Wind-Diesel Efficiency and Life Cycle Cost Analysis using Simulink®

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- Needs, Challenges & Solutions??
- Objectives
- Wind-Diesel Co-Gen System
- Village Load Profiles
- HARPSim: Performance Analysis
- Conclusions

Needs, Challenges, & Solutions??

- <u>Needs:</u>

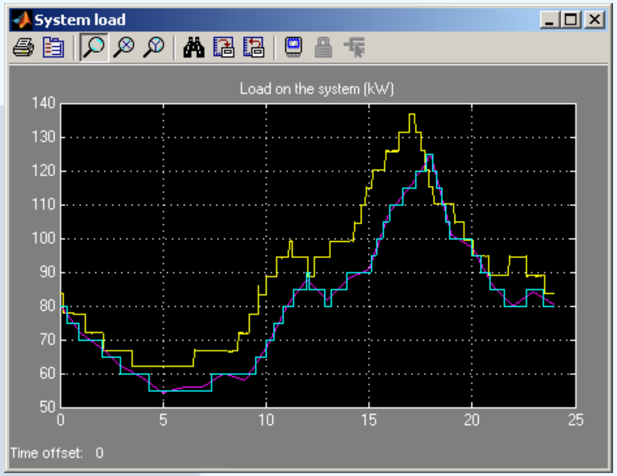
  The need for ***energy efficient***, ***reliable***, and ***affordable*** power for rural villages in Alaska.

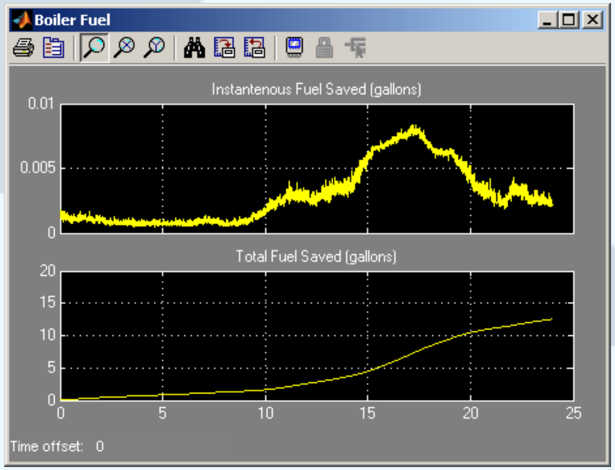
- <u>Challenges:</u>
  - Remoteness of sites (grid extensions not feasible)
  - Rising oil prices & high transportation costs for fuels
  - Maintenance & operational costs
  - New environmental standards (carbon tax)
  - **"…Can't manage what you don't measure…"**

- <u>Solutions??:</u>
  - Energy Management (Smart Grid)
    - Remote monitoring & control (SCADA)
    - Demand-side management
  - Renewable (Alternative) Energy Systems

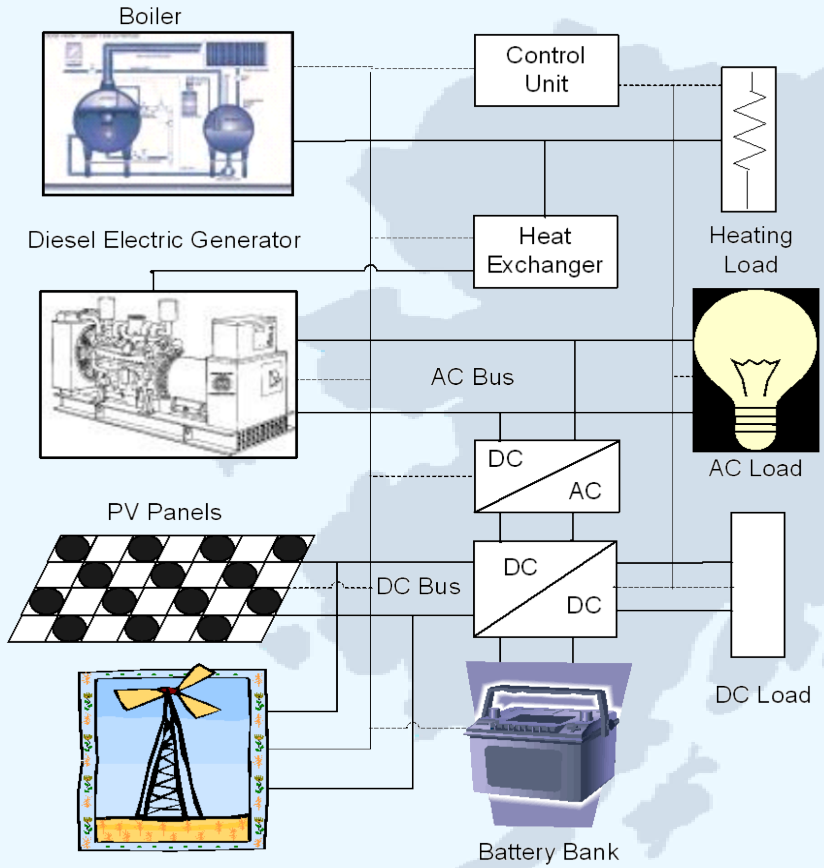
Objectives

- Survey of existing village power monitoring systems
- Data collection and management
- Village power analysis with integrated renewables:
  - load profiling
  - energy efficiency analysis (engine efficiency & fuel consumption)
  - economic analysis (life-cycle cost & payback)
  - environmental analysis (NO_X, PM_{10}, CO_2)



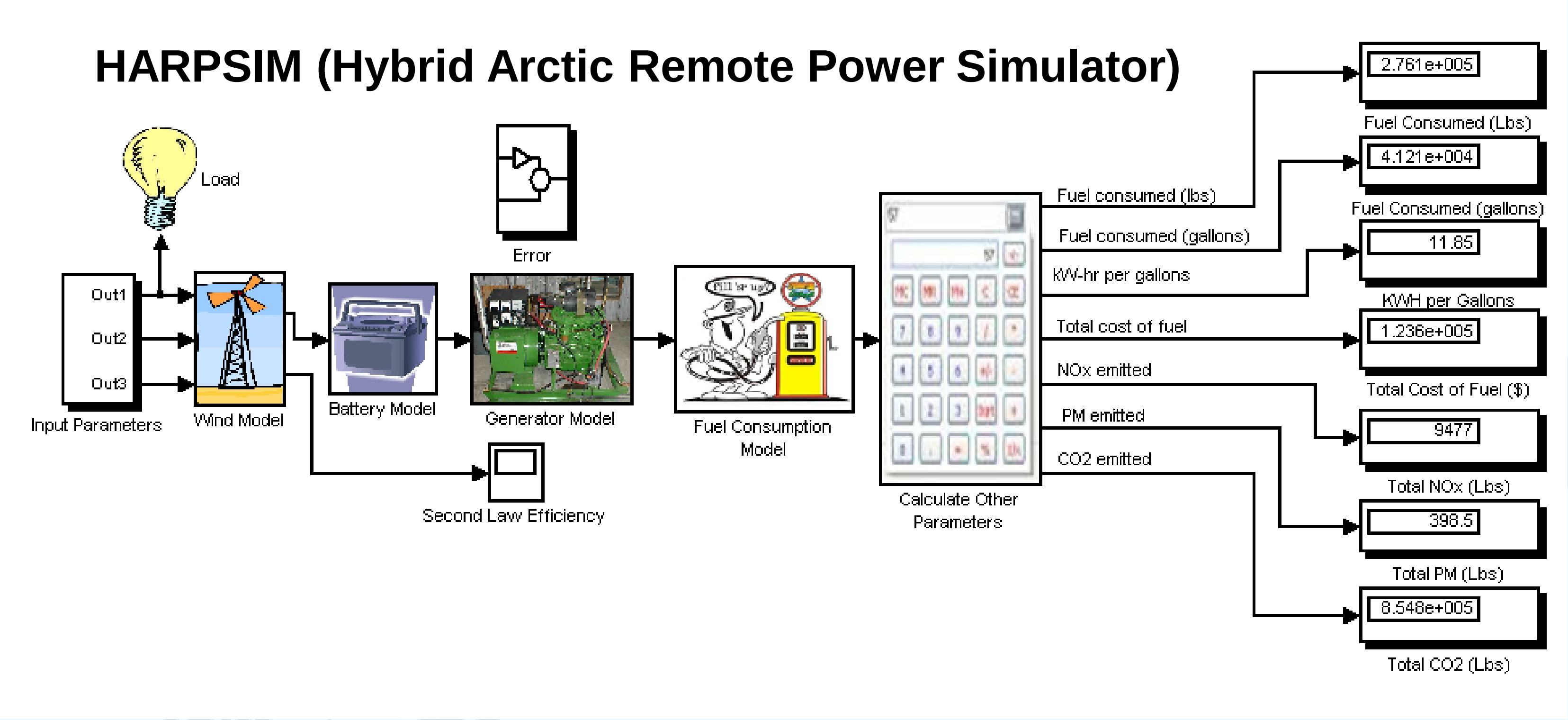


Wind-Diesel Co-Gen System



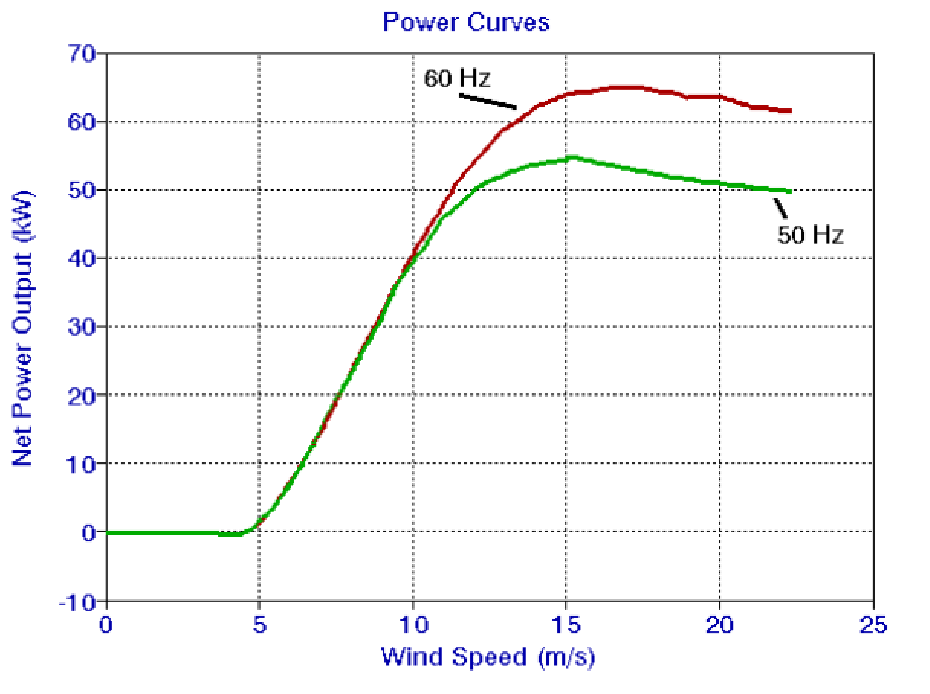
Village Power Analysis

- Village Load Profiles
- Run Time, DEG Efficiency, Fuel Use, Fuel Cost & Emissions
- Fuel Savings and Cost of Energy (COE) Reduction w/ Introduction of Renewable Energy Sources



Wind Turbine Generator (WTG)

Power Curve and Look-up Table for 15/50 Atlantic Orient Corporation WTG.

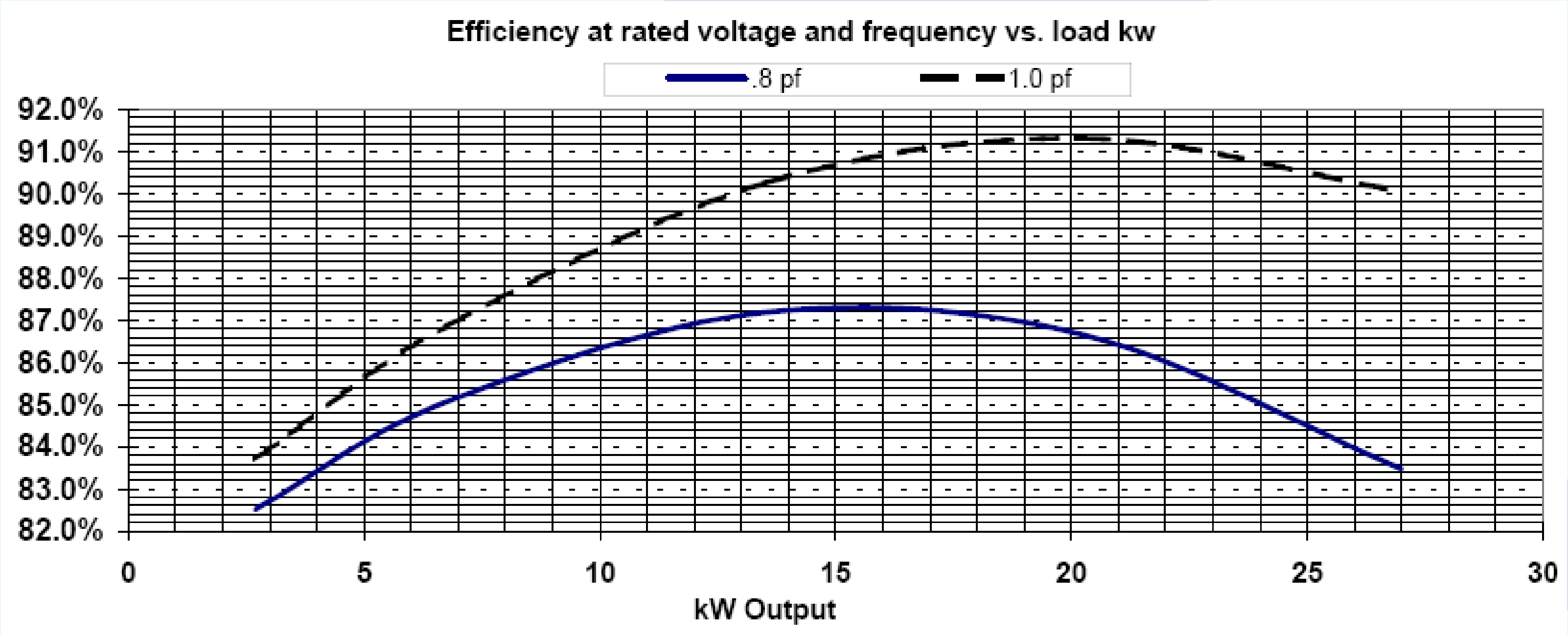


Sr. No.	Wind speed		Net power output (kW)
	Meters/second	Miles/hour	
1	0	0	0
2	5	11.18468	2
3	10	22.37	40
4	11.5	25.725	50
5	13.5	30.1986	60
6	15	33.554	63
7	17	38.028	65
8	19	42.5	63
9	21	46.975	62
10	22.5	50.331	61

$$P_{max} = \frac{1}{2}\rho A V^3 \times (0.59)$$

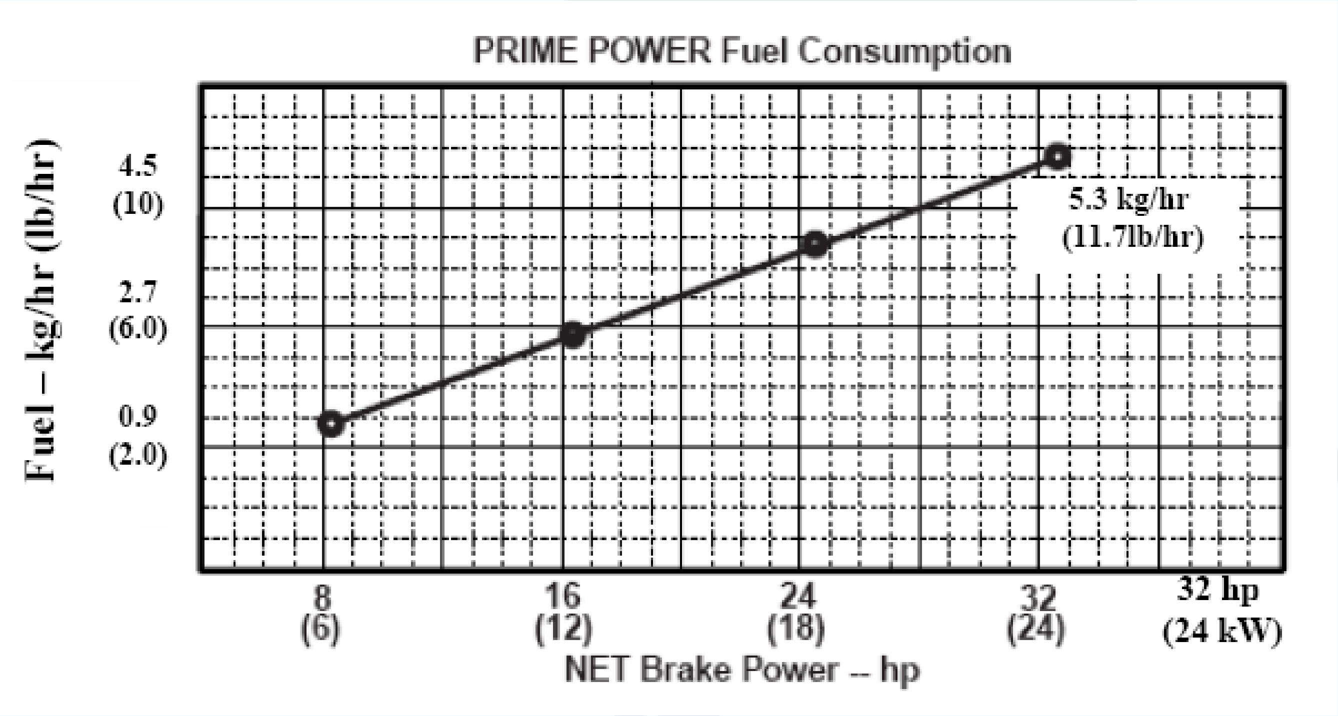
DEG Efficiency (1)

- Efficiency for Electric Generator



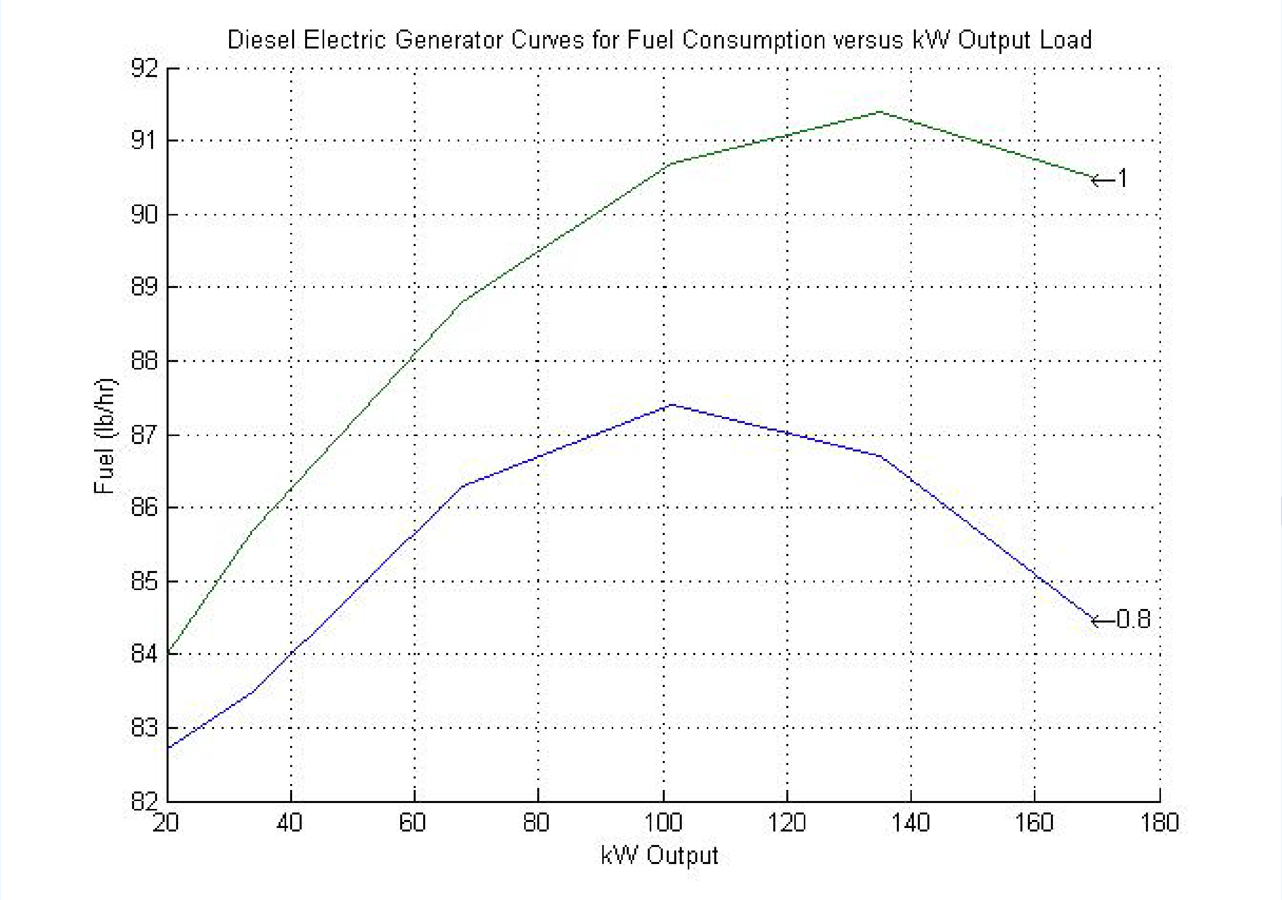
DEG Efficiency (2)

- Efficiency for Diesel Engine



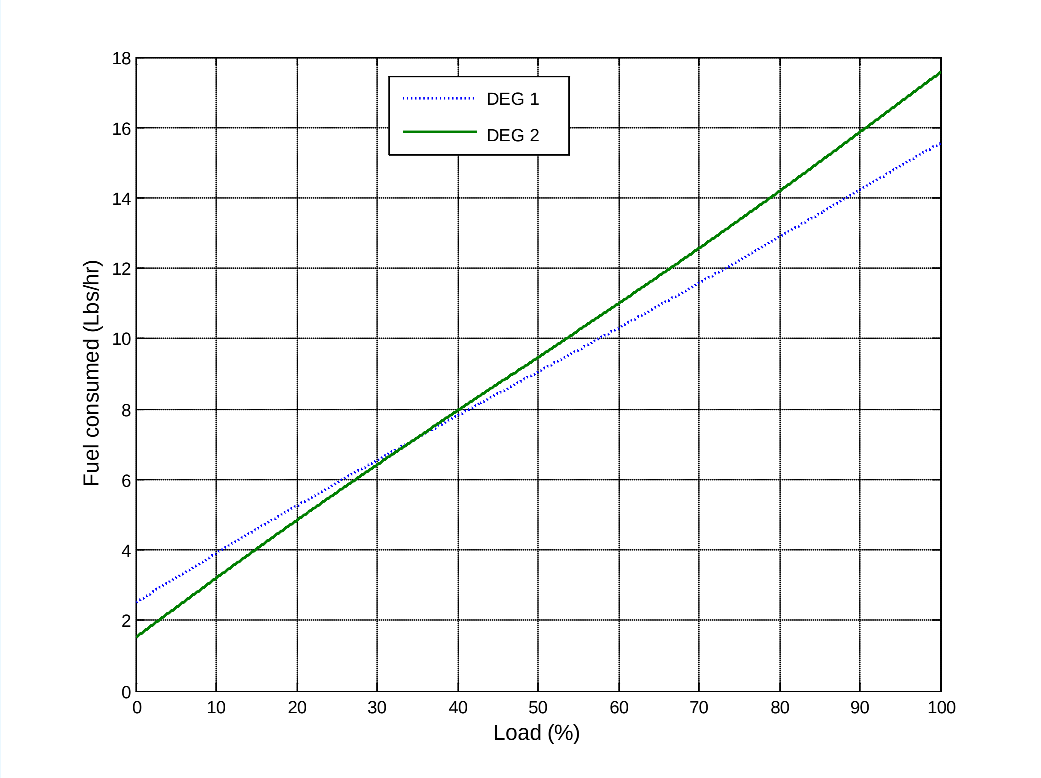
Load Effects on a DEG

- Efficiency of DEG Set



Effects of Load on Multiple DEG Efficiency

- Load: % Loading based on DEGs generation capacity has largest impact on fuel efficiency.



Emissions

- Light Diesel Combustion

$$C_nH_{1.8n} + (1.45n)(O_2 + 3.76N_2) = nCO_2 + 0.9nH_2O + (1.45N_2)(3.76N_2)$$

$$\text{Total pollutant in kg (lb)} = \frac{\text{pollutant}}{\text{kWh}} * \text{kWh}_{\text{Gen}}$$

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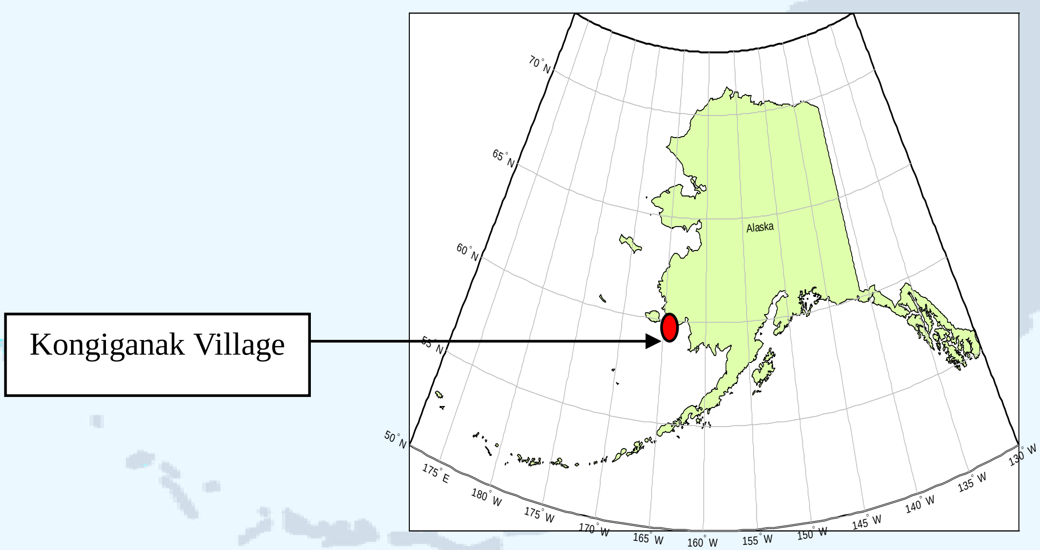
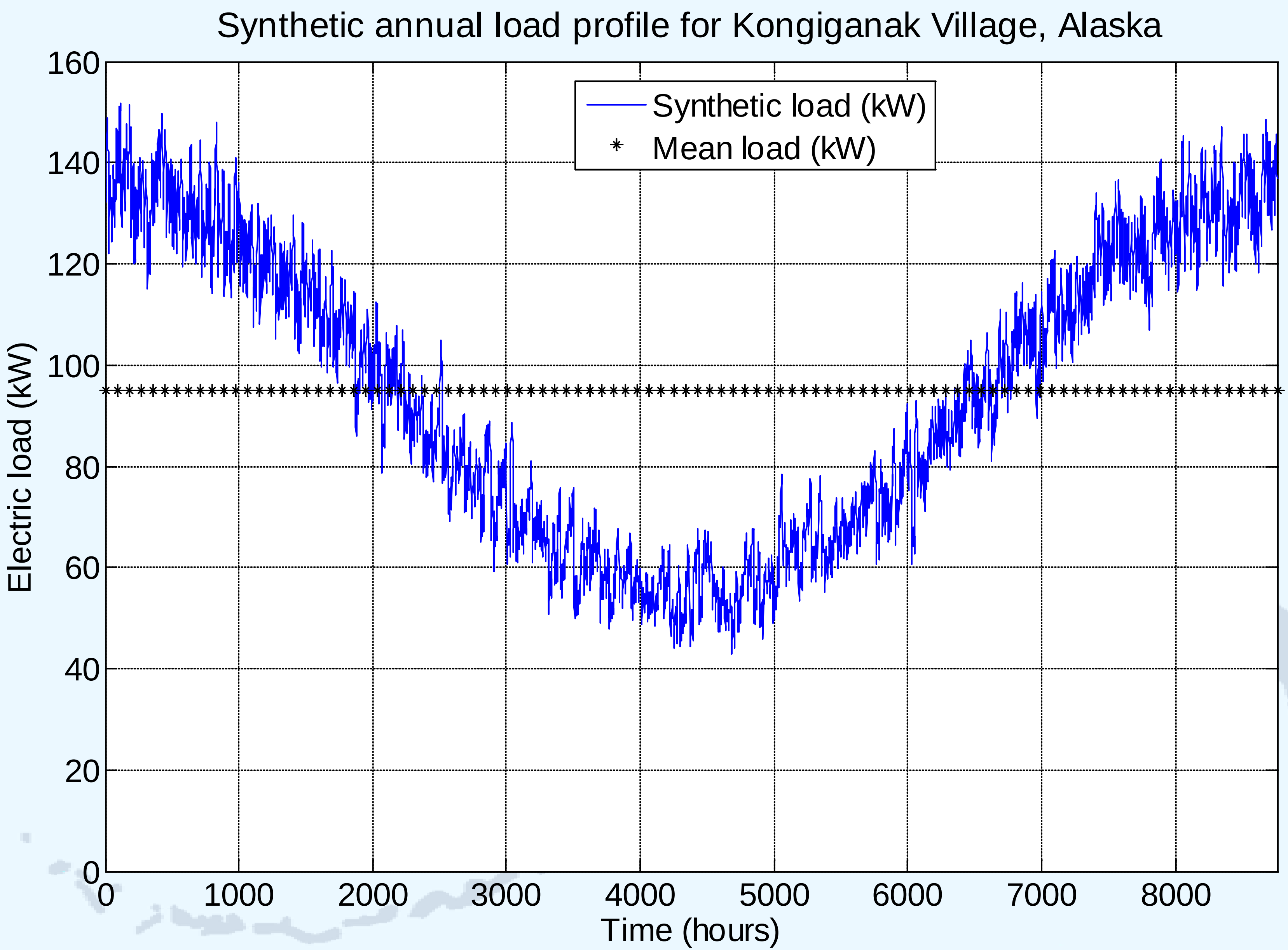
Performance Analysis (1): Kongiganak

- Location: western shore of Kuskokwim bay, 451 miles west of Anchorage (north latitude 59.96°, west longitude 162.89°).
- 90 housing units, 11 vacant, one school attended by 116 students (US 2000 Census).
- Marine climate: temp range 6°F - 57°F.
- Average annual precipitation: 22 inches
- Average annual snowfall: 43 inches

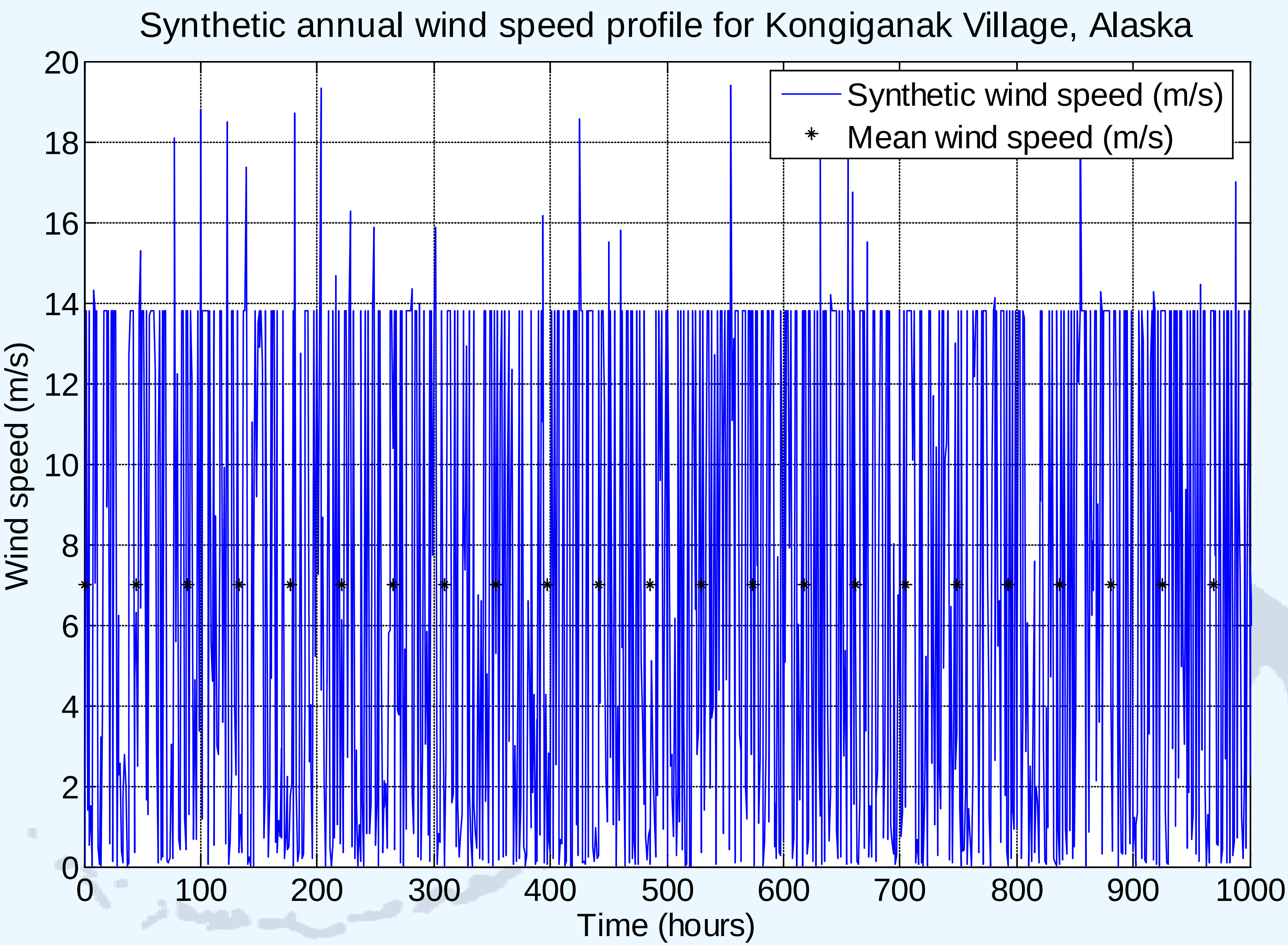


- Current Power System/MET Data:
  - DEGS:
    - Diesel #1: 235 kW
    - Diesel #2: 190 kW
    - Diesel #3: 190 kW
    - Diesel #4: 140 kW
  - One DEG is sufficient to supply the load
    - Avg: 95 kW
    - Min: 45 kW
    - Max: 150 kW
  - Wind Speed: 7 m/s (15.6 mph)
- Test System:
  - 2 - 190kW DEGS (one as backup)
  - 100 kWh absolyte IIP battery bank
  - 1 or 2 - 65kW Integrity 15/50 WTGs
  - 100kVA bidirectional converter

Performance Analysis (2)



Performance Analysis (3)



Performance Analysis (4)

Installation cost for different components for Kongiganak Village

Item	Cost per unit (USD)	No of units	Diesel-only system (USD)	Diesel-battery system (USD)	Wind-diesel-battery system (USD)	2 wind-diesel-battery system (USD)
140 kW diesel generator	40,000	1	40,000	40,000	40,000	40,000
190 kW diesel generator	45,000	1	45,000	45,000	45,000	45,000
Switch gear to automate control of the system	16,000	1	16,000	18,000	20,000	30,000
Rectification/Inversion	18,000	1	0	18,000	18,000	28,000
New Absolyte IIP 6-90A13 battery bank	2,143	16	0	34,288	34,288	68,576
AOC 15/50 wind turbine generator	55,000	1	0	0	55,000	110,000
Engineering		1	3,000	3,500	4,000	6,000
Commissioning, Installation, freight, travel, miscellaneous		1	13,000	14,000	18,000	30,000
		TOTAL	**117,000**	**172,788**	**234,288**	**357,576**

Performance Analysis: Comparison of Results (5)

Item	Diesel-battery	Wind-diesel-battery	2 wind-diesel-battery
	HARPSim	HARPSim	HARPSim
System cost (USD)	172,788	234,288	357,576
Engine efficiency (%)	**29.3**	**29.3**	**29.3**
kWh/liter (kWh/gallon) for engine	**3.11 (11.75)**	**3.11 (11.75)**	**3.11 (11.75)**
Fuel consumed in liters (gallons)	267,662 (70,810)	193,249 (51,124)	151,252 (39,961)
Total cost of fuel (USD @ $3.00/gal)	212,429	153,373	119,883
Energy supplied			
(a) Diesel engine (kWh)	832,152	597,145	469,542
(b) WTG (kWh)	-	235,007	470,015
Energy supplied to load (kWh)	832,152	832,152	832,152
Operational life			
(a) Generator (years)	5	5	5
(b) Battery bank (years)	5.5	5.5	5.5
Net present value (USD) with *i* = 7% and n = 20 years	-	1,954,127	1,748,988
Cost of Electricity (USD/kWh)	**0.301**	**0.237**	**0.22**
Payback period for renewable (years)	-	**1.07**	**1.56**
Emissions			
(a) CO_2 in metric tons (US tons)	660 (728)	477 (526)	367 (405)
(b) NOx in kg (lbs)	7,322 (16,143)	5,288 (11,657)	4,068 (9,112)
(c) PM_{10} in kg (lbs)	308 (679)	222 (490)	171 (383)

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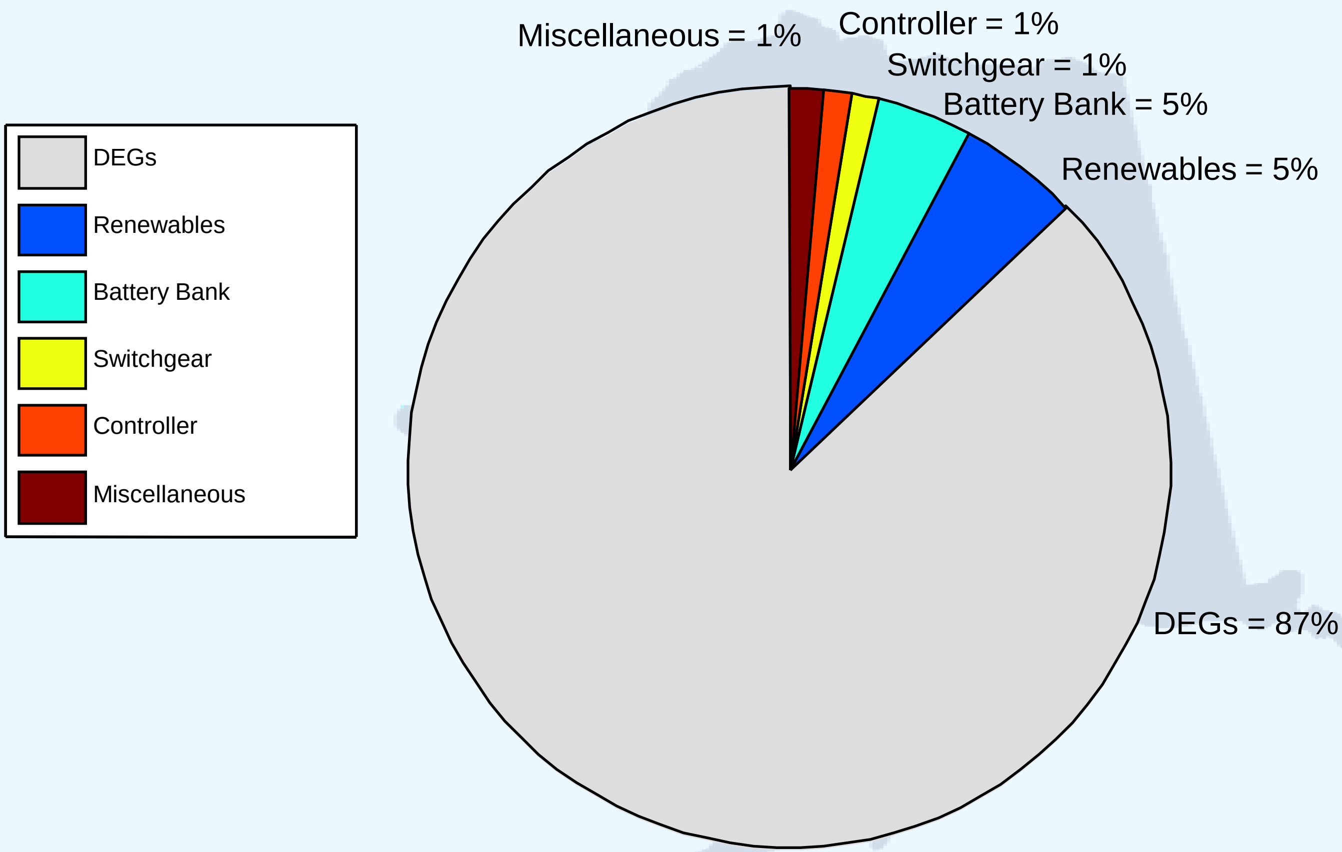
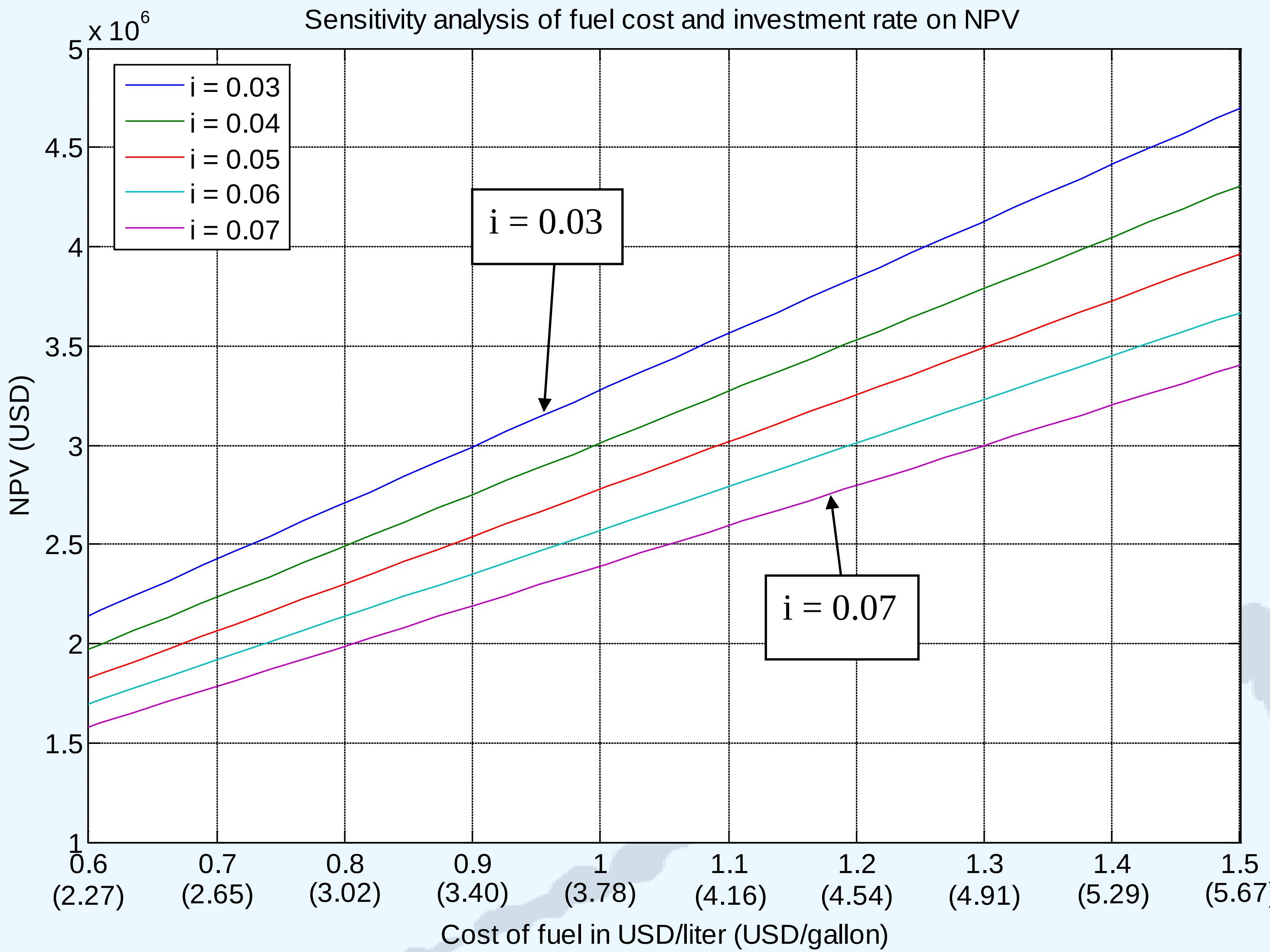
Performance Analysis (6)

20-year LCC analysis of the Kongiganak Village hybrid power system using HARPSim

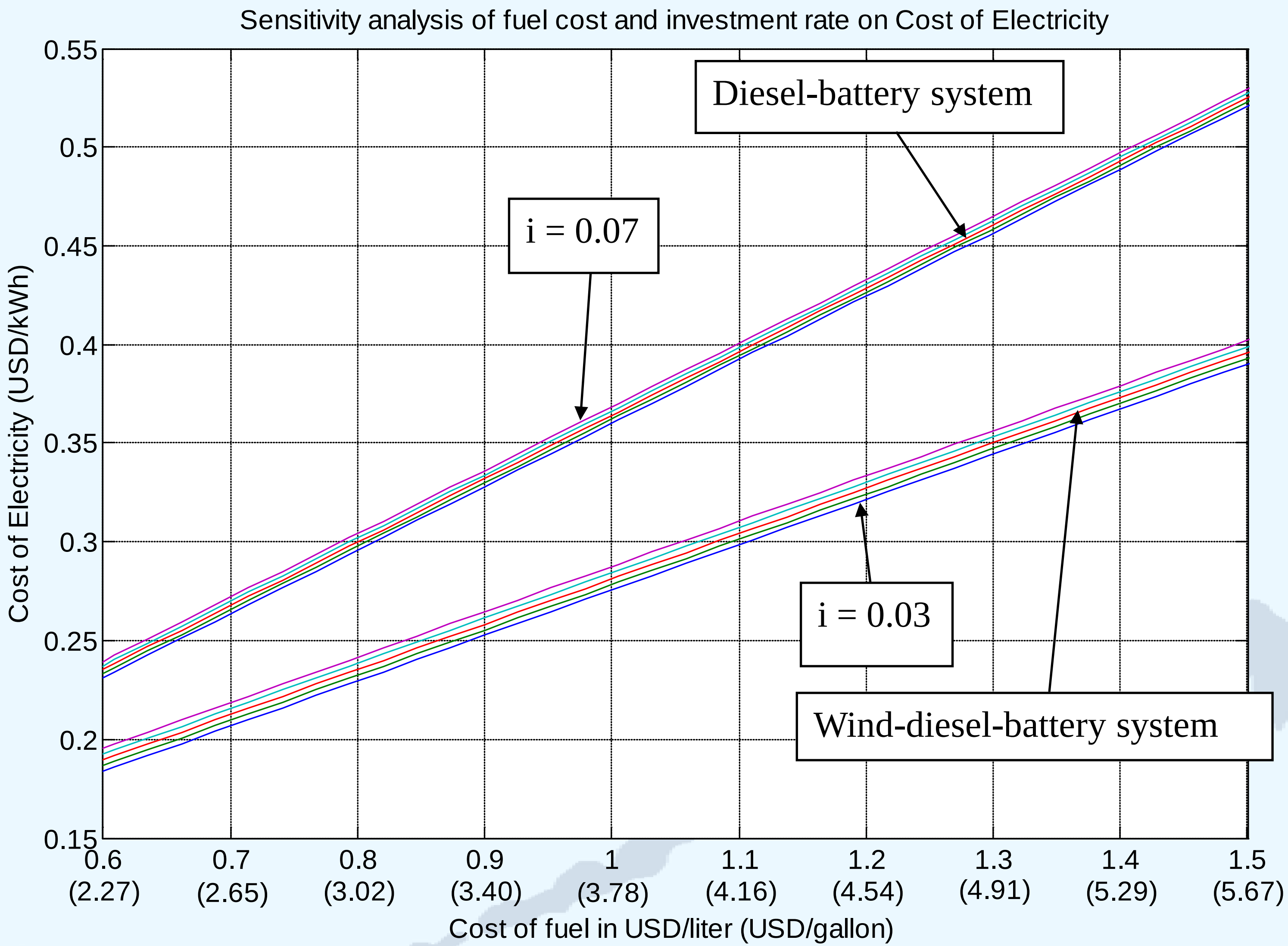


The NPV of the system, with i = 7% and fuel cost = 0.79 USD per liter (3.0 USD per gallon), is 1,974,389 USD

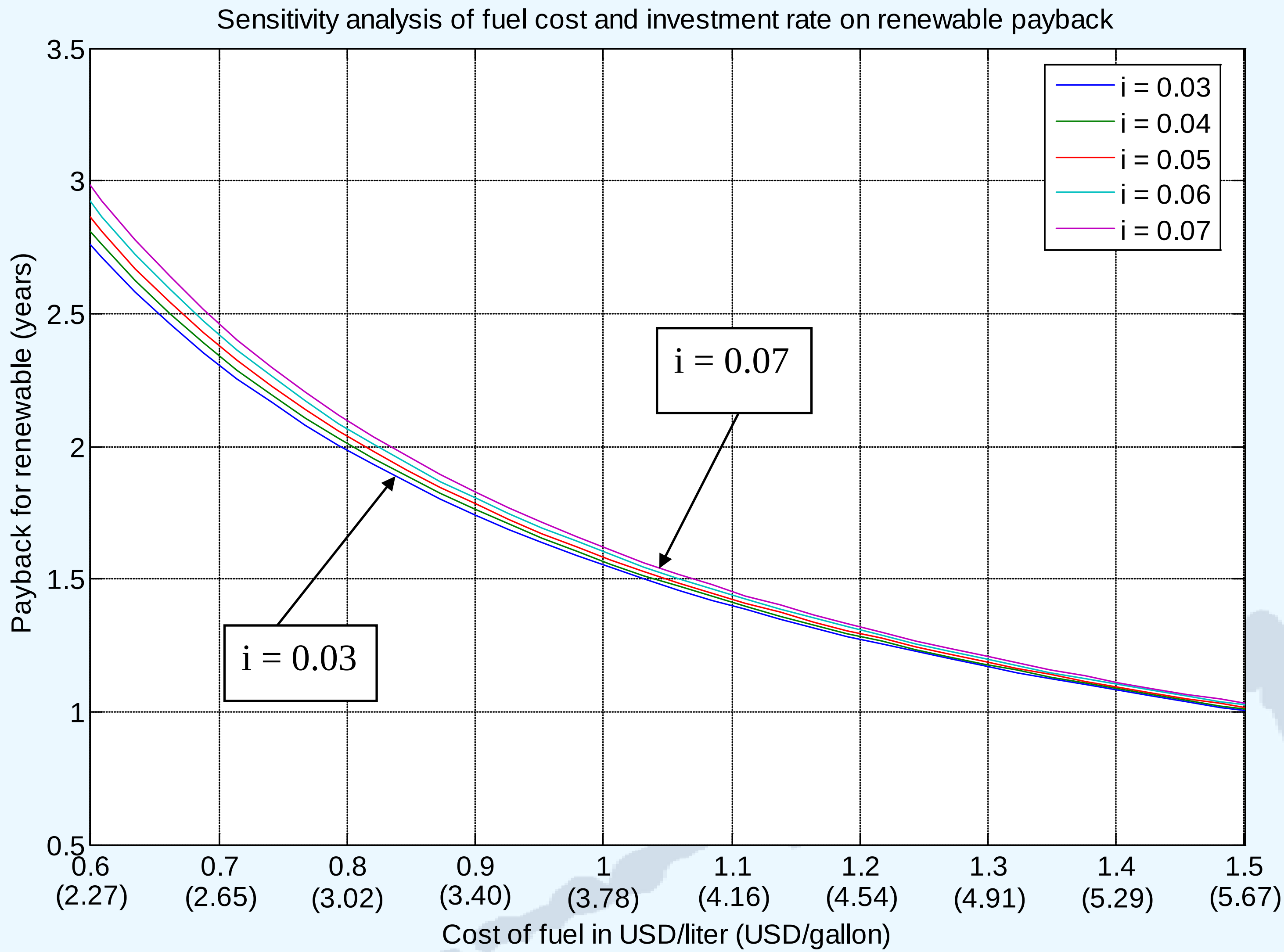
Performance Analysis (7)



Performance Analysis (8)



Performance Analysis (9)



Conclusions

- WTG systems are economically feasible for arctic rural villages with suitable wind resources.
- The economic analysis shown here illustrates a decrease in the COE with WTGs integrated into the DEG system.
- Distributed or hybrid energy systems integrating renewable energy sources with DEGs can result in:
  - more economical and efficient generation of electrical energy and heat
  - increased lifetime and reliability of the DEGs

THE END OF THE BEGINNING

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Book (Print on Demand): *Hybrid Electric Power Systems: Modeling, Optimization, and Control*, A. Agrawal, Richard Wies, & Ron Johnson, VDM Verlag, July 2007.

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