Alaska Village Electric Cooperative
ADAPTIVE MICROGRIDS
Emerging Priorities in Energy Research
Anchorage Alaska October 2018

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900 KW EWT
100 KW NW100
Even Smaller Turbines
Photo courtesy of Kotzebue Electric

Renewables are Disruptive

Microgrids have to ensure they have enough generation.

-- A major problem for microgrids is ensuring that there is sufficient generation to supply the power the system demands, not just now but also 5 minutes or an hour from now. With renewables, now you have to worry also how much generation there will be.

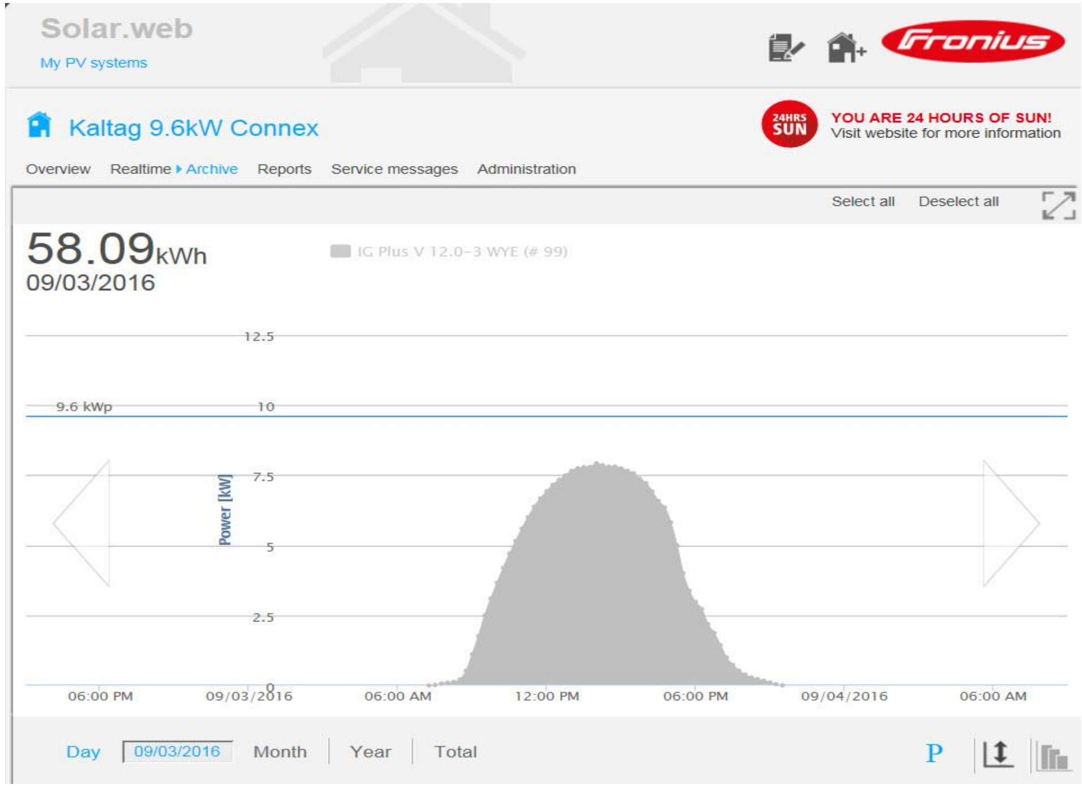
Microgrids have to be stable

-- Additional power fluctuations require additional methods to keep the system solid.

And Renewables don't help

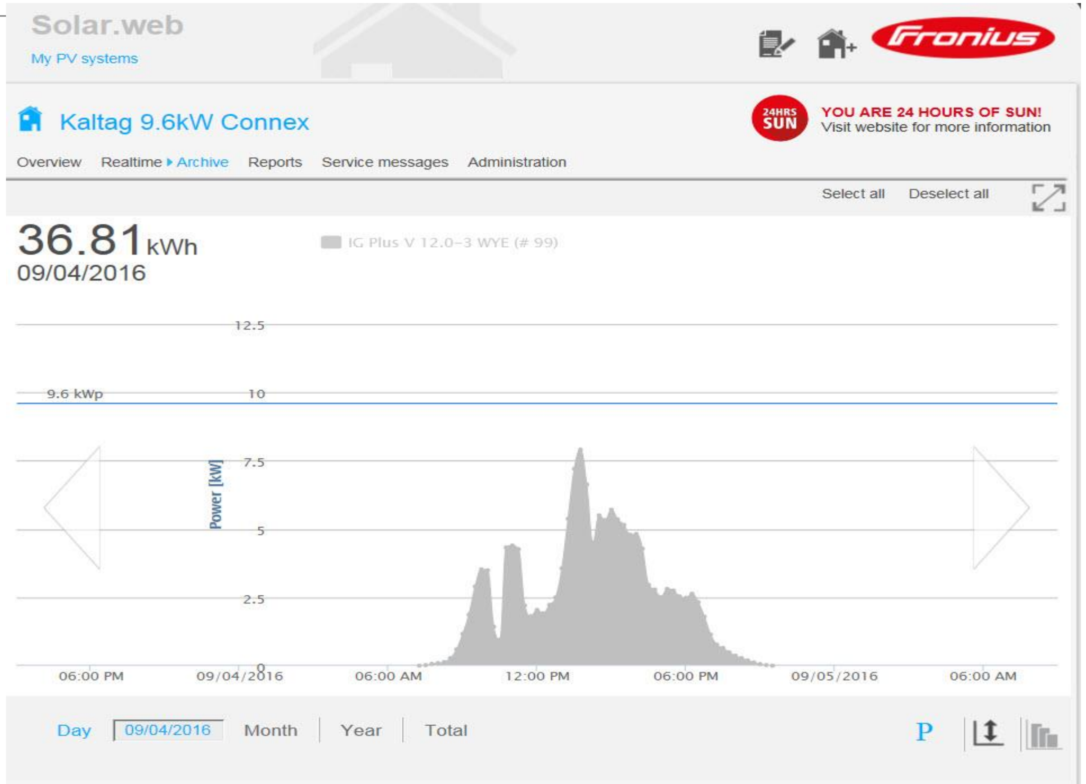
- Larger Wind, gusting conditions. Sudden loss of wind
- Solar can have sudden cloud cover,

But Why are they Disruptive?



Renewables are Disruptive

Not Only does solar help at only certain times of day, but clouds can cause sudden drops in generation.



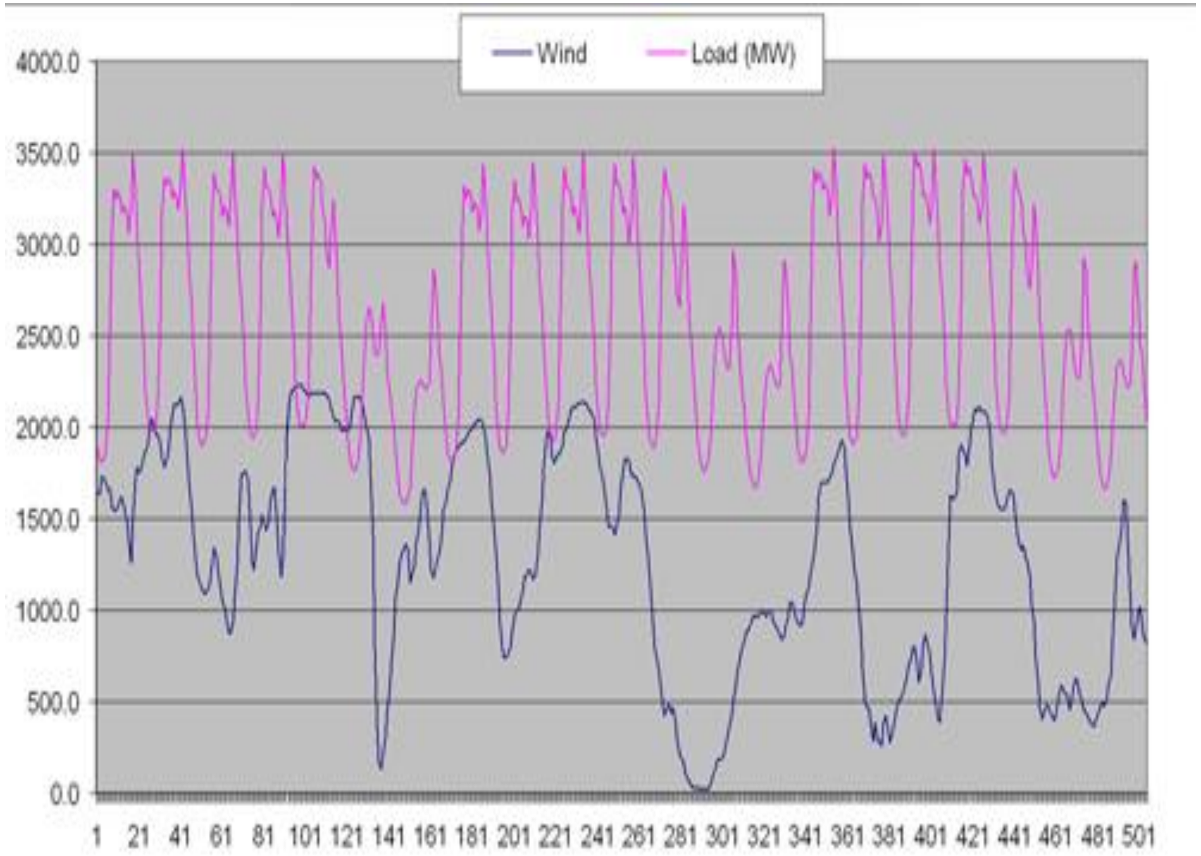
Renewables are Disruptive

And here is what unpredictable wind does to your power forecasting.

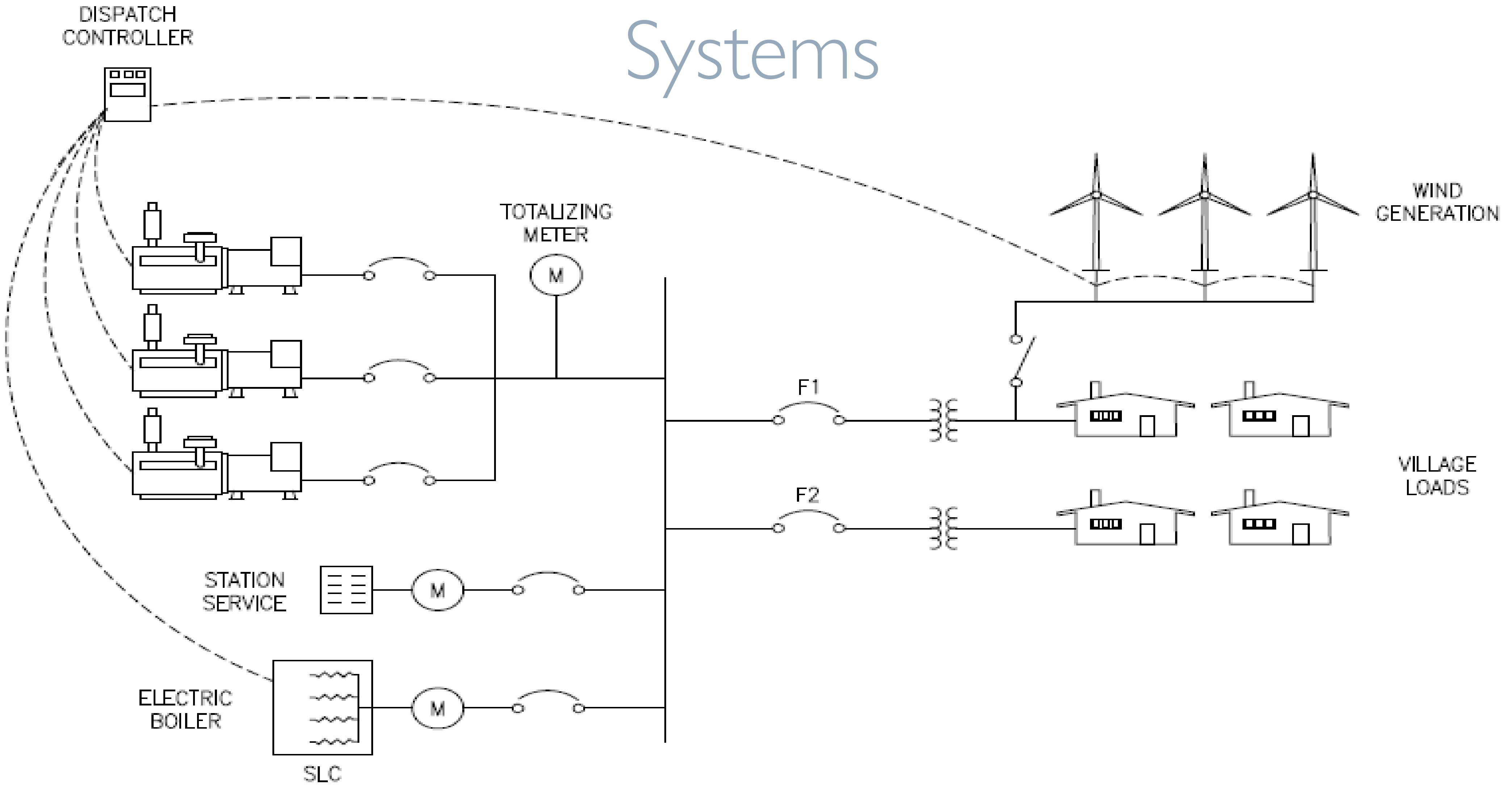
At least the day/night load variations are somewhat predictable.

Here are 21 days of load, showing the daily variations in load (pink), and also what is typical variations in wind output.

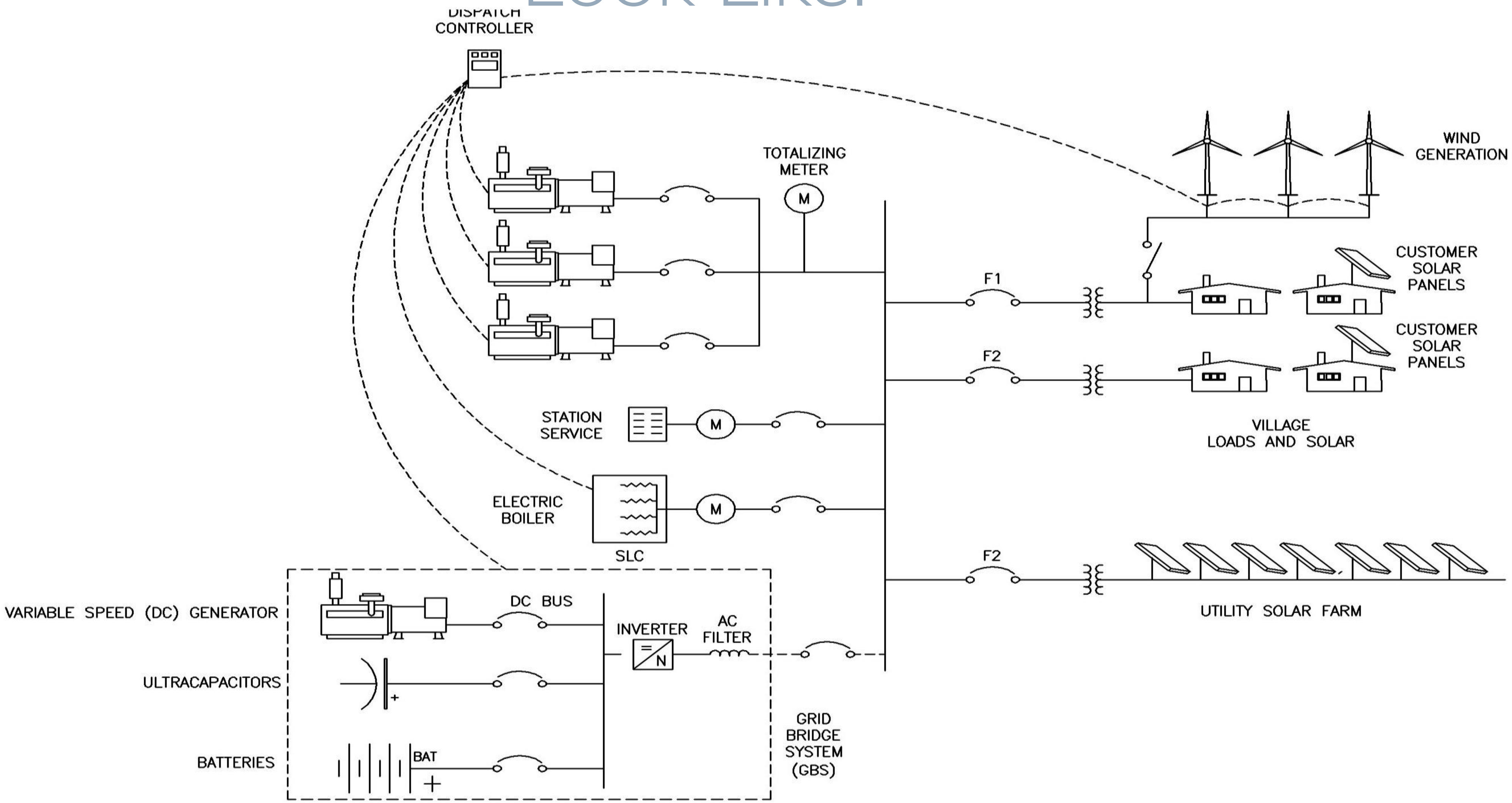
Add the two variations together, and we have some serious operating difficulties.



AVEC 2017 State of the Art Power Systems



What does a Adaptive Microgrid Look Like?



Microgrid Solutions

What we need is Spinning Reserve

-- We cannot afford to run large diesels at no load for days on the off chance a large wind turbine will be suddenly lost.

- We need enough power to cover the loss of any generation unit, including wind turbines and solar farms.

- We need enough time duration to decide whether or not to start another diesel and get it on line, so minutes, not hours.

Microgrid Solutions

Batteries & Ultra-capacitors for energy storage

- Are they a savior? When does it make sense?
- If we want full power for only 5 minutes, then that is called a C12 discharge rate
- Ultracapacitors can do that easily, repeatedly, for millions of cycles, for years, but they are expensive.

- Lithium Ion batteries and others were considered, but the discharge rate that could be handled without excessively reducing life started at C0.5 and occasionally C6. This would mean a large expensive battery bank, perhaps even a full container.

- Lithium Titanium Oxide (LTO) batteries were found to be available and able to handle discharge rates close to the desired rate, with sufficient longevity.

Microgrid Solutions

Lithium Titanate Batteries can be quickly charged and discharged, like Ultracapacitors

Grid Bridging System

The Initial design was based on Ultracapacitors Only

- Ultracapacitors are not a chemical device, but rather an electrostatic.
- They could easily handle the million cycles a year required for stabilizing wind fluctuations.
- Because of their high efficiency, they did not heat very much while being cycled.
- Because of their high power density, a few tall racks full could supply the 500 kW-1000kW desired to handle turbines like the 900 kW EWT.
- They are inherently fire-safe
- They can be discharged for servicing, which is a great safety feature in a rural environment.
- They do have three downsides – The first is their low energy density, but still sufficient for a few minutes of storage.
- Another is that their voltage varies significantly while charging and discharging.
- They are expensive (currently almost $500K for a 500 kW capacity).

Grid Bridging System

The Second design was based on a combination of Ultracapacitors and LTO Batteries.

- We found out that a reasonable volume of LTO batteries could handle the occasional need for providing spinning reserve when a generation unit went off line or when a precipitous loss of wind occurred (even once a day totaled up to a manageable 3600 cycles over a 10 year lifetime.
- A much smaller number of Ultracapacitors were kept to handle second by second variation in wind power.
- Integration was required to switch between capacitors and batteries, but we felt that was manageable.
- The inverter still needed to handle a wide range of DC input voltage.
- But the cost of the energy storage dropped by %30 -%60!

Grid Bridging System

The Current design is based on LTO Batteries only.

- We found out that a LTO battery sized for spinning reserve requirements could also handle the small fluctuations required for stability, without reducing the 10 year longevity requirement, hence eliminating the Ultracapacitors completely.
- Saves additional cost
- Fire risk is low for LTO
- Reduces the design issues for the inverter by reducing the voltage variations on the DC input.
- Reduces the volume of the energy storage component to a size where an indoor electric enclosure can contain both a 500 kW inverter and the energy storage.
- Cost potentially reduces such that a 1000 kW GBS can now be purchased for less than our budgeting for the original 500 kW design.

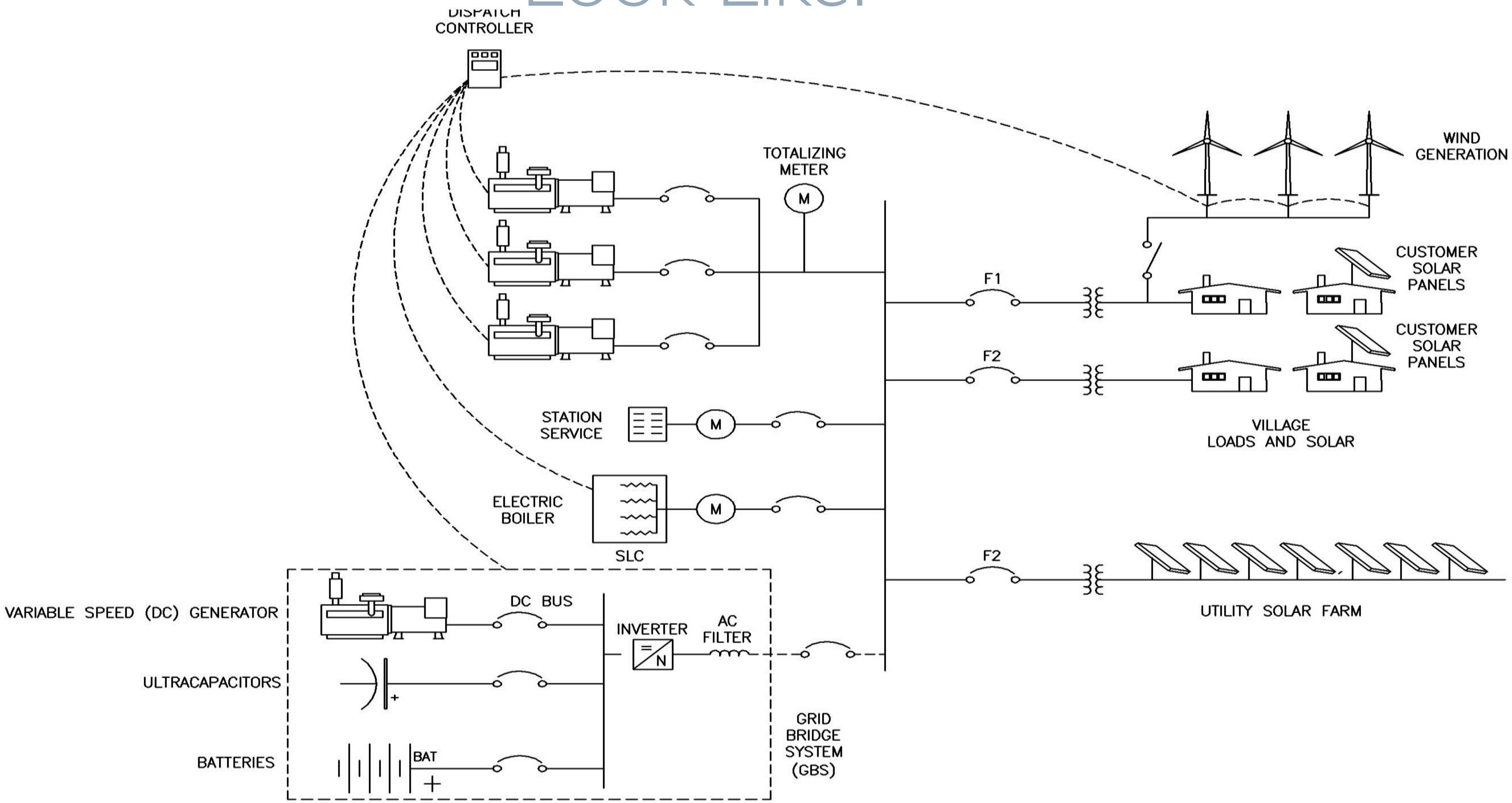
Grid Bridging System

Would we still build an Ultracapacitor GBS? Yes.

- But only if the cost drops significantly

- They are safer to ship than batteries
- They are safer to service than batteries
- They have greater longevity than batteries
- They are easier to manage and monitor than batteries, for instance, the voltage on the bank is exactly the state of charge, unlike batteries.
- Safer and easier end of life recycling

What does a Adaptive Microgrid Look Like?



What is Islanded Grid Flexibility?

Stability

- Ultracapacitors connected to a fully capable inverter system – A Grid Bridging System (GBS).

Spinning Reserve

- A GBS with additional ultra-capacitors or a battery.

1 MVA Inverter – Kotzebue Ak

What is Islanded Grid Flexibility?

Variable Speed Generation

- A VSG added to a GBS provides a method to efficiently generate at low loads.
- Because they do not supply spinning reserve, they are difficult to use otherwise

What to do with Surplus Generation?

Use Surplus Energy as Heat

- AVEC has been using electric heaters in their power plants.

Time Shifting Surplus Energy

- Adding additional batteries to a GBS can provide the ability to time shift energy

350 kW Water Heater

Revenue flexibility?

Revenue maintenance

- Rationalize demand and standby charges.
- AMR (Automated Meter Reading) systems
- Dynamic Pricing Formulas

A Grid Bridging System Would Provide

- STABILITY-Allow greater percentage of renewable generation
- SPINNING RESERVE- Allow most efficient diesel operation
- Many More Generation Operating Options
- IMPROVED POWER QUALITY AND FUEL EFFICIENCY
- “FUTURE PROOFING” of the Grid for consumer generation

The Grid Bridging System is the key to Adaptability. To get there we need…

- Small and compact footprints (easier shipping and install)
- Standardized vendor neutral specification.
- Multiple Vendor availability
- Testing to certify adherence to the standard specification
- Specific software modeling tools to ease calculation of pay-back and correct sizing
- Design for reduction in cost by volume production
- NO MORE RESEARCH AND DEVELOPMENT PROJECTS
- NO MORE “ONE-OFFS”

Power Systems Integration Lab

- 500 kW islanded hybrid-diesel grid emulator
- 12 station 480 VAC bus
- 320 kW DEG, 100 kW Wind, 100 kW PV, 320 kW ESS, 550 kW reactive load
- Custom and commercial SCADA
- 1000+ channels: electrical and mechanical data
- Diesel-off capability (incl. black start)
- Experienced team
    - Flywheel integration project
    - VRLA integration project
    - Dual DC bus integration project – hydrokinetic turbine and Li battery

Questions?

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Operations Manager, AVEC

Additional informative slides

Notes on GBS Costing

Complete Ultracapacitor 500 kW GBS components -- $600K

Hybrid Ultracapacitor + LTO 500 kW GBS components - $300K - $500K

LTO 500 kW GBS components - $200K - $400K

Double these costs for a 1000 kW system.

Notes on Disruptive Technologies

Instability

Wind and solar are both variable, and add their variability on top of pre-existing load variations. Short term power variations, less than or about a second in duration, create instabilities in the remote grid that may be hard for diesels to compensate for.

Spinning Reserve

A cloud moves in front of a major solar array, the wind dies down precipitously. If the utility operator does not keep additional ready capacity on line at all times, then outages can increase due to overloading.

Notes on Disruptive Technologies

Very low or even Negative Load

How do you efficiently supply and pay for very low loading and yet keep enough capacity on line to operate the system? What do you do when the load goes negative?

Large Variations in the marginal Cost of Energy

When using diesels only, the marginal cost of energy is pretty constant. As soon as renewable installations approach high penetration and diesels reach minimum possible generation, the cost of energy changes wildly. Tariff structures must take that into account.

Notes regarding Islanded Grid Flexibility?

Stability

- is provided by ultracapacitors connected to a fully capable inverter system – A Grid Bridging System (GBS). This does not provide a large amount of energy, but can provide an almost unlimited number of cycles and good longevity.

Spinning Reserve

- is provided by taking the GBS components needed for stability and either adding a battery or adding additional ultracapacitors. The amount of energy has to be enough to supply spinning reserve while additional diesel generation is started and put on line.

Notes regarding Islanded Grid Flexibility?

Variable Speed Generation

- Once a GBS system has been installed for stability and Spinning reserve, now is the time to consider variable speed generation. The problems of VSG are solved by already having a GBS. Not only can VSG provide a method to efficiently generate at low loads, but connecting using DC into the inverter removes the need to synchronize, allowing much faster replacement of lost generation, reducing the demand on the GBS for spinning reserve.

Notes regarding Surplus Generation?

Use Surplus Energy as Heat

- AVEC has been doing this with electric heaters in their power plants. When heat recovery is being utilized, there is a residual value for this power. We have also installed remote uninterruptible loads that can be turned on during times of surplus.

Notes regadring Surplus Generation?

Time Shifting Surplus Energy

- Adding additional batteries to a GBS can provide the ability to shift from times of low marginal cost of power to times when the cost of energy is determined by burning diesel. I would suggest a wheeling charge be calculated for every kW/hr so shifted, intended to pay for transfer inefficiencies and the life cycle costs of operating a battery bank.

Notes regarding Revenue flexibility?

Revenue maintenance

- First of all rationalize your demand and standby charges. Clients must be paying for their right to connect to the grid, not necessarily for an energy source anymore.
- An appropriate price for back-fed generation must be created. It must be understood that this price may vary constantly. An AMR (Automated Meter Reading) system is vital here to obtain the power flows from multiple clients on a continuing basis. Pricing formulas must be acceptable to regulatory authorities.
- A method to reward reductions in the cost of generation to your loyal non-co-generating clients must be arrived at. This might be a monthly calculation or something much more frequent.

What is a Grid Bridging System?

The GBS is comprised of three essential elements and two optional ones. The essential ones are:

Essential requirement #1: A fully grid-forming inverter (programmed to simulate a rotary generator) The simulation should include speed droop, VAR droop and frequency adjustment capabilities. They should act just like a gen-set, not an inverter.

This may be new territory for many inverter suppliers, but it is essential to provide an always-on system that plays well with others.

Because it is always on, quiescent power consumption by the inverter should be minimized.

What is a Grid Bridging System?

Essential requirement #2: A high power energy storage element. Ultracapacitors are recommended due to their long cycle life, high efficiency, safe maintenance, and low risk.

Once again, using ultracapacitors may stretch the capabilities of some suppliers, but High Power Density is essential for fulfillment of the GBS's goals.

What is a Grid Bridging System?

Essential requirement #3: A system controller, which can monitor the state of charge of the energy storage and choose to start/load-up the most efficient generation source or stop/unload the least efficient one. Typically these would be diesels, but curtailing wind output with pitch control is another possibility.

When controlling multiple diesels, the system control will need to know the efficiency curves for each gen-set, at least sufficiently to know when to switch to a different unit or combination.

The system controller may be the only source of rate information - how much value should be given to customer generated renewables?

Optional GBS Elements

4: If economically justified, then an energy storage array, typically a chemical battery. The cost to operate is the charge-discharge life cycle cost. The advantage is to take advantage of times of low marginal cost power (such as wind turbines in high wind) by charging, and then discharging during high marginal cost power, typically offsetting diesel fuel. If you don't have times of low marginal cost power, then you don't need this.

5: A load of last resort. This is typically a resistance element dumping surplus energy into a heat recovery system. You need this if your un-controlled renewable energy sources exceed your system load. Future consumer installations of PV arrays may require this!

Containerized Lithium Battery

AVEC Hybrid Systems: 2015 Toksook Bay

- Gross Diesel – 2,868,968 kWh
- Gross Wind – 729,037 kWh
- Total Gross – 3,600,184 kWh
- Peak Load – 702 kWh
- Avg Load – 411.71 kWh
- Fuel Oil Used – 207,133 Gallons
- Diesel Efficiency – 13.85/13.90
- System Efficiency – 17.38/17.42
- Efficiency Increase % 25.3%
- Wind Turbine Capacity Factor – 20.9%
- Net Diesel – 2,761,956 kWh
- Net Wind – 702,437 kWh
- Net – 3,402,473 kWh
- Net Wind % of Net Total Production 20.2%
- SLC (Boiler) Excess Energy – 12,386
- % of Excess Wind Available – 1.9%
- kWh sold – 3,309,814
- kWh Sold/gallon – 15.98
- Fuel offset 49,644 gallons
- Savings from Wind Generation $156,378

AVEC Hybrid Systems: 2015 Shaktoolik

- Gross Diesel – 794,510 kWh
- Gross Wind – 329,269 kWh
- Total Gross – 1,123,779 kWh
- Peak Load – 248 kWh
- Avg Load – 128.49 kWh
- Fuel Oil Used – 58,691 Gallons
- Diesel Efficiency – 13.54/13.48
- System Efficiency – 19.15/19.40
- Efficiency Increase % 44.9%
- Wind Turbine Capacity Factor – 9.5%
- Net Diesel – 765,610 kWh
- Net Wind – 276,987 kWh
- Net – 1,042,597 kWh
- Net Wind % of Net Total Production 26%
- SLC (Boiler) Excess Energy – 49,475
- % of Excess Wind Available – 13.8%
- kWh sold – 1,003,498
- kWh Sold/gallon – 17.10
- Fuel offset 20,947 gallons
- Savings from Wind Generation $65,865.75