% | 6.22% |
| 1,200 to 12,000 | 28 | 0.293 | 0.277 | 6.23% | 5.93% |
| >12,000 | 10 | 0.283 | 0.281 | 4.67% | 3.85% |

Source: MEDP 2012

Diesel PV Hybrid Options

- Integrate solar PV without batteries
 - Use grid-connected PV inverters
 - Consider the minimum genset load ratio requirement
 - Consider the genset capacity reserve due to variable PV output and changing load demand
 - Use hybrid controller for maximum PV penetration
- Integrate solar PV with batteries
 - Higher renewable energy fraction/penetration
 - Gensets can be turned off using grid forming inverters
 - Battery chemistry, capacity, depth of discharge, cycle life



Baseline: Base load + 3 x 500kW Diesel Gensets

HOMER Pro Microgrid Analysis Tool [ACEF2016 SPUG LoadGenset.homer]* 3.2.2

2 simulations in 00:07.6.
6,207.40 ms per simulation.

RESULTS

Export... Column Choices... Tabular Graphical

Sensitivity Cases: Left Click on sensitivity case to see optimization cases.

| Architecture | | | | Cost | | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|----------|----------|--------------|---------------------|----------------------|--------------|-----------|-------|----------|-------|----------|-------|
| Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours |
| 500 | 500 | 500 | CC | \$0.365 | \$28,641,370 | \$2,157,520 | \$750,000 | 0 | 1,078,170 | 8,760 | 494,556 | 8,562 | 33,731 | 871 |

Export... Categorized Overall

Optimization Cases: Left Double Click on simulation to examine details.

| Architecture | | | | Cost | | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|----------|----------|--------------|---------------------|----------------------|--------------|-----------|-------|----------|-------|----------|-------|
| Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours |
| 500 | 500 | 500 | CC | \$0.365 | \$28,641,370 | \$2,157,520 | \$750,000 | 0 | 1,078,170 | 8,760 | 494,556 | 8,562 | 33,731 | 871 |

Baseline: Base load + 3 x 500kW Diesel Gensets (Initial Result)

The screenshot displays the HOMER Pro Microgrid Analysis Tool interface. The title bar reads "HOMER Pro Microgrid Analysis Tool [ACEF2016 SPUG LoadGensetPV.homer] 3.2.2". The menu bar includes FILE, LOAD, COMPONENTS, RESOURCES, SYSTEM, and HELP. The toolbar contains icons for Home, Design, Results, Library, Generator, PV, Wind Turbine, Battery, Flywheel, Converter, Boiler, Hydro, Reformer, Electrolyzer, Hydrogen Tank, Hydrokinetic, Grid, Thermal Load Controller, and a Calculate button.

The main workspace is divided into two panes: SCHEMATIC and DESIGN. The SCHEMATIC pane shows an AC system with three diesel generators (Gen1, Gen2, Gen3) and a PV array connected to a SPUG Baseload load. The load is specified as 16608.00 kWh/d and 1381.75 kW peak. The DESIGN pane shows a map of the Philippines with a location pin at Unnamed Road, Baleno, Masbate, Philippines (12°22.2'N, 123°28.2'E). The map includes labels for Quezon City, Manila, Cebu City, and Puerto Princesa City. A location search bar is visible below the map.

A blue callout box points to the PV component in the schematic, containing the text: "PV on the AC side \$2,000/kW 0 to 700kW by 100kW increments".

The bottom of the interface features a "SUGGESTIONS:" section with a warning: "Model does not match results" and "Newer version of HOMER Pro available". Below this is the HOMER PRO logo. At the bottom right, there is a promotional banner that reads: "WE CAN DO YOUR ANALYSES FOR YOU" and "CLICK TO LEARN MORE" with an image of hands pointing at a laptop displaying charts.

At the bottom of the interface, there are input fields for financial parameters: Discount rate (%): 8.00, Inflation rate (%): 2.00, and Annual capacity shortage (%): 0.00.

PV Diesel Hybrid: Base load + 3 x 500kW Diesel Gensets + PV(0 to 700kW)

HOMER Pro Microgrid Analysis Tool [ACEF2016 SPUG LoadGenSetPV.homer] 3.2.2

64 simulations in 00:15.0.
403.61 ms per simulation.

Calculate

RESULTS

Export... Column Choices... Sensitivity Cases: Left Click on sensitivity case to see optimization cases.

| Architecture | | | | | | | Cost | | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|-----------|----------|----------|--------------|---------------------|----------------------|--------------|----------|--------|----------|-------|----------|-------|------|--|
| PV (kW) | Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours | | |
| 700.0 | 500 | 500 | 500 | CC | \$0.333 | \$26,132,520 | \$1,855,153 | \$2,150,000 | 17 | 932,415 | 8,760 | 380,296 | 7,058 | 33,169 | 856 | | |

Warning: High PV penetration can cause grid stability problem (>300kW)

Export... Sensitivity Cases: Left Double Click on simulation to examine details.

| Architecture | | | | | | | Cost | | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|-----------|----------|----------|--------------|---------------------|----------------------|--------------|-----------|--------|----------|-------|----------|-------|------|--|
| PV (kW) | Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours | | |
| 700.0 | 500 | 500 | 500 | CC | \$0.333 | \$26,132,520 | \$1,855,153 | \$2,150,000 | 17 | 932,415 | 8,760 | 380,296 | 7,058 | 33,169 | 856 | | |
| 600.0 | 500 | 500 | 500 | CC | \$0.338 | \$26,522,920 | \$1,900,823 | \$1,950,000 | 15 | 954,924 | 8,760 | 393,912 | 7,386 | 33,169 | 856 | | |
| 500.0 | 500 | 500 | 500 | CC | \$0.344 | \$26,949,170 | \$1,949,267 | \$1,750,000 | 12 | 977,759 | 8,760 | 409,147 | 7,741 | 33,169 | 856 | | |
| 400.0 | 500 | 500 | 500 | CC | \$0.349 | \$27,380,290 | \$1,998,086 | \$1,550,000 | 10 | 1,000,309 | 8,760 | 425,058 | 8,089 | 33,244 | 858 | | |
| 300.0 | 500 | 500 | 500 | CC | \$0.354 | \$27,752,630 | \$2,042,359 | \$1,350,000 | 7 | 1,024,381 | 8,760 | 438,668 | 8,322 | 33,319 | 860 | | |
| 200.0 | 500 | 500 | 500 | CC | \$0.358 | \$28,079,300 | \$2,083,100 | \$1,150,000 | 5 | 1,047,726 | 8,760 | 452,404 | 8,465 | 33,356 | 861 | | |
| 100.0 | 500 | 500 | 500 | CC | \$0.362 | \$28,371,780 | \$2,121,195 | \$950,000 | 2 | 1,066,493 | 8,760 | 470,054 | 8,535 | 33,581 | 867 | | |
| 0 | 500 | 500 | 500 | CC | \$0.365 | \$28,641,370 | \$2,157,520 | \$750,000 | 0 | 1,078,170 | 8,760 | 494,556 | 8,562 | 33,731 | 871 | | |

PV Diesel Hybrid: Base load + 3 x 500kW Diesel Gensets + PV(0 to 700kW) Result

Compare Economics

Select a base case system to compare to the current system:

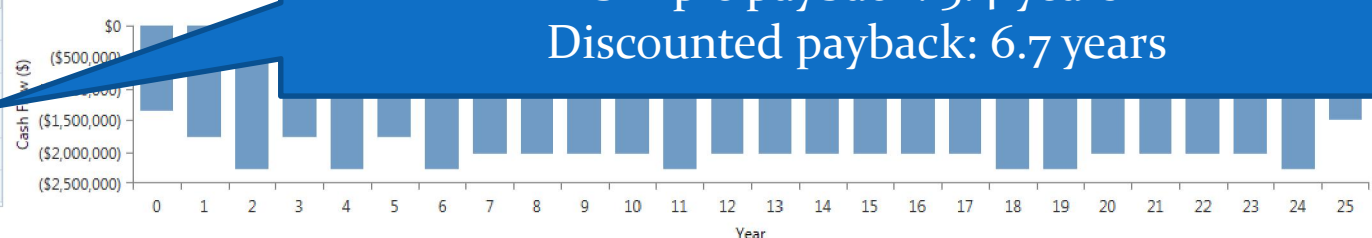
Categorized Overall

| Architecture | | | | | | Cost | | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|-----------|----------|----------|--------------|---------------------|----------------------|--------------|-----------|-------|----------|-------|----------|-------|--|
| PV (kW) | Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours | |
| 300.0 | 500 | 500 | 500 | CC | \$0.354 | \$27,752,630 | \$2,042,359 | \$1,350,000 | 7 | 1,024,381 | 8,760 | 438,668 | 8,322 | 33,319 | 860 | |
| 200.0 | 500 | 500 | 500 | CC | \$0.358 | \$28,079,300 | \$2,083,100 | \$1,150,000 | 5 | 1,047,726 | 8,760 | 452,404 | 8,465 | 33,356 | 861 | |
| 100.0 | 500 | 500 | 500 | CC | \$0.362 | \$28,371,780 | \$2,121,195 | \$950,000 | 2 | 1,066,493 | 8,760 | 470,054 | 8,535 | 33,581 | 867 | |
| | 500 | 500 | 500 | CC | \$0.365 | \$28,641,370 | \$2,157,520 | \$750,000 | 0 | 1,078,170 | 8,760 | 494,556 | 8,562 | 33,731 | 871 | |

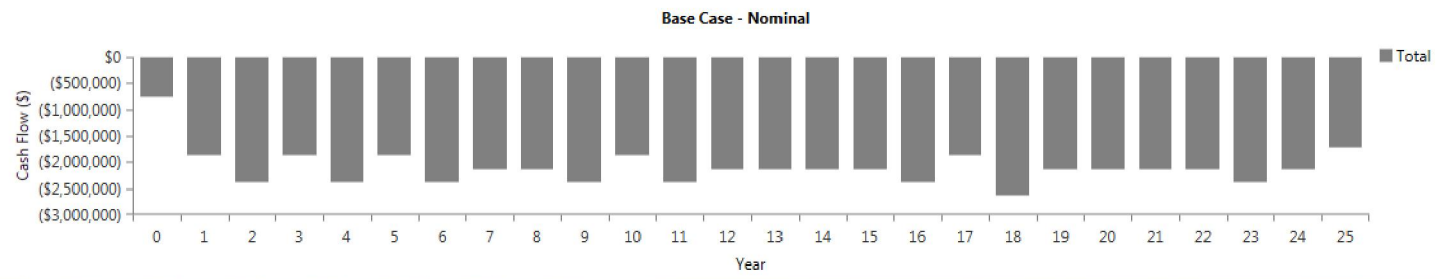
| | PV (kW) | Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | NPC (\$) | Initial capital (\$) |
|----------------|---------|-----------|-----------|-----------|--------------|----------------------|
| Base case | | | | | | |
| Current system | 300 | 500 | 500 | 500 | 2.864137E+07 | 750000 |
| | 100 | 500 | 500 | 500 | 2.775263E+07 | 1350000 |

| Metric | Value |
|-----------------------------|-----------|
| Present worth (\$) | \$888,742 |
| Annual worth (\$/yr) | \$83,256 |
| Return on investment (%) | 19.2 |
| Internal rate of return (%) | 18.7 |
| Simple payback (yr) | 5.41 |
| Discounted payback (yr) | 6.67 |

Comparison to Baseline: ROI 19.2%, IRR 18.7%
 Simple payback: 5.41 years
 Discounted payback: 6.7 years



- Display:
- Graph
 - Table
 - Both
 - Difference
 - Annual
 - Cumulative
 - Nominal
 - Discounted



Comparison of Baseline vs 300kW PV Hybrid

The screenshot displays the HOMER Pro Microgrid Analysis Tool interface. The title bar reads "HOMER Pro Microgrid Analysis Tool [ACEF2016 SPUG LoadGensetPVLiBatt.homer] 3.2.2". The menu bar includes FILE, LOAD, COMPONENTS, RESOURCES, SYSTEM, and HELP. The toolbar contains icons for Home, Design, Results, Library, Project, Search Space, Sensitivity Inputs, Input Report, Estimate, and Clear Results. A status bar indicates "15,414 simulations in 01:11:37." and "299.50 ms per simulation." A green "Calculate" button is visible in the top right.

The main interface is divided into two tabs: SCHEMATIC and DESIGN. The SCHEMATIC tab shows a power flow diagram with AC and DC buses. The AC bus is connected to three diesel generators (Gen1, Gen2, Gen3) and a SPUG Baseload. The DC bus is connected to a PV array and a Lithium Battery (LI Batt). A bidirectional inverter (INV) connects the AC and DC buses. The SPUG Baseload is specified as 16602.00 kW/d and 1381.75 kW peak.

The DESIGN tab shows a map of the Philippines with a red pin indicating the location: "Unnamed Road, Baleno, Masbate, Philippines (12°22.2'N , 123°28.2'E)". The map includes labels for Quezon City, Manila, Cebu City, and Puerto Princesa City. A "Resources" button is located in the top right of the map area.

A blue callout box with white text states: "Addition of bi-directional inverter, Lithium battery bank, PV with charge controller".

The bottom of the interface features a "SUGGESTIONS:" section with two messages: "PV search space may be insufficient" and "Newer version of HOMER Pro available". Below this is the HOMER PRO logo. At the bottom right, there is a promotional banner for "WE CAN DO YOUR ANALYSES FOR YOU" with a "CLICK TO LEARN MORE" button and an illustration of hands pointing at a laptop displaying charts.

Financial parameters are listed at the bottom left:

| | | |
|------------------------------|------|-----|
| Discount rate (%) | 8.00 | (-) |
| Inflation rate (%) | 2.00 | (-) |
| Annual capacity shortage (%) | 0.00 | (-) |

PV+Battery Diesel Hybrid: baseload + 3 x 500kW Diesel Gensets + PV+ Battery

HOMER Pro Microgrid Analysis Tool [ACEF2016 SPUG LoadGensetPVLiBatt.homer] 3.2.2

15,414 simulations in 01:11:37.
299.50 ms per simulation.

RESULTS

Export... Column Choices... Sensitivity Cases: Left Click on sensitivity case to see optimization cases.

| Architecture | | | | | | | | | | Cost | | | System | Gen1 | | Gen2 | | Gen3 | |
|--------------|-----------|-----------|-----------|---------|----------|----------|----------|--------------|---------------------|----------------------|--------------|-----------|--------|----------|-------|----------|-------|------|--|
| PV (kW) | Gen1 (kW) | Gen2 (kW) | Gen3 (kW) | LI Batt | INV (kW) | Dispatch | COE (\$) | NPC (\$) | Operating cost (\$) | Initial capital (\$) | Ren Frac (%) | Fuel (L) | Hours | Fuel (L) | Hours | Fuel (L) | Hours | | |
| 1,600.0 | 500 | 500 | 500 | 2,000 | 1,600 | LF | \$0.509 | \$39,870,280 | \$1,837,962 | \$16,110,000 | 33 | 740,292 | 7,083 | 306,038 | 5,355 | 31,153 | 803 | | |
| 1,600.0 | 500 | 500 | 500 | | 1,600 | CC | \$0.325 | \$25,470,810 | \$1,652,353 | \$4,110,000 | 27 | 818,027 | 8,304 | 326,832 | 5,752 | 33,094 | 854 | | |
| | 500 | 500 | 500 | 2,000 | 1,600 | LF | \$0.583 | \$45,672,470 | \$2,509,567 | \$13,230,000 | 0 | 1,077,938 | 8,759 | 494,433 | 8,560 | 33,731 | 871 | | |
| | 500 | 500 | 500 | | | CC | \$0.365 | \$28,641,370 | \$2,157,520 | \$750,000 | 0 | 1,078,170 | 8,760 | 494,556 | 8,562 | 33,731 | 871 | | |

Export... details. Categorized Overall

Result shows that the battery increased the RE fraction, reduced fuel consumption but increased the Cost of Energy

PV Diesel Hybrid: Base load + 3 x 500kW Diesel Gensets + PV + Li Battery Result

Possible Hybrid Implementation Arrangements

- Hybrid implementation by SPUG through Competitive Selection Process (CSP)
- Hybrid implementation by New Power Producer (NPP)
- Hybrid implementation by Qualified Third Party (QTP)
- Implementation by Distribution Utilities (DU), Electric Cooperatives (EC), Local Government Units (LGU), private sector for own use

Hybrid Implementation Challenges

- Low oil prices slows down interest in Hybrid projects
- NPC-SPUG cannot borrow capital and relies only on internally generated cash to do RE projects
- Loss of market of existing NPPs to be displaced by RE generation
- There is a limited number of private sector participants that are selective to only develop areas with high true cost of generation and with significant scale
- Administrative requirements on permitting , service contract, financing, others.

Conclusion

- Homer can be used by NPC-SPUG in optimizing hybrid configurations on its diesel plants to provide 24h supply
- Homer demonstrated how to size hybrid components that results to the least cost of energy generation without compromising the grid stability
- Homer can be used to validate hybrid proposals submitted to SPUG for implementation