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PT PLN (Persero)
Electricity For A Better Life

Solar Photovoltaic (PV) and Diesel/PV Hybrid System Training Workshop

Project Planning, Implementation, Operation

By Brian Hirsch, PhD
Deerstone Consulting LLC
Bali, Indonesia
25 to 29 January 2016

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Presentation topics

- Extreme Environments
- Case Studies/Lessons Learned
  - Sabu Island
  - Colville Lake, NWT, Canada
  - Various Alaska locations
  - Daly River System, Australia
- Penetration Levels & Considerations
- Big Picture Questions/Issues
- Moving Toward Standard System Architectures & Development Approaches

Alaska and Indonesia – Similarities & Differences

Alaska & Indonesia, Continued

SIMILAR CHALLENGES

- Remote, spread out → challenging logistics
- Diesel dependency; price volatility; energy vulnerability
- Small internal markets in remote locations
- Many islands, few roads → good for EVs?
  - **All of the above results in… High Energy Costs & Incentive to Innovate**

SIMILAR OPPORTUNITIES

- Strategic location (Asian markets, global perspective, importance of shipping/marine industry & technologies
- Prominent role of traditional cultures, diverse & established institutions
- Islanded grids easier to measure and have impact on
- Lots of RE resource potential
- Tourism & natural resource-based economies → Clean Energy demand

DIFFERENCES

- Extreme seasonality →Meeting thermal needs not "optional", but could be cooling or water management in Indonesia
- Overall economic trends

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Hybrid Power System Classifications & Considerations

Penetration Class	Operating Characteristics	Instantaneous Penetration	Average Penetration
LOW	• Diesel runs full-time • Wind/solar power reduces net load on diesel • All wind/solar energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind/solar power levels, secondary loads are dispatched to insure sufficient diesel loading or wind/solar generation is curtailed • Requires relatively simple control system	50%–100%	20%–50%
HIGH	• Diesels may be shut down during high wind/solar availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100%–400%	50%–150%

- Note: any system with the capability to have instantaneous penetrations above 50% will likely require specialized load controls and other grid integration measures
- Consider penetrations when system is at minimum load (at night, high winds, etc.)

Courtesy NREL

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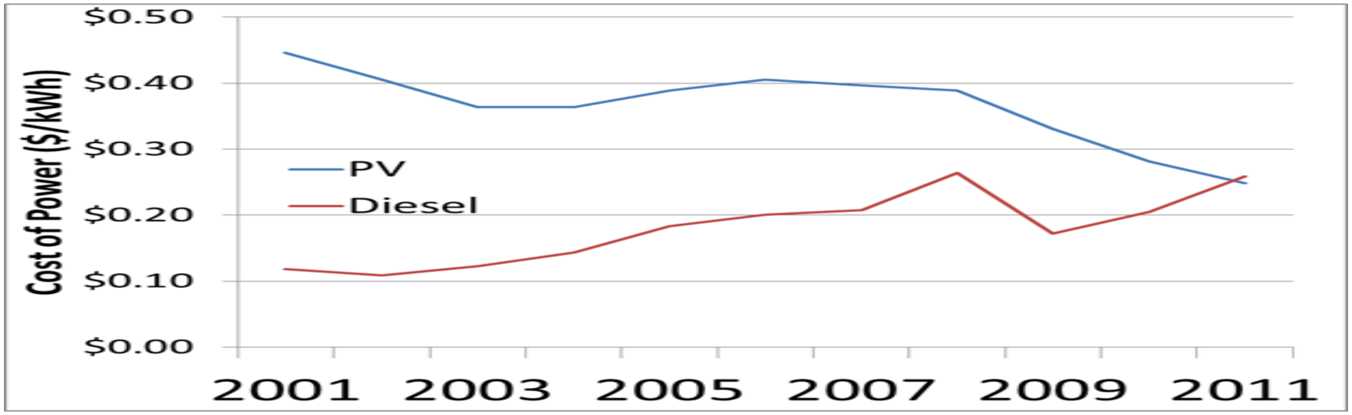
General Assumptions

- Decisions made now will have long-term impact: “Historic Moment”
- Solar will scale up if done properly and become cost-effective
- Focusing comments on isolated microgrids
- Focused on diesel fuel displacement and grid integration
- Global fossil fuel prices will NOT continue to drop, and will eventually “settle out” at above $40/barrel
- Degradation of solar PV panels @ ~ 1%/year
- Mostly utility owned solar PV, or if IPP, one or a few “large” systems on each isolated diesel grid
- Recent Energy Storage trends & technology innovation will continue, similar to PV and wind
- “End game” will likely be PV/wind/battery/diesel hybrids with substantial “diesel off”/ battery state of charge operation; role for medium penetration & variable speed or low load diesels
- All of these trends are now emerging in advanced markets (US, AUS, Canada, Caribbean)…. And coming here soon!

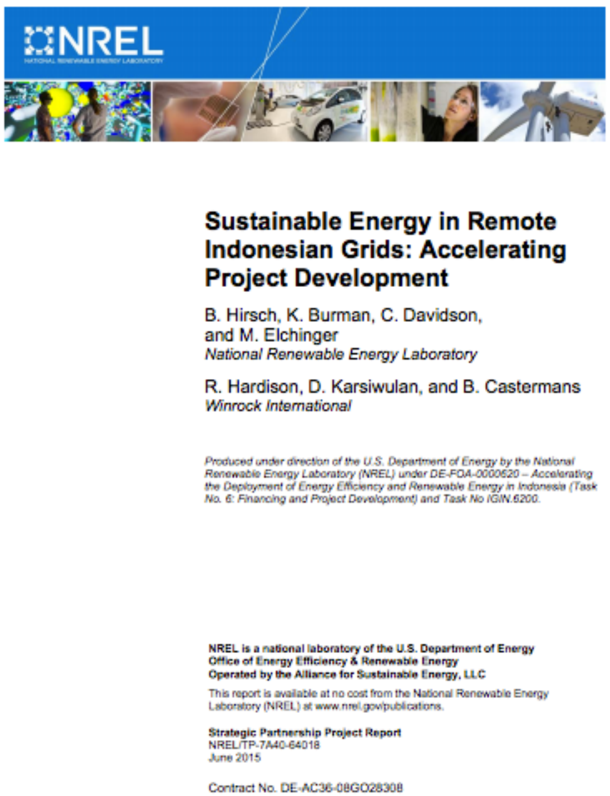
Challenges & Opportunities with isolated hybrid grids:

- Small isolated grids will be the smart grid trailblazers.
- Problem with renewables is too much power.
- Baseload vs. peaking is obsolete
  - Flexibility is key criterion.
- Storage at today's prices is no panacea
  - It will not make wind or solar act like coal.
  - Multiple value streams are necessary



Courtesy: HOMER Energy

USDOE/NREL – Sustainable Energy for Remote Indonesia Grids (SERIG)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Sustainable Energy in Remote Indonesian Grids: Accelerating Project Development

B. Hirsch, K. Burman, C. Davidson, and M. Elchinger
National Renewable Energy Laboratory

R. Hardison, D. Karsiwulan, and B. Castermans
Winrock International

Produced under direction of the U.S. Department of Energy by the National Renewable Energy Laboratory (NREL) under DE-FOA-0000620 – Accelerating the Deployment of Energy Efficiency and Renewable Energy in Indonesia (Task No. 6: Financing and Project Development) and Task No IGIN.6200.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

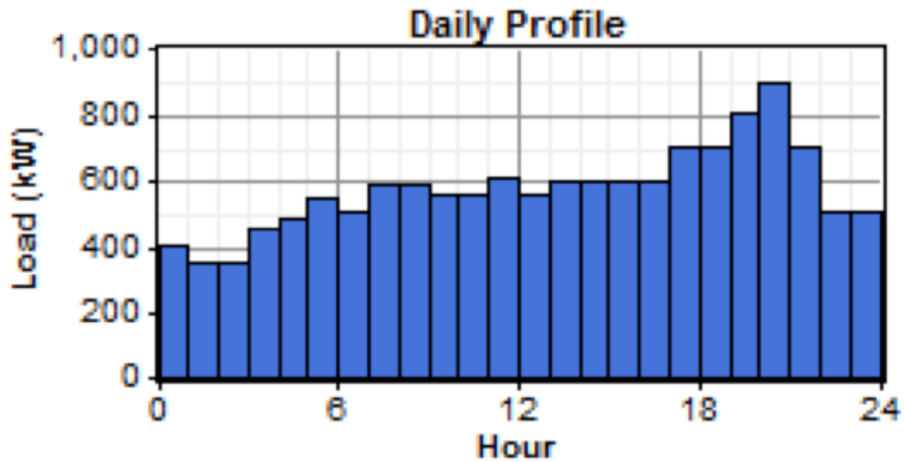
Strategic Partnership Project Report
NREL/TP-7A40-64018
June 2015

Contract No. DE-AC36-08GO28308

- http://www.nrel.gov/docs/fy15osti/64018.pdf
- Pre-feasibility analysis of POME (Lamandau); Solar PV (Sabu); Wind (Sumba)
- National Replication Strategy coming soon

Sabu Island Baseline Assumptions, 2013 (HOMER Inputs)

Data	Total
Average power (kW)	573
Average (kWh/d)	13,744
Peak Power (kW)	980
Load factor	0.58
Annual fuel consumption (Liters)	1,785,584
Average Annual production	5,016,561 kWh/year



Additional Assumptions:

- Load growth ~ 10% annually
- Solar PV installed @ US$4.50/W
- 25% spinning reserve
- Diesel @ US$1/liter

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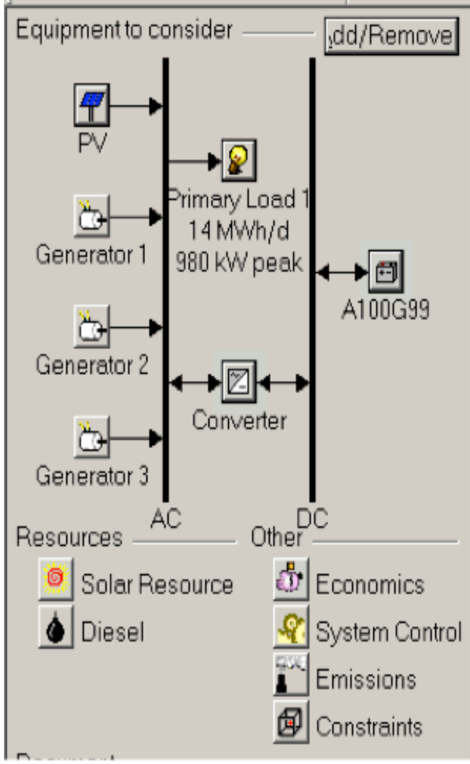
HOMER Modeling - Sabu Island, Base Case (no PV), 2013

HOMER - [Sabu_basecase 12_3 w PV_storage.hmr *]

File View Inputs Outputs Window Help



Calculate

Simulations: 640 of 640
Sensitivities: 6 of 6
Progress:
Status: Completed in 30 seconds.

Sensitivity Results | Optimization Results

Sensitivity variables

Primary Load 1 (kWh/d) 13,744 Diesel Price ($/L) 1

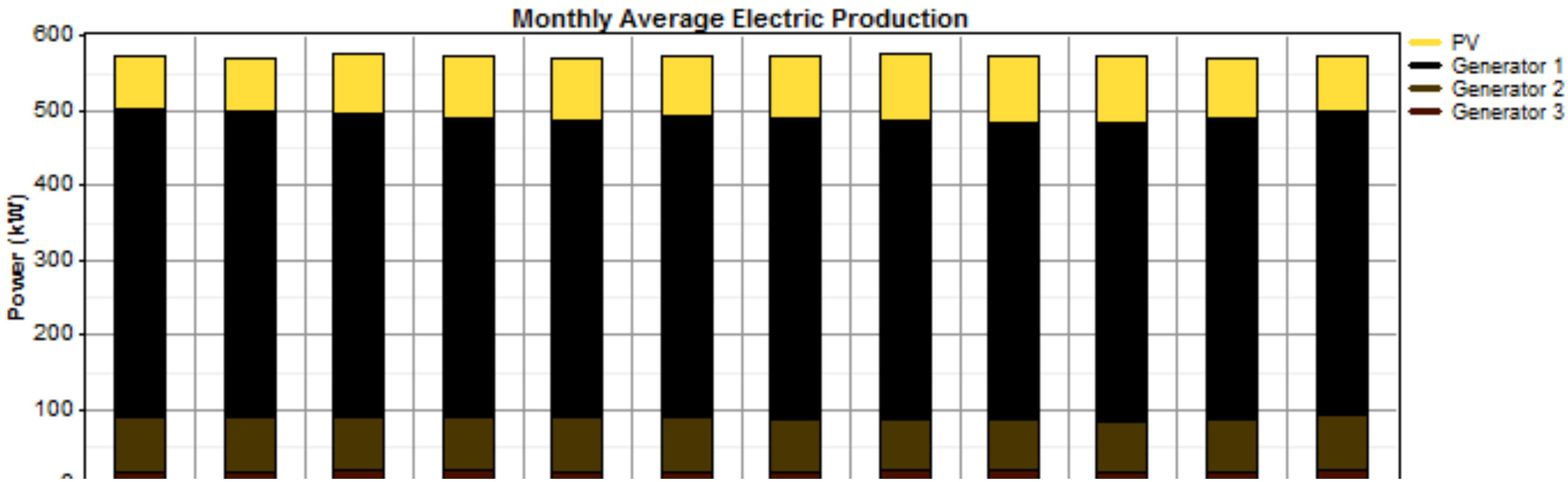
Double click on a system below for simulation results.

PV (kW)	Gen 1 (kW)	Gen 2 (kW)	Gen 3 (kW)	A100G99	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen 1 (hrs)	Gen 2 (hrs)	Gen 3 (hrs)
800	500	250	250	48	200	$ 4,017,733	1,323,794	$ 17,014,934	0.345	0.30	1,206,968	6,134	3,791	658
800	500	250		72	500	$ 4,272,733	1,347,914	$ 17,506,748	0.355	0.30	1,193,172	6,171	3,420	
800	500		250	72	500	$ 4,272,733	1,347,914	$ 17,506,748	0.355	0.30	1,193,172	6,171		3,420
800	500	250	250			$ 3,600,000	1,475,480	$ 18,086,480	0.367	0.29	1,326,512	7,371	5,455	1,415
	500	250	250	24	200	$ 282,733	1,885,186	$ 18,791,768	0.382	0.00	1,734,242	8,760	5,721	681
	500	250	250			$ 0	1,950,762	$ 19,152,866	0.389	0.00	1,785,584	8,760	7,434	1,618
	500	250		72	500	$ 672,733	1,918,407	$ 19,507,940	0.396	0.00	1,731,667	8,760	5,698	
	500		250	72	500	$ 672,733	1,918,407	$ 19,507,940	0.396	0.00	1,731,667	8,760		5,698

Sabu Island – Impacts from 350 kW of solar PV

Production	kWh/yr	%
PV array	715,065	14
Generator 1	3,530,917	70
Generator 2	623,185	12
Generator 3	147,413	3
Total	5,016,581	100

Fuel use without PV: 1,785,584 L
Fuel use with 350 kW PV: 1,568,617 L



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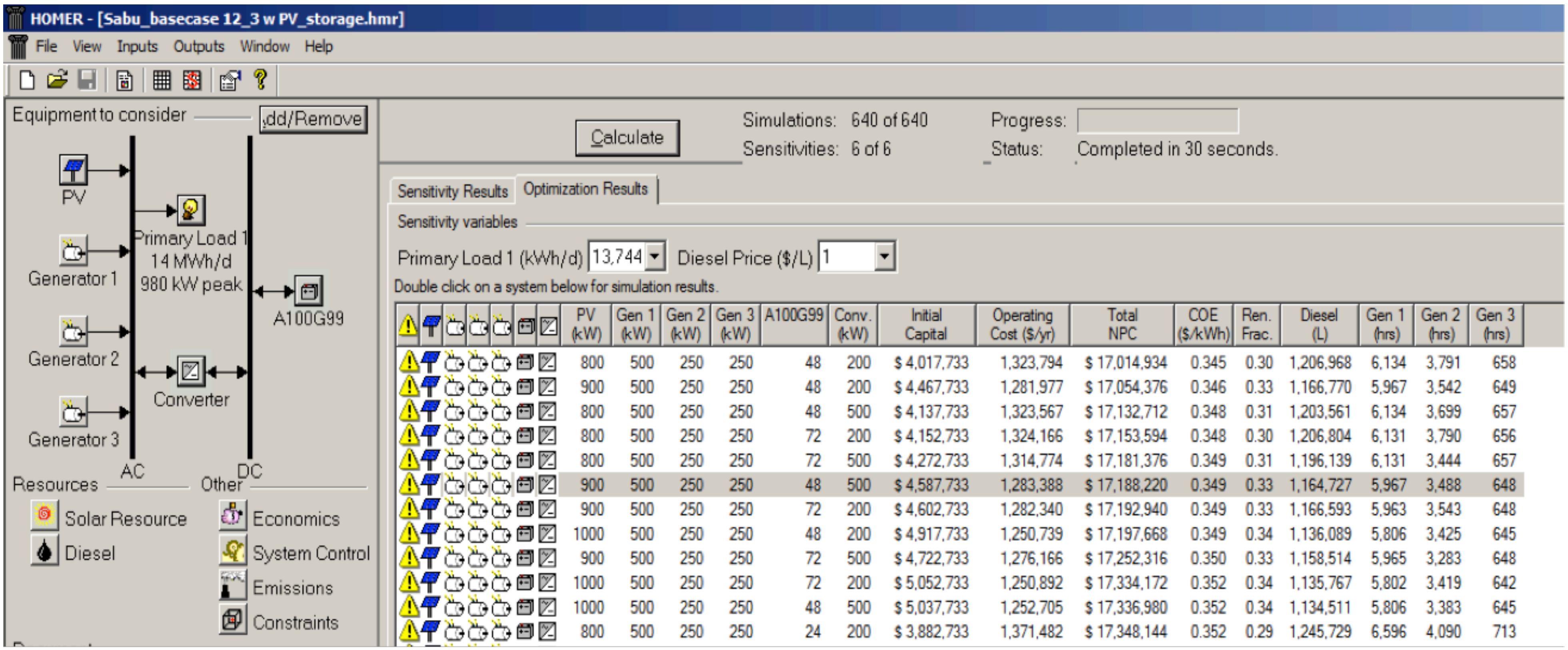
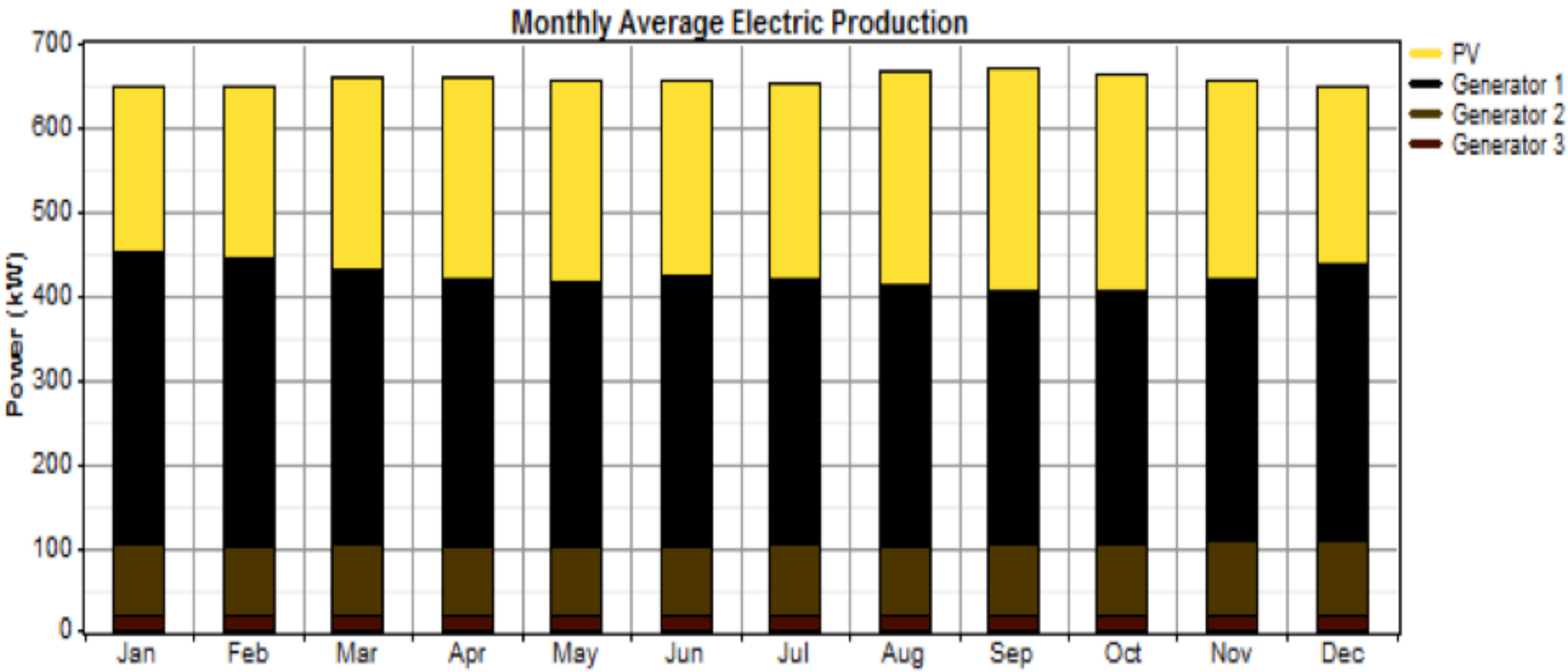
HOMER High Penetration Model (900 kW PV & 461 kWh Battery)

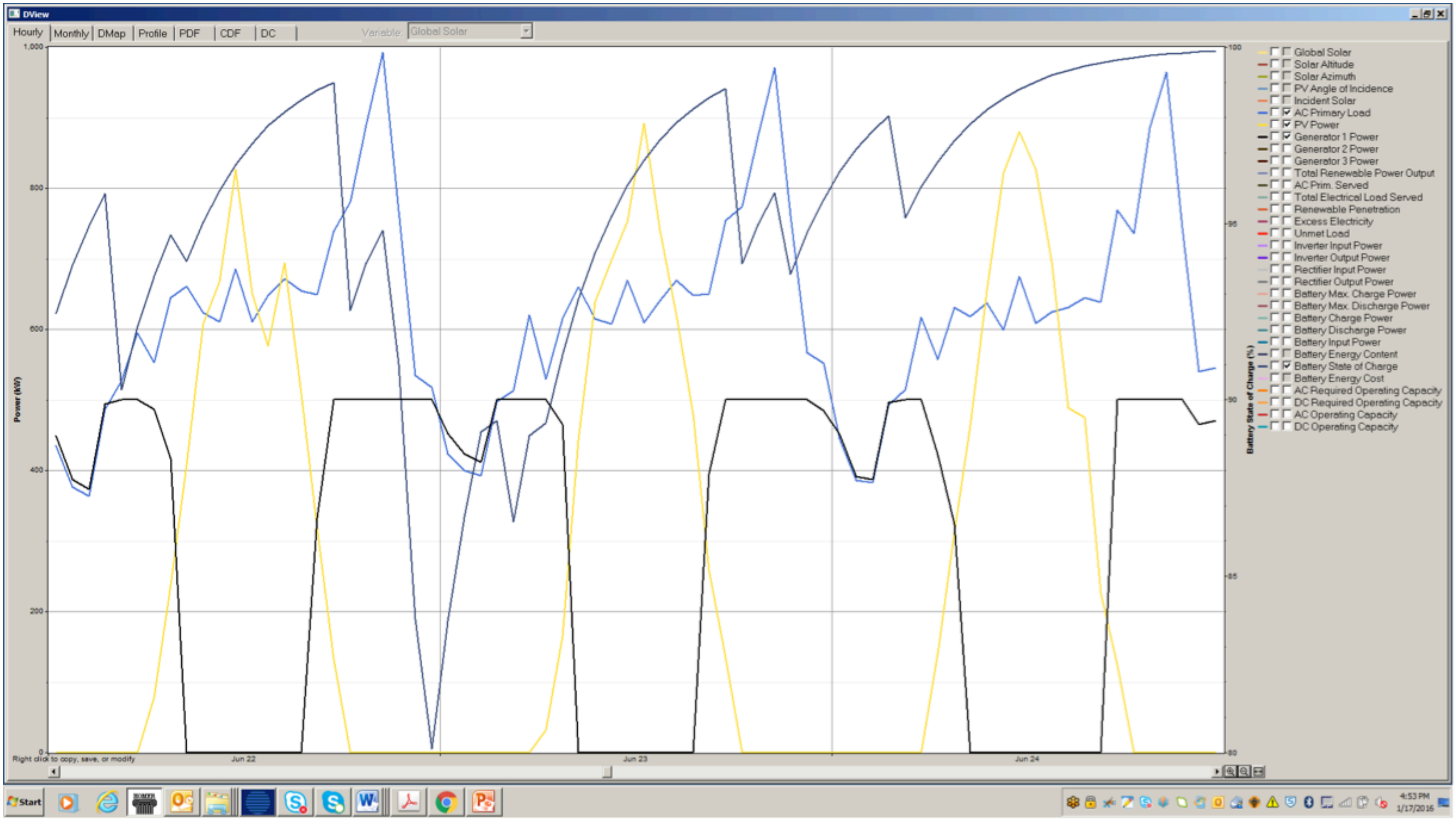


PV (kW)	Gen 1 (kW)	Gen 2 (kW)	Gen 3 (kW)	A100G99	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen 1 (hrs)	Gen 2 (hrs)	Gen 3 (hrs)
800	500	250	250	48	200	$ 4,017,733	1,323,794	$ 17,014,934	0.345	0.30	1,206,968	6,134	3,791	658
900	500	250	250	48	200	$ 4,467,733	1,281,977	$ 17,054,376	0.346	0.33	1,166,770	5,967	3,542	649
800	500	250	250	48	500	$ 4,137,733	1,323,567	$ 17,132,712	0.348	0.31	1,203,561	6,134	3,699	657
800	500	250	250	72	200	$ 4,152,733	1,324,166	$ 17,153,594	0.348	0.30	1,206,804	6,131	3,790	656
800	500	250	250	72	500	$ 4,272,733	1,314,774	$ 17,181,376	0.349	0.31	1,196,139	6,131	3,444	657
900	500	250	250	48	500	$ 4,587,733	1,283,388	$ 17,188,220	0.349	0.33	1,164,727	5,967	3,488	648
900	500	250	250	72	200	$ 4,602,733	1,282,340	$ 17,192,940	0.349	0.33	1,166,593	5,963	3,543	648
1000	500	250	250	48	200	$ 4,917,733	1,250,739	$ 17,197,668	0.349	0.34	1,136,089	5,806	3,425	645
900	500	250	250	72	500	$ 4,722,733	1,276,166	$ 17,252,316	0.350	0.33	1,158,514	5,965	3,283	648
1000	500	250	250	72	200	$ 5,052,733	1,250,892	$ 17,334,172	0.352	0.34	1,135,767	5,802	3,419	642
1000	500	250	250	48	500	$ 5,037,733	1,252,705	$ 17,336,980	0.352	0.34	1,134,511	5,806	3,383	645
800	500	250	250	24	200	$ 3,882,733	1,371,482	$ 17,348,144	0.352	0.29	1,245,729	6,596	4,090	713

Sabu Gensets 1-3 & PV @ High Penetration



Sabu Output – Diesel, Battery SOC, PV, Load, June 22-24



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Sabu- 350 kW PV (Low/ Medium Penetration)

System Specs and Load	Reference	Optimistic	Conservative	Units
Capacity	350			kW
Load served	715,065			kWh/yr
Capacity factor	23.32%	24.49%	22.16%	CF
Generation	715,065			ann kWh
Degradation	0.80%	0.76%	0.84%	%/year

System Costs	Reference	Optimistic	Conservative	Units
Capital Cost	$1,575,000			USD
$/W	$4.50	$4.28	$4.73	USD/W
O&M/yr	$10,150	$9,643	$10,658	USD/yr

Financial Inputs	Reference	Optimistic	Conservative	Units
Inflation	4.4			%
Real discount rate	14%	13.30%	14.70%	%
Analysis period	20			years
Target IRR	14			%
PPA price	$0.20			USD/kWh
Federal tax rate	25%			%
DSCR	1.3	1.3	1.3	
Interest rate	8%	7.60%	8.40%	%
Project debt term	18			years
Depreciation	15-year straight-line			

Replacement	Reference	Optimistic	Conservative	Units
Inverter Cost	$0.1125	$0.10688	$0.11813	USD/W
Inverter Life	15			years
Inverter Depreciation	15-year straight-line			

Sabu – 1 MW PV & 461 kWh Battery (High Penetration)

System Specs and Load	Reference	Optimistic	Conservative	Units
Capacity	1,000			kW
Load served	2,043,045			kWh/yr
Capacity factor	23.322%	24.49%	22.16%	CF
Generation	2,043,045			ann kWh
Degradation	0.80%	0.76%	0.84%	%/year

System Costs	Reference	Optimistic	Conservative	Units
PV Capital Cost	$4,500,000			USD
$/W	$4.50	$4.28	$4.73	USD/W
Battery capital cost	$270,000	$256,500	$283,500	USD
O&M/yr	$32,200	$30,590	$33,810	USD/yr

Financial Inputs	Reference	Optimistic	Conservative	Units
Inflation	4.4			%
Real discount rate	14%	13.30%	14.70%	%
Analysis period	20			years
Target IRR	14			%
PPA price	$0.25			USD/kWh
Federal tax rate	25%			%
DSCR	1.3	1.3	1.3	
Interest rate	8%	7.60%	8.40%	%
Project debt term	18			years
Depreciation	15-year straight-line			

Replacement	Reference	Optimistic	Conservative	Units
Inverter Cost	$0.1125	$0.10688	$0.11813	USD/W
Inverter Life	15			years
Inverter Depreciation	15-year straight-line			
Inverter Cost	$0.28273	$0.26859	$0.29687	USD/W
Inverter Life	16			years
Inverter Depreciation	15-year straight-line			

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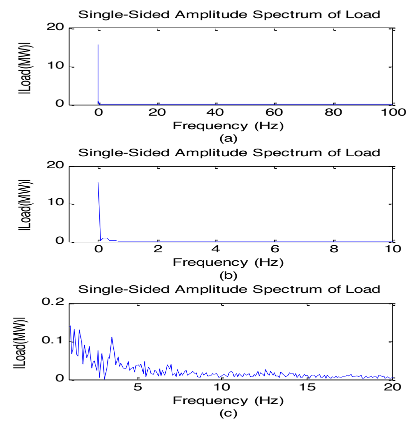
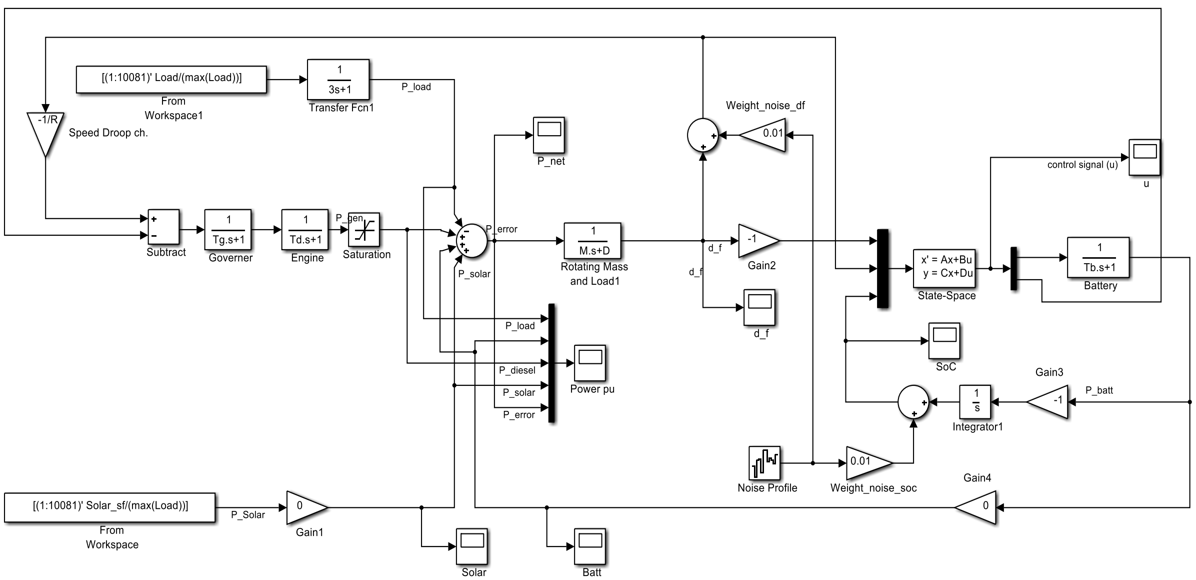
Basic stability assessment

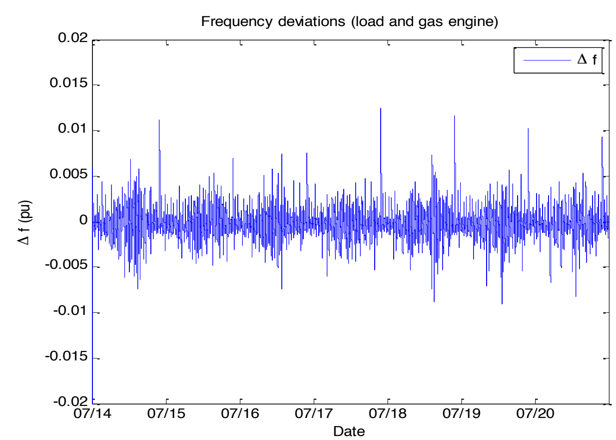
- Stability assessment of the microgrid
  1. Load and RE data analysis
  2. Controller and simulation model



Step 1: Frequency spectrum of load



Step 2: Controller and simulation model



Step 3: Frequency stability assessment

Courtesy NREL

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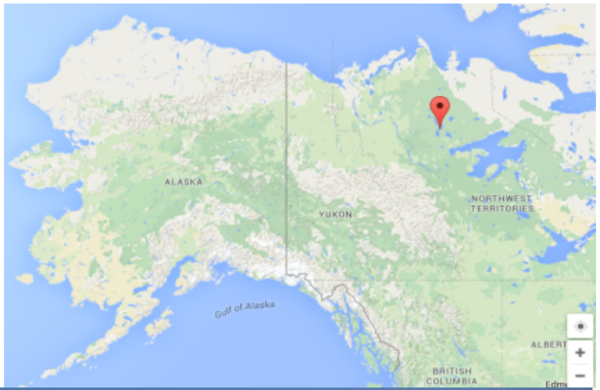
Global Challenge & Opportunity

- 4,300+ communities with stand-alone diesel systems (< 1 MW)
- 1.3 billion people with no electricity, 85% in rural areas[1]
    - IEA: 770 million people best served by mini- or off-grid hybrid power systems
- Hundreds of RE/diesel hybrid systems deployed, but RE contribution typically 20%-30%
- Disproportionate costs and complexity to increase RE contribution
- Technical, institutional, financial barriers to widespread deployment
    - Customized system design and engineering → "one-off" systems
    - Underperforming expensive hardware
    - Lack of agreement on development path, preferred architecture
    - Business models and financing strategies need refinement

[1] *IEA, World Energy Outlook* http://www.iea.org/publications/freepublications/publication/name-49561-en.htm

Northwest Territories Power Corporation (Canada) – Colville Lake Microgrid

NORTHWEST TERRITORIES POWER CORPORATION *Empowering Communities*



- An electrical island - 50 km north of Arctic Circle
- 150 inhabitants
- 150 kW peak; 30 kW base load
- Diesel fuel delivery only by ice road
  - Cost of generation ~$2.60 / kWh!
- New power station
  - 2 x 100 kW diesels + 150 kW diesel
  - 50 kW of solar in summer 2014 – to be expanded in 2015

Courtesy Jim McDowall, SAFT - ABB (8 slides)

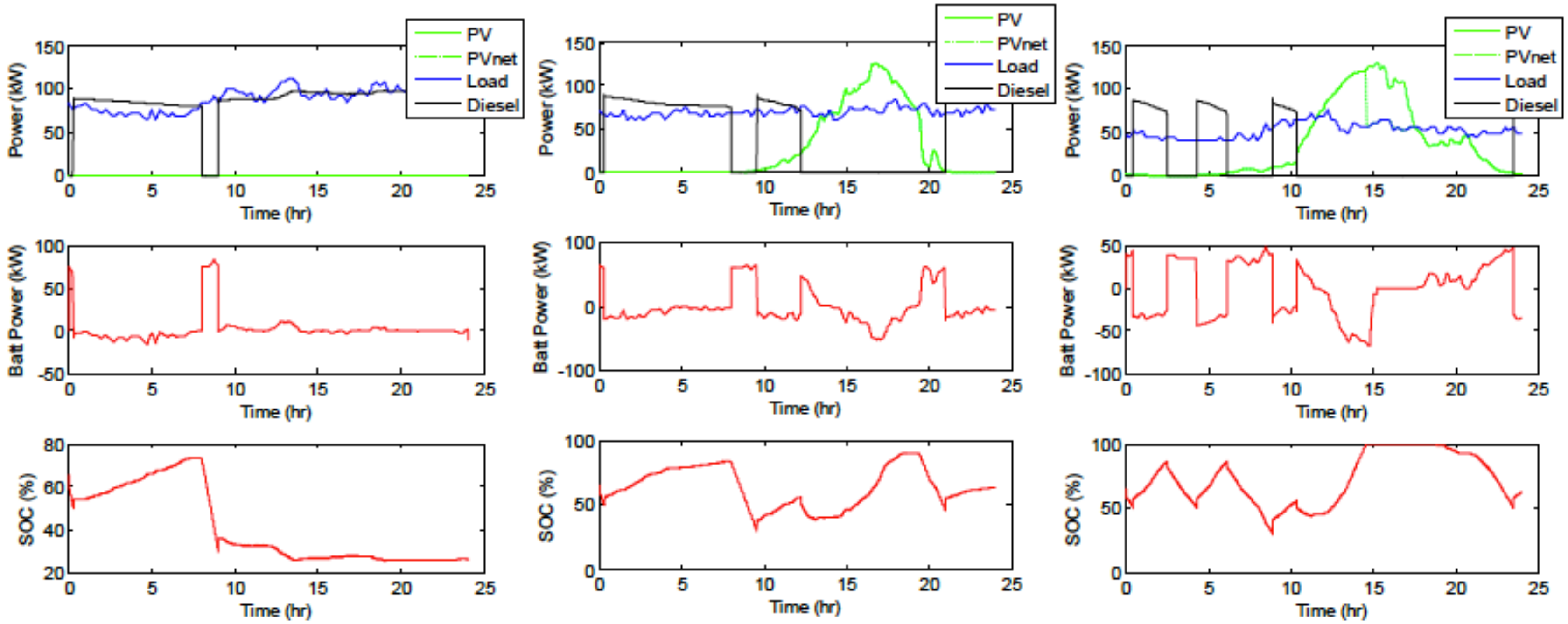
System Need for Storage

- Energy storage needed to maximize fuel savings

- Without storage a diesel must be running 24 / 7
  - Covering sudden PV ramps
  - PV curtailment likely in order to run diesel efficiently
  - No possibility to cover entire load with PV

- RFP for 200 kW / 200 kWh ESS

- Modeling allows fuel savings to be quantified



5% fuel saved **37% fuel saved** **65% fuel saved**

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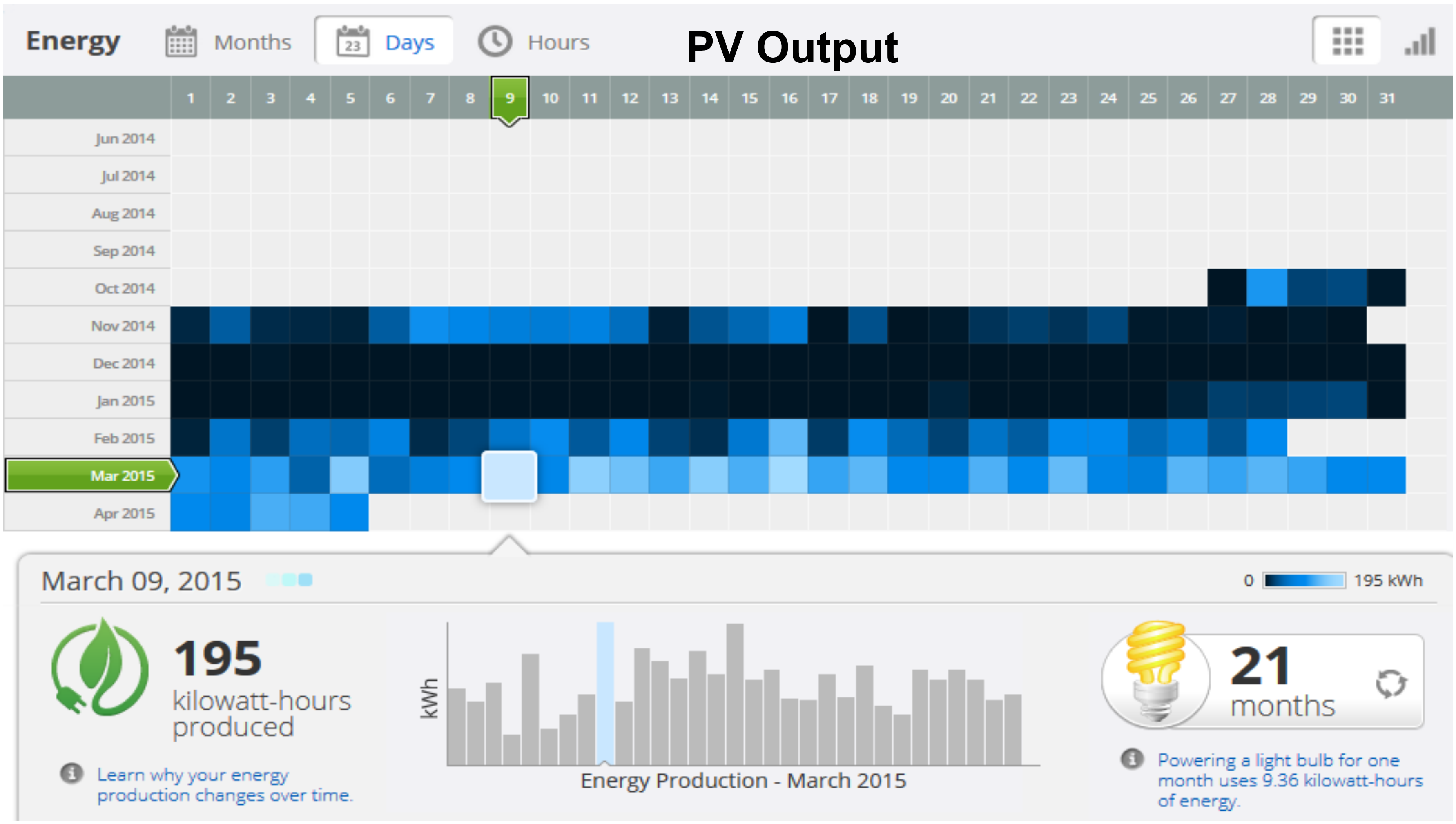
PV Output



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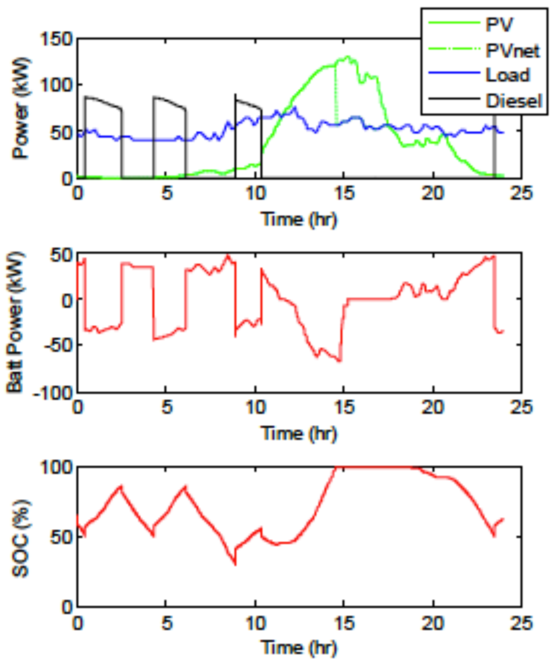
Managing PV Curtailment

- Use of Enphase microinverters with no central controller
  - Normal curtailment is via frequency droop
- Curtailment needed when battery reaches full state of charge
  - Frequency droop control not possible without rotating equipment on the network
  - Curtailment managed by switching off array sections



PROJECT TIMELINE

- Contract signed July 2014
- Intensium Max 20M container 232 kWh with 240kW ABB PCS100
- Development of cold-weather package
  - Insulation for –50°C
  - Hydronic heating coil for glycol heating
- Delivery to Edmonton for integration December 2014
- Ice-road transportation February 2015
- Installation / commissioning July 2015

ICE ROAD TRANSPORTATION

- Ice roads are unforgiving
  - Schedule inflexibility
  - Transportation shock
  - No cranes!
- Equipment braced inside container
- NTPC paid extra for speed limitation
- Equipment arrived safely without triggering shock sensors

Next steps

NEXT STEPS

- PV expansion in June / July
- ESS commissioning in July
- Integration testing in August
- Possible system expansion in 2016?
  - Battery container designed to accommodate doubling of energy to 464 kWh
  - Reduce PV curtailment and fuel consumption
  - Deployment of wind turbines also a possibility
- Success in Colville Lake will pave the way for similar systems to be installed in other remote communities

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Recent Insights from Power & Water Corporation (AUS) Tender & Project Development (Daly River High Penetration System)

- O&M costs varied 5-10X; Battery prices 2-5X
- CapX & OpX vary across bidders (500 kW peak load; 1 MW PV)
- Performing O&M inside your organization gives you more control & flexibility (but requires a commitment)
- HOMER gives “good” answers excluding civil, O&M, contractor variation
- Size PV-batteries @ 20% min load (1.5 MWh; 800 kVA inverter)
- Battery pricing is relatively linear
- Selected Li-ion; aimed for 50% fuel savings (required diesel-off), then sized to avoid PV curtailment
- Fault tolerance & reliability – system design basis

Big Issues to Consider/Questions to Ask

- IPP and/or internal PLN development?
  - System Design
  - Construction
  - Integration (including load control if possible)
  - O&M
- How to Monetize (& Optimize) Fuel Savings
  - Technical
  - Contractual

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Potentially Biggest Variables/Costs/Unknowns

- Supervisory Controls/Control System
- Civil Works/Construction
- System Architecture/Design (FEED; Hardware)
- Diesel system (gen-sets, switchgear) needs/upgrades
- Energy Storage
- O&M
- Fuel costs

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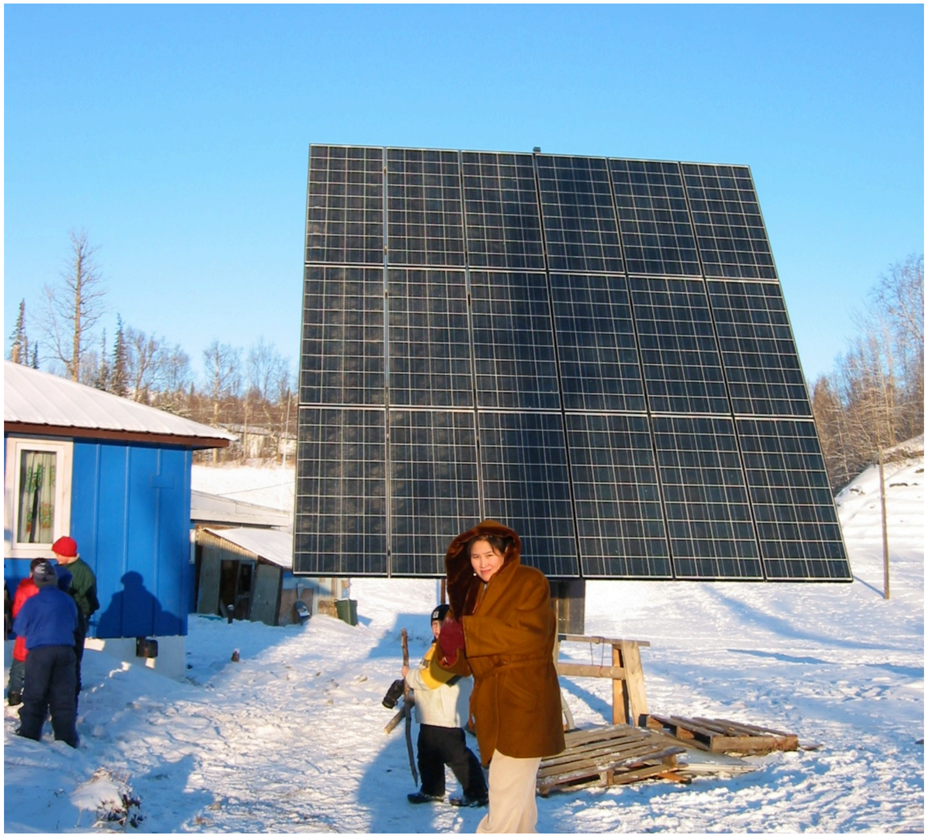
Deering, AK Water Plant

Chickaloon Village,AK School



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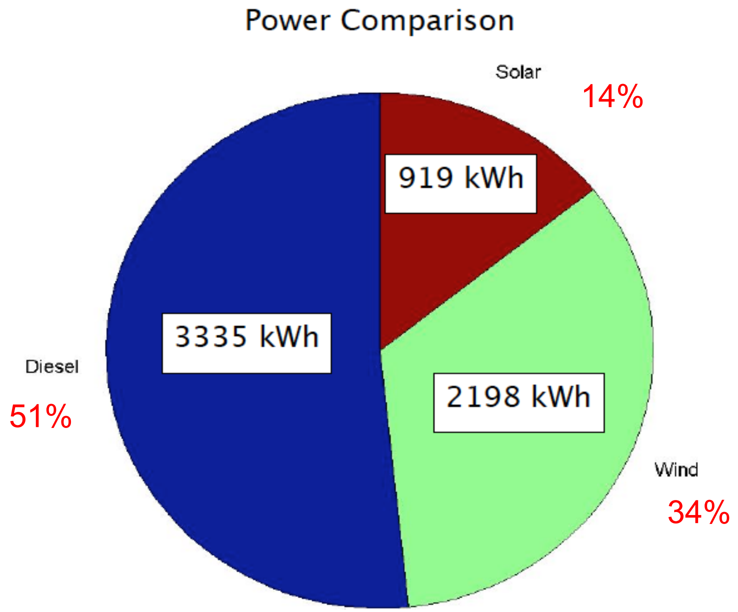
PV PEFORMANCE ABOVE THE ARCTIC CIRCLE

Community	installed	installed size Kw	production MWh Since comm.	Current $/Kwh retail	Value $	CO 2 offset lb	Disel offset Gallon	Cost $	Cost/watt installed	Performance Kwh/day 11/7/15	Payback years	Payback years 1Mwh/1Kw	maint.cost $/year $ 100.00/1Kw	Type and Orientation	Tilt Deg
Ambler	3/1/13	8.4	17.2	0.67	$11,524.00	50,588	1274.07	75,000	8.928571	17.53312946	22.38948615	17.0575693	840	60 deg, South/East	60
Ambler IRA	3/1/13	2.2	6	0.67	$4,020.00	17,647	444.44	25,000	11.36364	6.116207951	20.39153547	20.69199457	220	flat south	60
Kobuk	3/1/13	7.38	10.6	0.73	$7,738.00	31,176	785.19	75,000	10.1626	10.80530071	32.45837125	17.34602962	738	180 deg circle	65
Shungnak	10/1/13	7.5	9.5	0.73	$6,935.00	27,941	703.70	75,000	10	12.38591917	28.40712684	17.12328767	750	180 deg horseshoe	60
Noorvik	10/1/13	12	13.5	0.55	$7,425.00	39,706	1000.00	75,000	6.25	17.60104302	29.7163415	15.90909091	1200	180 deg horseshoe	60
Noatak	11/1/13	11.27	15.55	0.78	$12,129.00	45,735	1151.85	75,000	6.654836	21.12771739	17.1527766	11.73696904	1127	180 deg horseshoe	60
Deering	11/1/13	11.13	19.79	0.71	$14,050.90	58,206	1465.93	75,000	6.738544	26.88858696	14.75636963	13.01203447	1113	180 deg circle	70
Kotzebue-1	10/15/14	10.53	3.27	0.45	$1,471.50	9,618	242.22	83,000	7.882241	8.427835052	78.97653592	23.07164715	1053	180 deg horseshoe	65
Kotzebue-2	11/10/14	10.53	2.54	0.45	$1,143.00	7,471	188.15	83,000	7.882241	7.016574586	94.8612759	23.07164715	1053	180 deg horseshoe	65
Selawik	11/20/14	9.72	8.82	0.51	$4,498.20	25,941	653.33	83,000	8.539095	25.05681818	23.00439202	21.64528363	972	90 deg Horseshoe	65
Kiana	8/13/15	10.53	3.4	0.56	$1,904.00	10,000	251.85	83,000	7.882241	39.53488372	13.52876425	18.53971646	1053	180 deg Horseshoe	65
Buckland		10.53		0.47	$0.00	0	0.00	83,000	7.882241	0		22.08987493	1053	180 deg Horseshoe	65
Kivalina		10.53		0.55	$0.00	0	0.00	83,000	7.882241	0		18.87680221	1053		
Total		122.25	110.17		$72,838.60	324,029	8160.74	973,000	8.311422	192.4940162					

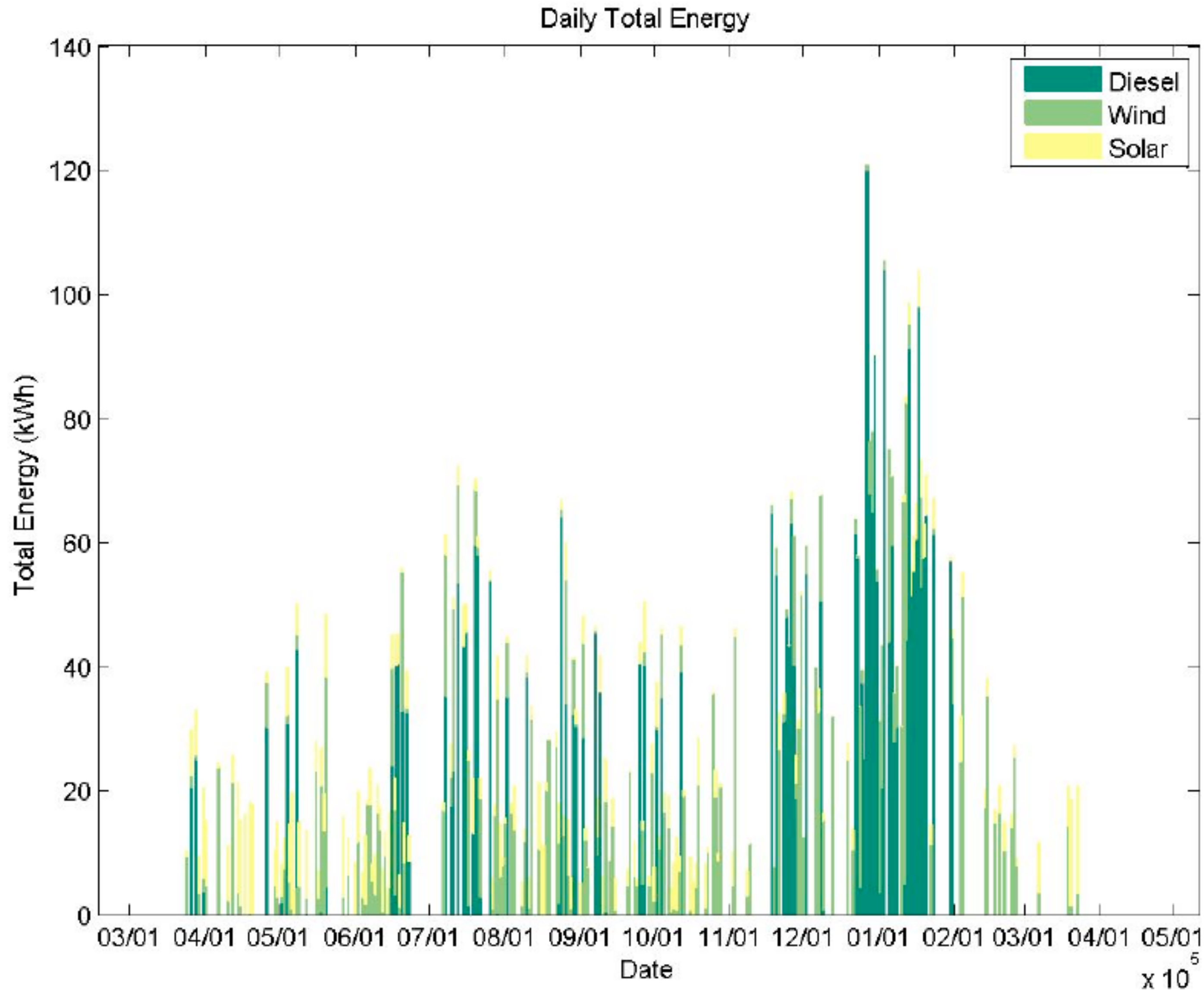
Electric Rates spring 20	real
Ambler	0.67
Kobuk	0.73
Shungnak	0.73
Noorvik	0.55
Noatak	0.78
Deering	0.71
Kotzebue-1	0.45
Selawik	0.51
Kiana	0.56
Buckland	0.47
Kivalina	0.55

Village of Ugashik, AK
Hybrid Performance Monitoring

- Working with ACEP at UAF, AEA
- Monitoring performance of wind-diesel-battery hybrid system to determine relative contribution of various RE inputs and diesel savings for system optimization
- Results replicable for other projects in region and beyond
- Very windy site (class 5), but PV performed as well as wind on kWh/kW installed basis, and better on a $/kW installed basis with current pricing



Ugashik Hybrid Power: Wind, Solar, Diesel, Battery



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High penetration requirements

- >60% fuel displacement (just for electricity) generally will require diesel-off
- Voltage/frequency reference
  - Inverter (with energy storage), synchronous condenser (inertia)
- ‘Oversized’ renewable generation
  - Provides additional electricity -> conversion to thermal energy makes sense
- Optimal control to handle competing objectives
  - Produce least cost electricity
  - Manage power quality
  - Manage/schedule generation assets (operational envelopes, maintenance schedules, etc.)
  - Diversion to distributed (thermal) loads

Courtesy UAF- ACEP

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Future high penetration system

- Wish list
  - Standard interfaces (cf. J1939 for diesels)
  - Use-case specific cycle-life models for energy storage
  - Improved system automation
    - Predictive models (generation and demand) for small systems
    - Instrumentation for preventative diagnostics
  - Modular system packaging?

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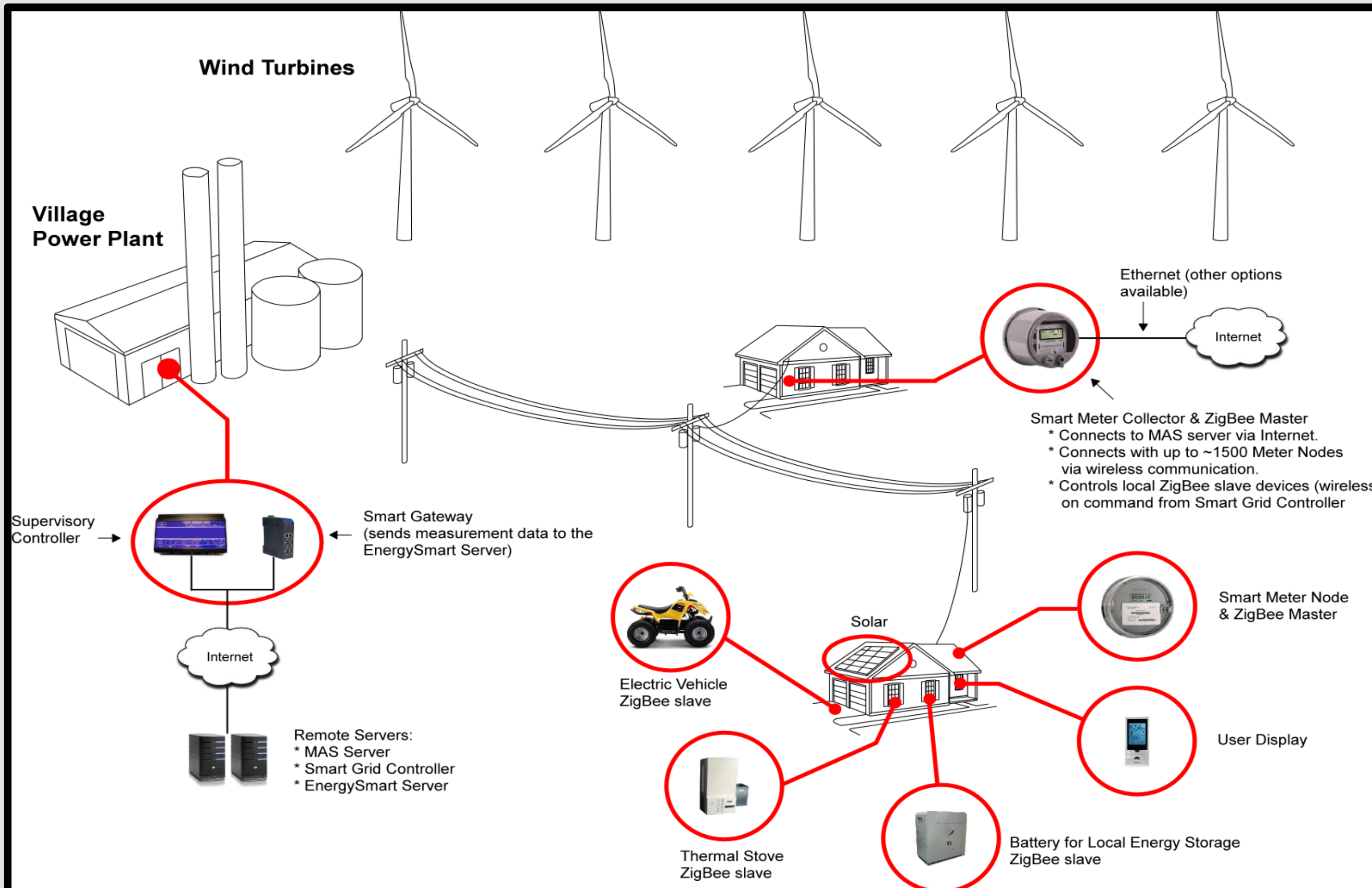
Technology Innovation & Community Development

Village Wind-Solar-Heat Smart Grid System

in Chaninik Wind Group Villages

Kwigillingok, Kongiganak, Tuntutuliak and Kipnuk, Alaska



Slide created by Intelligent Energy Systems. For more information please contact Dennis Meiners at 907-770-6367 or dennis@iesconnect.net.

DATA NEEDS

- Load Profiles; Large, discrete loads
- Existing hardware at diesel plant (gen-sets, switchgear, distribution system details, feeders, relays, etc)
- Fuel and generation costs
- Growth Projections
- Real-time Insolation/Resource Availability for weather forecasting (high penetration)

Typical Approach/Methodology

- Determine Project/Program Objectives
  - Fuel savings; cost savings; technology exposure; local industry/ development; national, regional goals (GHG/air/water, etc)
- Targeted Data Collection
  - Load profiles; large discrete system loads; resource availability; existing infrastructure
- Modeling
  - HOMER; PV Watts; Financial (e.g., SAM, CREST); Preliminary system design (techno-economic feasibility); system impact studies (load flow, stability, short-circuit, etc)
- RFP/Tender
- Procurement/Construction
- Ongoing Performance Monitoring & Verification; System Improvements

Four Possible System Designs/Architectures

- Low Penetration PV-Diesel
  - **Pro's:** Lower cost; less complicated; perceived lower risk
  - **Con's:** Lower impact/fuel savings; possible replication of mistakes
- Medium Penetration with Variable Speed Diesel
  - **Pro's:** Relatively high fuel savings/penetration with less complicated controls & minimal storage
  - **Con's:** Some technology risk, though diesels are mature; up-front cost vs. fixed speed diesel
- Medium Penetration with Lots of Dump Loads
  - **Pro's:** Higher penetration with minimal storage ("cheap" batteries); higher conversion efficiencies
  - **Con's:** Relatively complex controls & communication; need alternative loads (cooling and/or thermal)
- Diesel-off & Storage
  - **Pro's:** Maximum fuel savings; Reduced run-time on diesel gen-sets
  - **Con's:** Most complicated; technology risk; up-front costs; fuel prices?

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