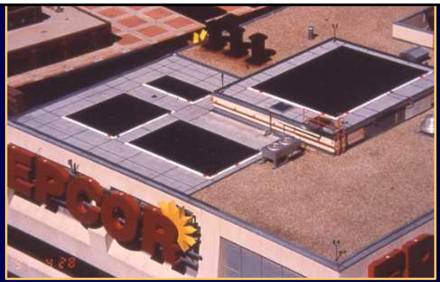




ECUC and Grid-Dependent MicroPower Generator Disconnects

ECUC Technical Subcommittee

Red Deer

2006 November 17 (updated 2007 December 11)

Gordon Howell, P.Eng.
Phone: +1 780 484 0476
E-mail: ghowell@hme.ca

Howell-Mayhew Engineering
- who we are -

- Based in Edmonton, for 21 years, work throughout the province
- Developers of:
  - solar energy systems
  - sustainable communities
- Do not sell equipment;
  Design, develop and manage solar projects
- Do not have a vested interest in any particular technology

Howell-Mayhew Engineering
- participation in standards work -

- Member of the International Electrotechnical Commission
  - Technical Committee 82 (solar PV)
  - Working Group 1 (glossary of terms)
  - Working Group 3 (PV systems)
- Member of the CSA CE Code Section 50 (solar PV)
- Participated in:
  - several Alberta DG standards committees
  - Micropower Connect
  - CSA Technical Committee on Interconnection
  - Measurement Canada working group on net metering

Interconnected Micropower Systems in Alberta

	Micropower System	Date	Capacity [kW]	Technology	WSP
1.	Cold Climate Solar Home, Edmonton 1st grid-connected solar PV system west of Toronto	1995	2.3	PV	Edmonton Power
2.	EPCOR Capitol Square building, Edmonton	1996	13	PV	EPCOR
3.	Narayana home, Edmonton – was never connected due to interconnection issues	2000	0.1	PV	EPCOR
4.	Guerrilla PV system – with battery bank, Calgary	2000	0.6	PV	ENMAX
5.	Banff Town Centre, Banff	2001	1	PV	FortisAB
6.	Guerrilla PV system, Calgary	2001	0.6	PV	ENMAX
7.	Spruce Meadows building, Calgary	2001	2	PV	ENMAX
8.	Fricke home, Calgary	2001	2	PV	ENMAX
9.	Airdrie Environmental Centre, Airdrie	2002	2	PV	FortisAB
10.	Belec home, Pigeon Lake	2002	0.4	PV	FortisAB

Interconnected Micropower Systems in Alberta

	Micropower System	Date	Capacity [kW]	Technology	WSP
11.	Kelly home, Calgary	2002	2	PV	ENMAX
12.	Alberta Legislature Building, Edmonton	2003	3	PV	EPCOR
13.	CAP Solar office, Olds	2003	1.5	PV	FortisAB
14.	Guerrilla PV system, Edmonton	2003	0.5	PV	EPCOR
15.	Steeden home, Edmonton	2003	2	PV	EPCOR
16.	Kerry Wood Nature Centre, Red Deer	2004-06	4 x 2.3	PV	Red Deer EL&P
17.	Wickman home, Calgary	2004	2.5	PV	ENMAX
18.	Welk home, Sundre	2004	1	PV	FortisAB
19.	Waldowski farm, Onoway	2004	10	Wind	Central Alberta REA
20.	Bull home, Edmonton – includes battery bank	2005	3	PV	EPCOR
21.	Cochrane High School, Cochrane	2005	3.3	PV	FortisAB

Interconnected Micropower Systems in Alberta

	Micropower System	Date	Capacity [kW]	Technology	WSP
22.	Wiebe home, Edmonton – guerrilla system	2005	2	PV	EPCOR
23.	Mitsch home, Calgary	2005	0.9	PV	ENMAX
24.	Avalon Discovery II home, Red Deer	2006	3.7	PV	Red Deer EL&P
25.	Lawrence farm, Pine Lake	2006	3	Wind	Central Alberta REA
26.	Habitat for Humanity duplex, Edmonton	2006	2 x 0.6	PV	EPCOR
28.	Visconti home, Edmonton	2006	8	PV	EPCOR
29.	UofC Child Development Centre, Calgary	2007	43	PV	Enmax
30.	AAMDC offices, Nisku	2007	5	PV	FortisAB
31.	Alberta Solar Municipal Showcase – 20 municipal buildings around the province	2006-08	20 x 1	PV	Enmax, EPCOR, FortisAB, ATCO Electric

Interconnected Micropower Systems in Alberta

	Micropower System	Date	Capacity [kW]	Technology	WSP
51.	Delia pump house, Delia	2007	8	PV	ATCO Electric
52.	Riverdale NetZero energy duplex, Edmonton	2007	2 x 5.6	PV	EPCOR
54.	Avalon Discovery III net zero energy home, Red Deer	2007	8.4	PV	Red Deer EL&P
55.	Laebon Homes CHESS net zero energy home, Red Deer	2007	6?	PV	Red Deer EL&P
56.	McConnell home, Spruce Grove	2008	2 x 1	Wind	FortisAB
57.	LeGrow home, Seeba Beach	2008	2.5	PV	FortisAB
58.	Janko home, Red Deer	2008	1	PV	Red Deer EL&P
59.	Uncle Bens RV building, Red Deer County	2008	2	PV	FortisAB
60.	Home, Fort Saskatchewan	2008	2?	PV	FortisAB
61.	Shifflett home, Parkland County	2008	5	PV	FortisAB

Interconnected Micropower Systems in Alberta

	Micropower System	Date	Capacity [kW]	Techn ology	WSP
62.	Solar Energy Society of Canada mobile demonstration trailer	2008	0.6	PV	Everyone
63.	Northern Alberta Radio Club	2008	1?	PV	FortisAB
64.	Echo Haven net zero energy home, Calgary	2008	5	PV	ENMAX
65.	Trimline Training Centre, Edmonton	2008	1	PV	EPCOR
66.	Verburg home, Leduc County	2008	2	PV /wind	Battle River REA
67.	Home, Parkland County	2008	2	PV	FortisAB
68.	Morin pump house, Morin	2008	8	PV	ATCO Electric
69.	Munson pump house, Munson	2008	8	PV	ATCO Electric
70.	Likely 10 other PV and microwind systems	2003-07	~10 x 2	PV	Alberta
80.	Several guerrilla PV systems	2002-08	~10 x 2	PV	Alberta

Presentation Goals

- Present sufficient evidence
  that microsolar and microwind turbines
  operate safely and reliably
  such that no additional WSP safety measures
  will be required
  other than what is already built into the
  micropower systems

Proposal to the ECUC

- Change the ECUC rule that requires WSPs to use an open, locked, tagged visible break to disconnect grid-dependent micropower systems

- Permit WSPs to rely on the anti-islanding mechanism of certified grid-dependent micropower inverters as equivalent to the open, locked, tagged visible break rule

Scope of Proposal

- Available to inverter-based Personal Load-Offset Generators (PLOGs) with anti-islanding
  - Load-offset not merchant power,
    - such as found on homes, farms and small businesses
  - Less than 0.050 MW per system
  - Built-in certified anti-islanding measures

Presentation Outline

- Context of PV markets
- Discussion about PV inverters and their operation
  - Technical
  - Metering
- Examples of systems in Alberta
- What is happening with technology around the world

Expectations from ECUC Meeting

- Good respectful thoughtful bi-lateral discussion and dialogue about the technical and relational matters being presented
- Identify possible need for further data
- Discuss next steps to effect the proposal

Context: Grid-Connected PV System Range of Sizes

- Solar PV can generate any amount of electricity.
- More PV modules gives larger capacity systems.
- Smallest grid-connected PV system: 0.000 100 MW
- Largest grid-connected PV system in the world:

  11 MW (currently), several more being installed, 40 MW and 154 MW proposed
- Typical house size: 0.001 MW to 0.010 MW

Context: Grid-Connected Solar PV Capacity and Market Growth – World

- Data from 20 IEA countries (not including China and India)
- 3 200 MW installed worldwide at end of 2005
- 1000 MW installed annually, growing to 5000 MW/year by 2010
- Nominally equivalent to 500,000 homes per year in 2005
- Growing at over 40% per year
- Prices dropping by 20% per doubling of annual market size

Context: Grid-Connected Solar PV Capacity and Market Growth – Canada

- 1.1 MW installed across Canada at end of 2005
- 0.6 MW installed in 2005
- PV market in Canada is 2% grid-connected
- Largest system is 0.1 MW, in Toronto
- Perhaps 200 systems across Canada, growing at 40+ per year?
- Ontario feed-in tariff of 42 c/kWh
- Plans for five 10 MW systems in Ontario

Context: Grid-Connected Solar PV Capacity and Market Growth – Alberta

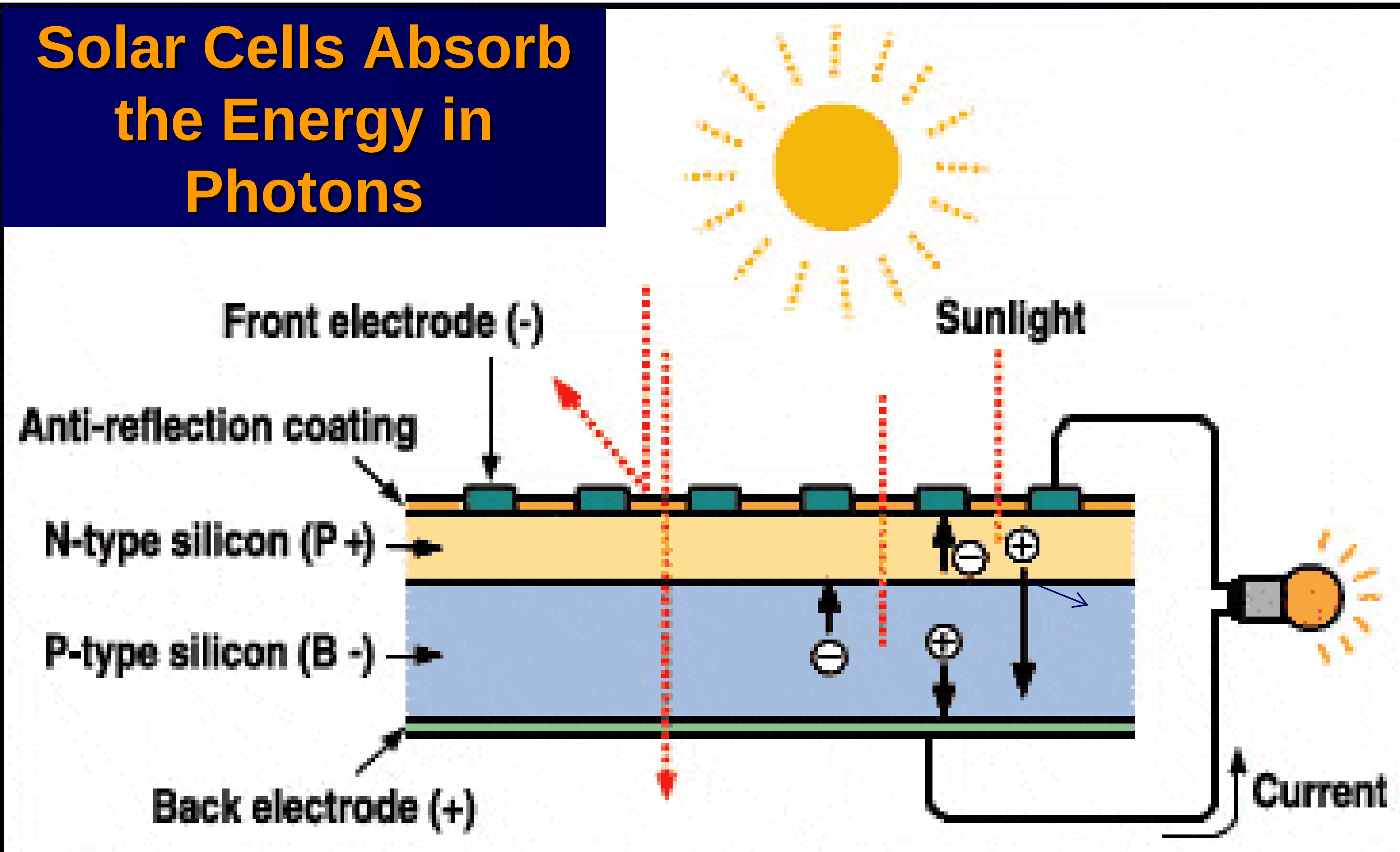
- Unknown capacity size – likely 0.030 to 0.040 MW
- Likely 50 systems now
- Largest is 0.043 MW on UofC Child Development Centre in Calgary
- New and recent projects of note:
  - three 0.008 MW systems in Starland County
  - 0.008 MW on home in Edmonton
  - 0.043 MW on U of C building
  - 0.001 MW systems on 20 municipal buildings (www.lassothesun.ca)

Questions ???

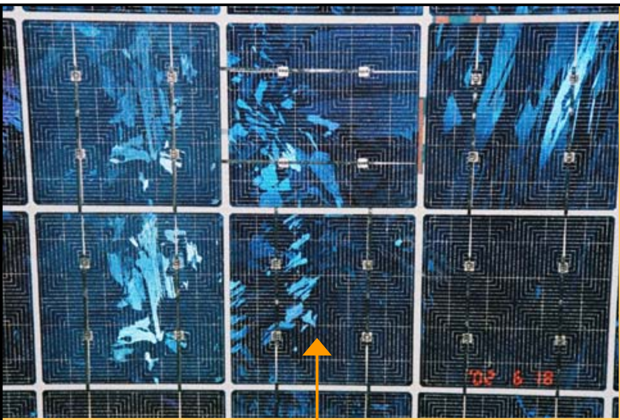
- Next:

  Solar PV technology and operation

Solar Cells Absorb the Energy in Photons



- The technology is called "photovoltaics", but we only call it "PV".
- The energy in the photons knocks electrons out of their orbital shell
  - 1 electron for 1 photon.
- The electric field generated by this turns the electrons into an electric current.
- Wires carry the current away.



Solar PV Module

Solar PV Cell

More modules
= bigger generating capacity

Solar PV Array

Xantrex ProSine
Canada
stand-alone inverter/charger
2 kW, 2.5 kW, 3 kW

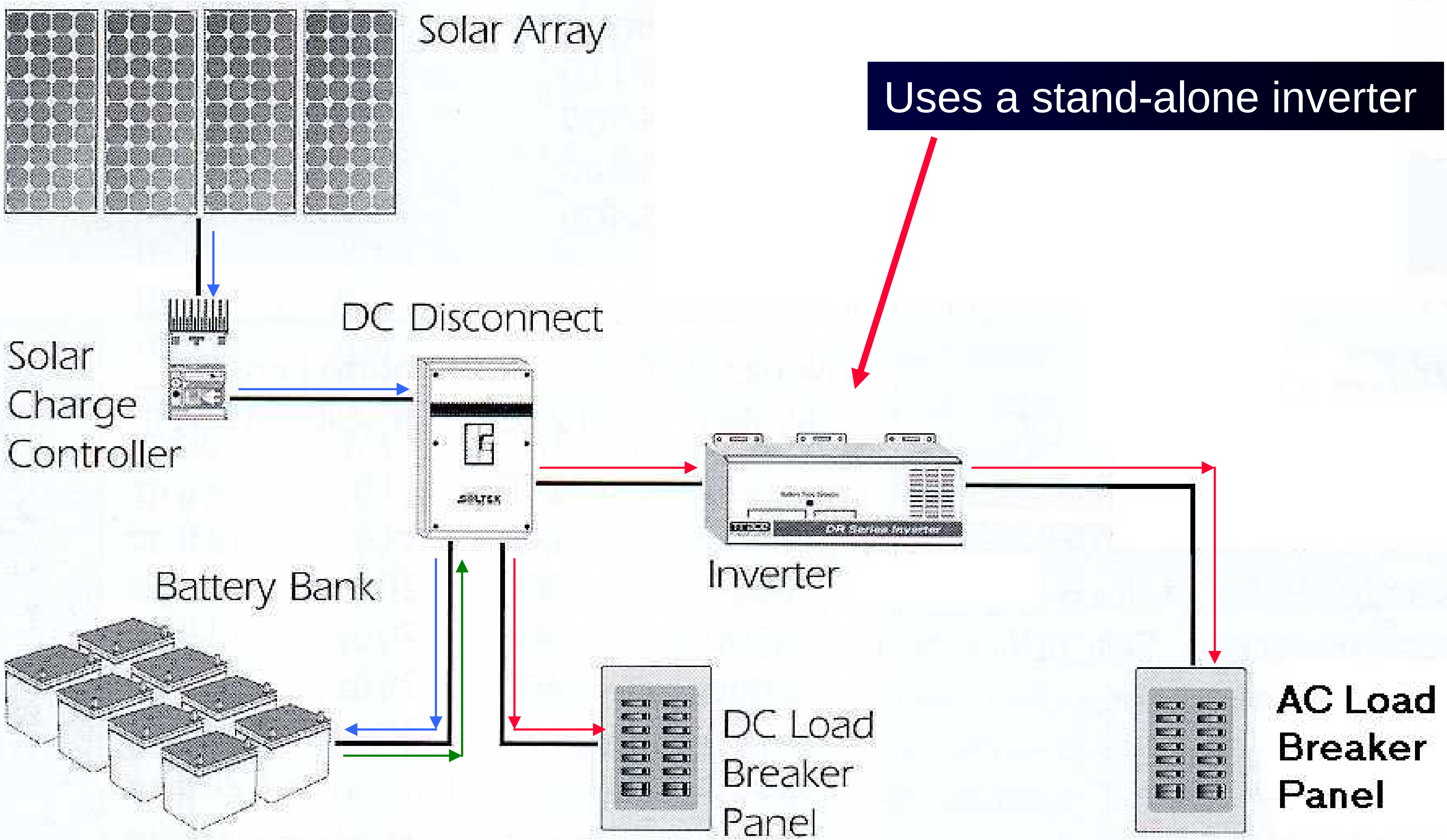
PV System
Inverter Types – #1

- Stand-alone inverter
  - Cannot operate in parallel with any other generator
  - Used in off-grid applications
  - Generates its own voltage waveform
  - Typical PV system size: 0.000 050 MW to 0.004 000 MW

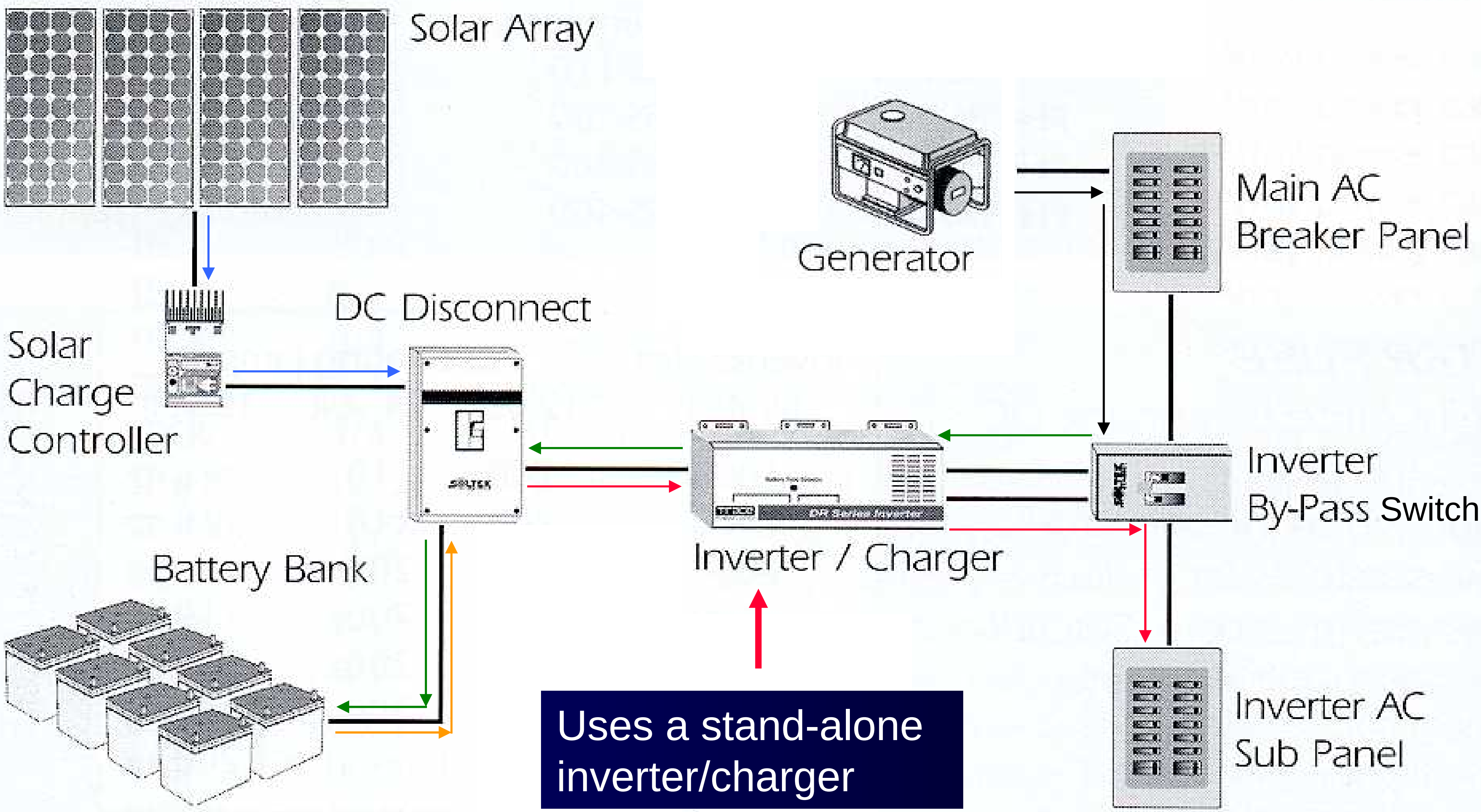
Outback FX
America
stand-alone inverter/charger
2 – 2.5 kW

Solar PV Stand-alone Off-grid AC System

Uses a stand-alone inverter



Solar PV Hybrid
Off-grid AC System



Uses a stand-alone inverter/charger

SMA Sunny Boy
Germany
grid-dependent
0.7 – 6 kW

PV System
Inverter Types – #2

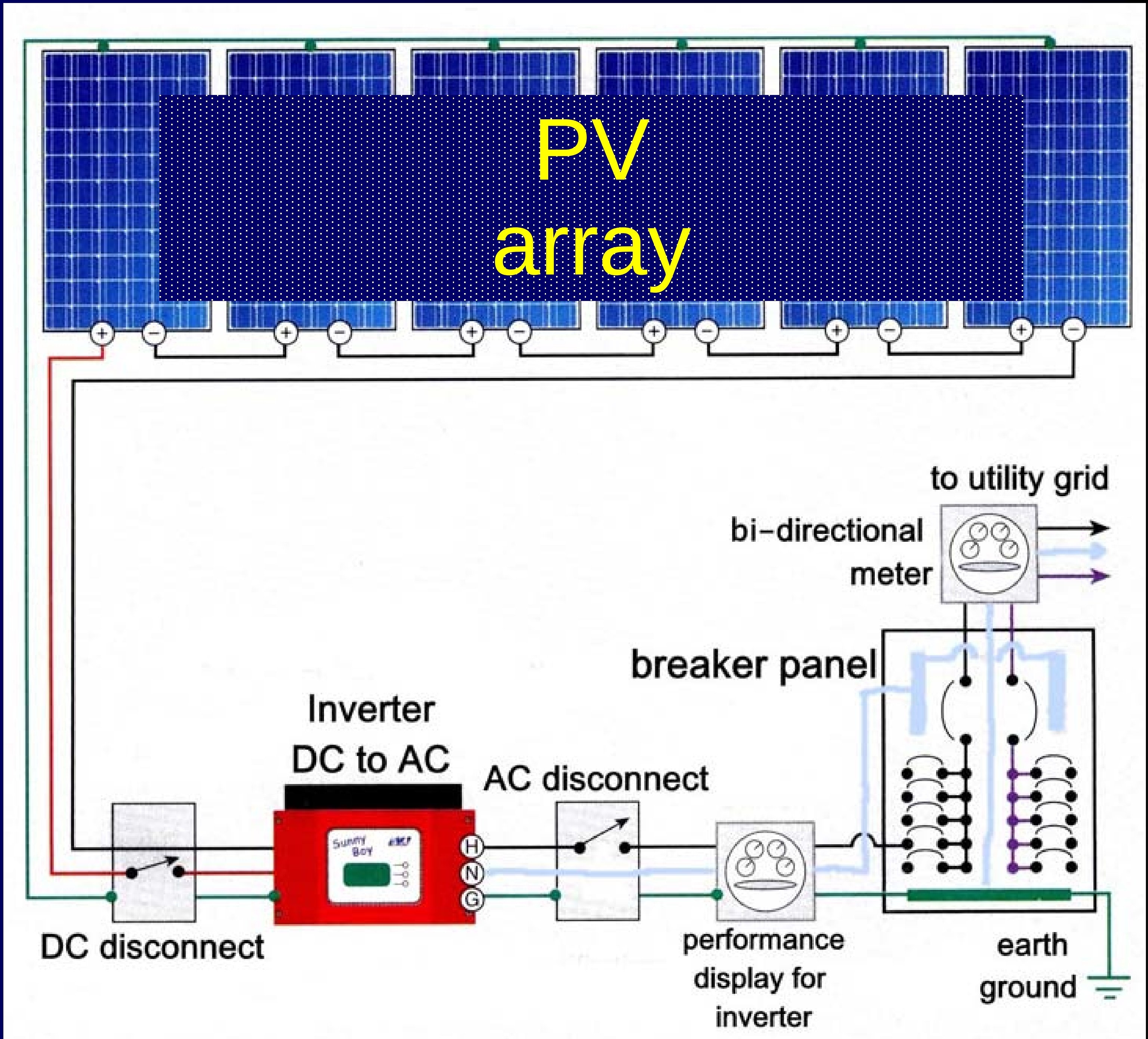
- Grid-dependent inverter
  - Designed, certified and tested to international standards to operate in parallel with the grid. Would likely be able to operate in parallel with any voltage source that meets grid voltage and frequency requirements.
  - Cannot use a battery bank
  - Used in most grid-connected applications
  - Does not generate its own voltage waveform
  - Injects current into an existing waveform
  - Sometimes incorporates internal relays
  - Incorporates anti-islanding as per CSA and IEC standards
  - Incorporates over- and under-voltage, over- and under-frequency trips
  - PV system size: 0.000 700 MW to 0.1 MW
  - Most common grid-connected inverter

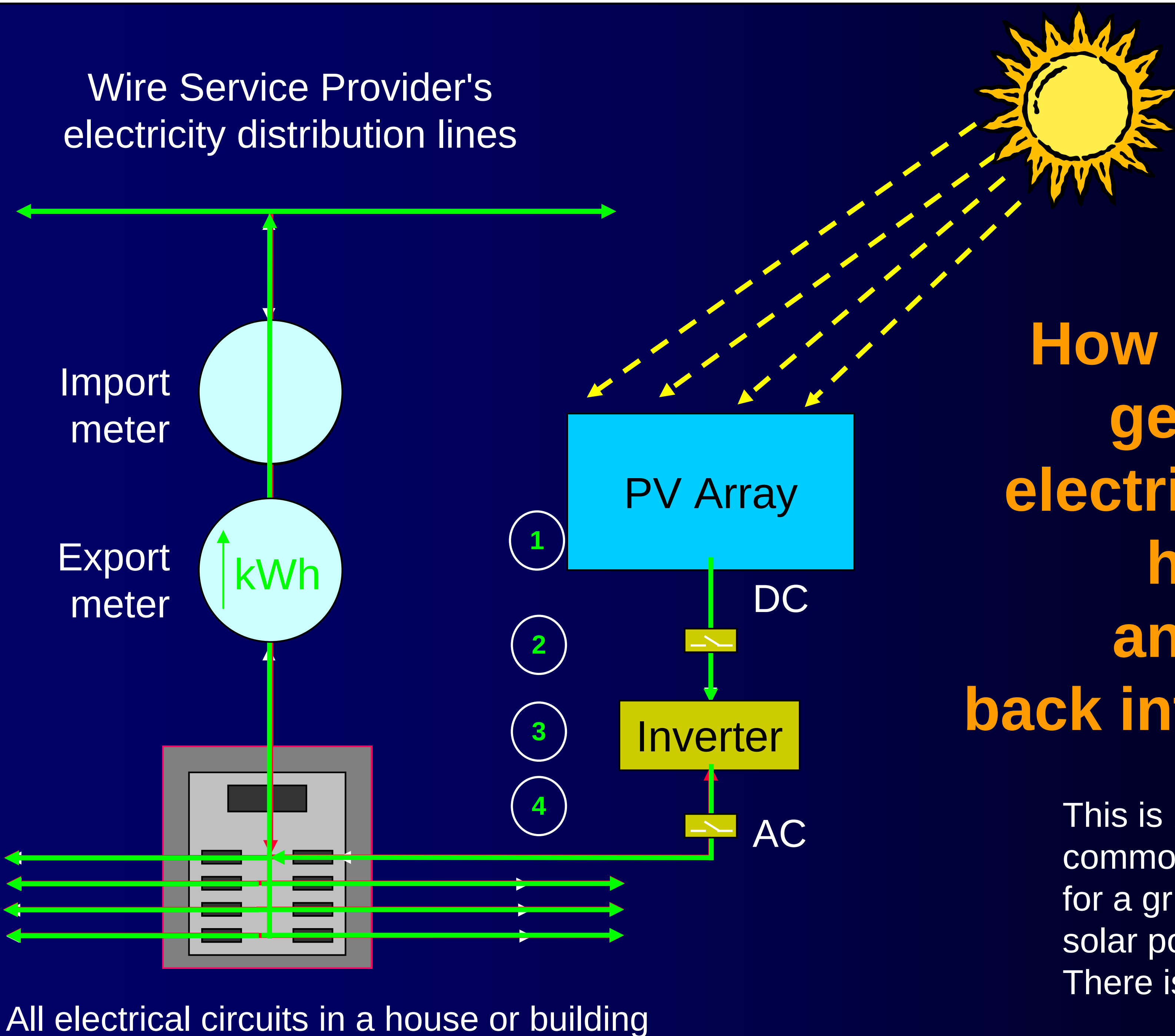
Xantrex SW Canada grid-connected inverter/charger 2.5 kW & 4 kW

PV System Inverter Types – #3

- Grid-interactive inverter
  - Requires a battery bank
  - Can operate in grid-parallel and stand-alone mode
  - Generates its own voltage waveform
  - Synchronizes its waveform with the grid
  - Incorporates an internal transfer switch
  - Incorporates anti-islanding as per CSA and IEC standards
  - Incorporates over- and under-voltage, over- and under-frequency trips
  - Not common – 10 in Canada that are grid-interactive?

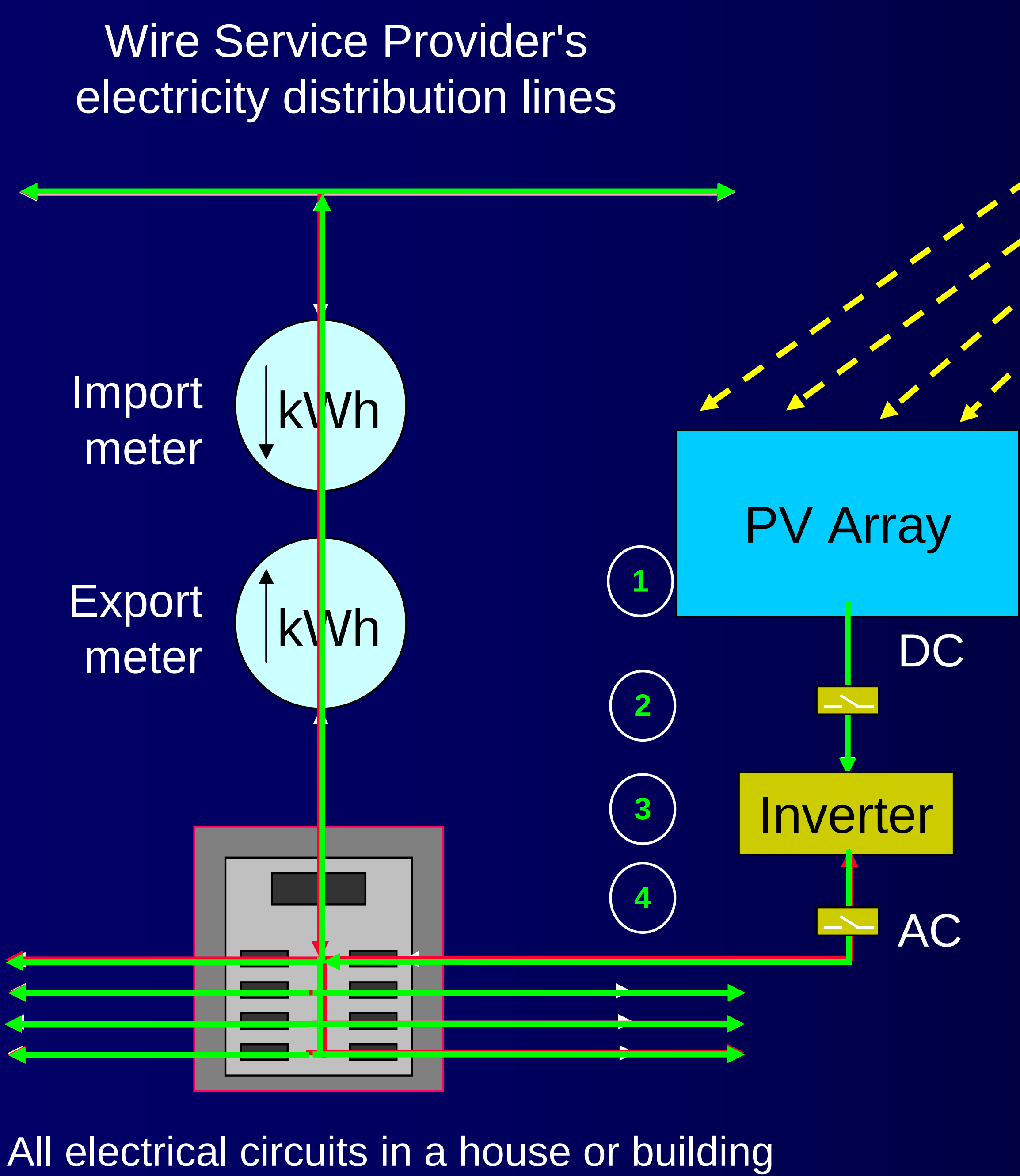
Grid-Dependent

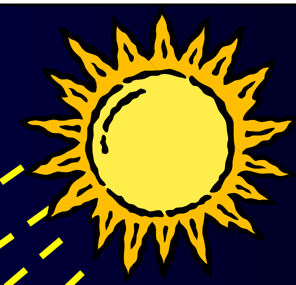




How does this generate electricity into a house and also back into the grid?

This is by far the most common configuration for a grid-connected solar power system. There is no battery bank.



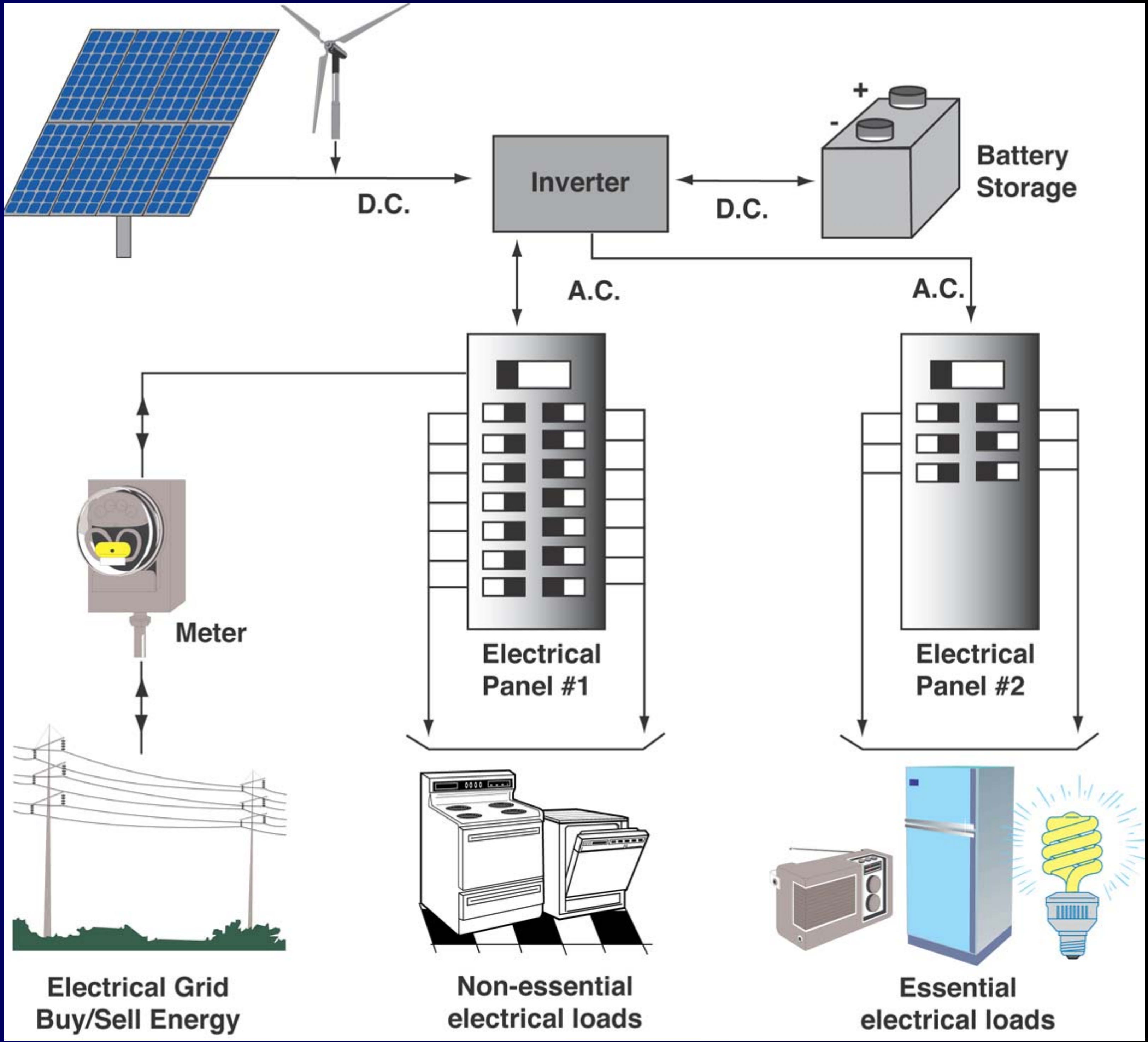


What happens during a power outage?

The inverter senses that there is a power outage and turns itself off.

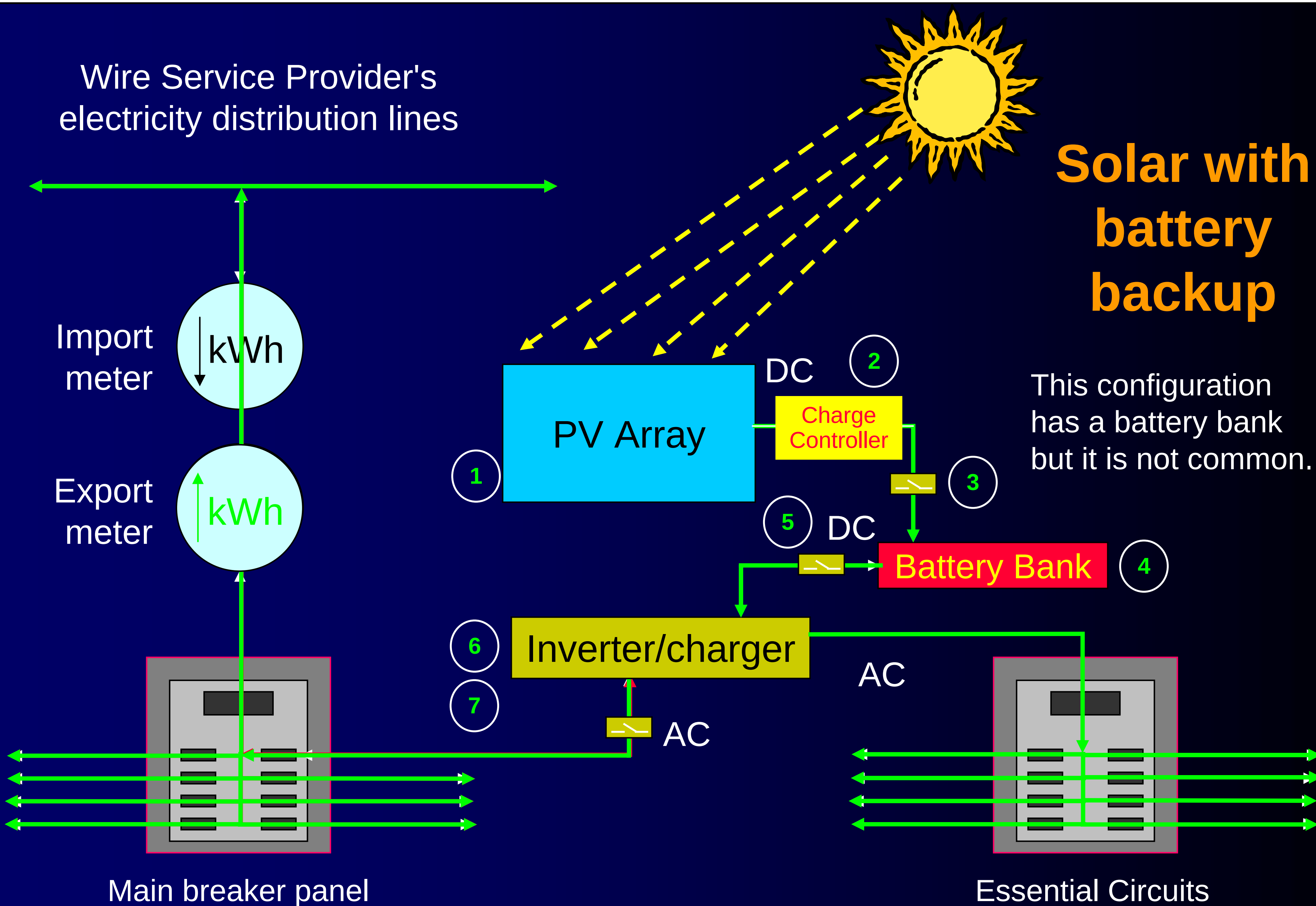
When power returns it turns itself on automatically.

Grid-Interactive



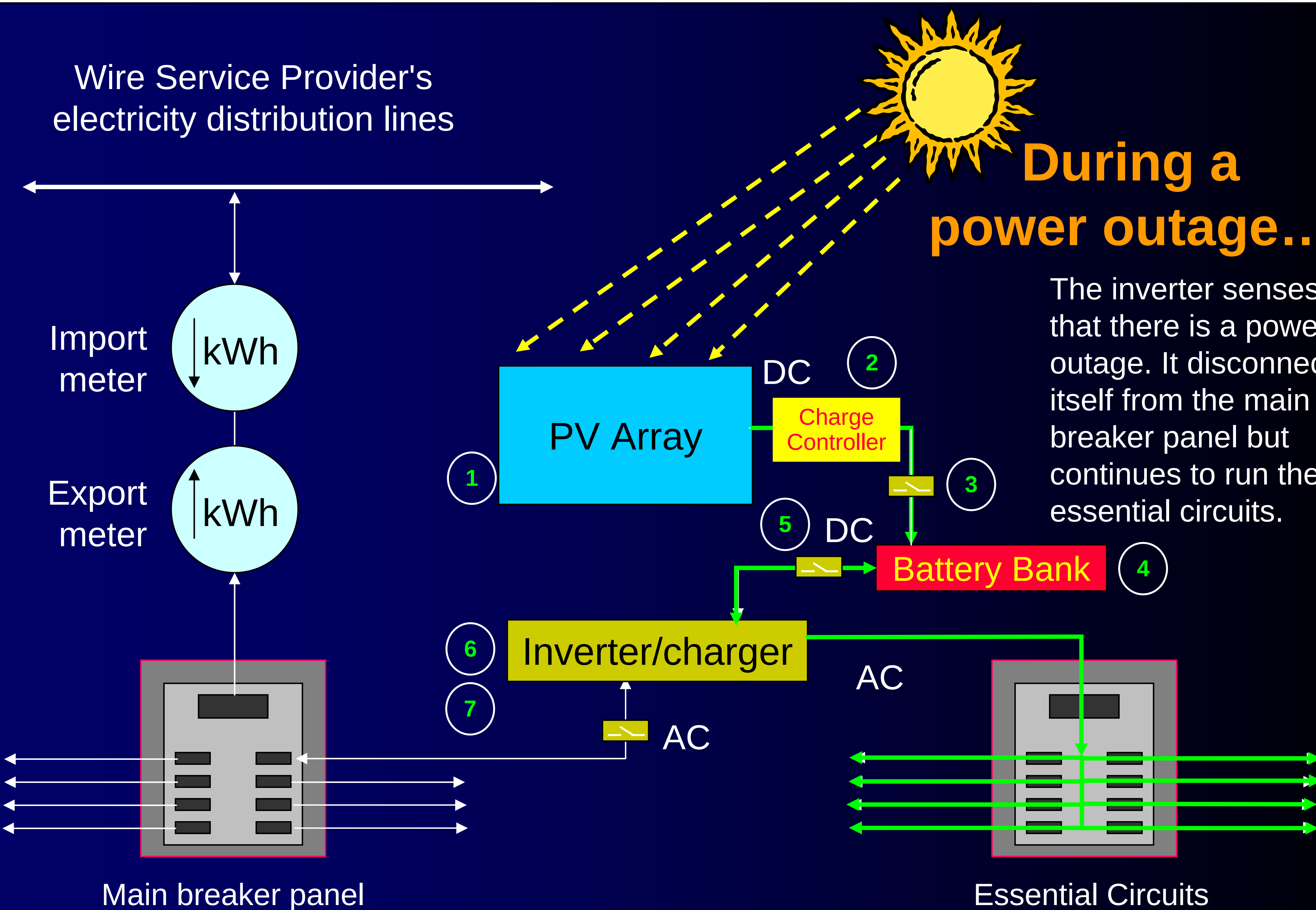
Solar with battery backup

This configuration has a battery bank but it is not common.



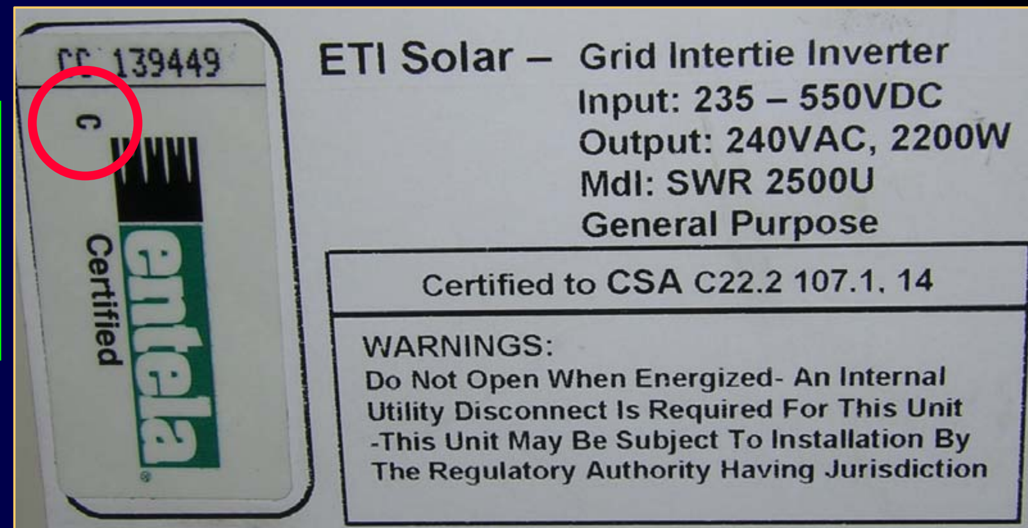
During a power outage…

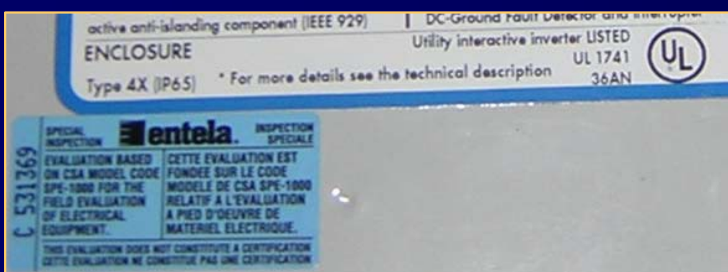
The inverter senses that there is a power outage. It disconnects itself from the main breaker panel but continues to run the essential circuits.

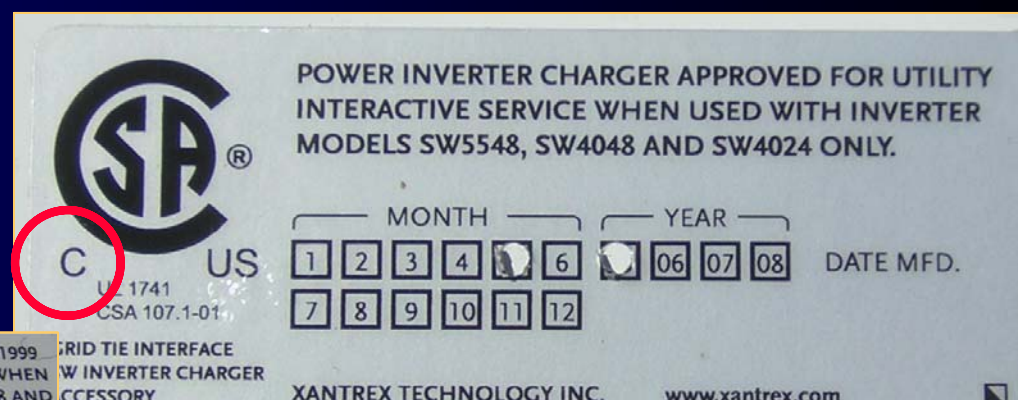


Grid-Connected Inverter Certifications

Need to be certified to CSA C22.2 107.1 Section 15







Questions ???

- Next:
  IEA research on PV and the grid

IEA PVPS Task 5 Workshop

- Workshop on Grid-Connected PV systems

- Most significant research and presentations:
  - How islanding methods work
  - What is the probability of an island occuring
  - What is the probability of an anti-islanding system failing to operate

Passive Islanding Detection

- Uses:
  - Under and over voltage detection
  - Under and over frequency detection
- Circuit RLC conditions can theoretically cause an islanding condition.   In order for this to island:
  - power consumption must equal power generation and
  - load must provide the frequency reference.
- Condition inherently unstable, but slow response.

Active Islanding Detection

- Impedance methods of several types
- Detection of impedance at a specific frequency
- Detection of harmonics
- Slip mode
- Frequency bias
- Sandia Frequency Shift
- Sandia voltage shift
- Frequency Jump
- ENS (Germany)

Probability of Islanding in Distribution Systems

Bas Verhoven (KEMA, NL)

- Objective: Determine probability of Islanding in utility network due to grid connected PV systems
- P = # of matches * # of seconds per match / seconds from 6 am to 6 pm in year

$$P = \frac{\text{\# of matches * \# of seconds per match}}{\text{seconds from 6 am to 6 pm in year}}$$

- Note that an outage must occur while the load power and PV power matches, in order to have a possibility of an island
- Range of probabilities:
  - 1×10^{-6} with 2% matching window
  - 1×10^{-3} with 15% matching window

Risk Analysis of Islanding

Neil Cullen (Risk Consultant, UK)

- Objective: Quantify risk of electric shock to network operators and DR owners due to islanding of PV systems

The Results – Extremely Low Risk

- $P(island) = P(match) * P(LOM)$
  - P(match 5 seconds) = $5x10^{-6}$
  - P(LOM-UK) = $4x10^{-6}$
  - P(island) = $2x10^{-11}$

- $P(PVrisk) = P(island) * P(anti\text{-}island\ failure)$
  - Anti-islanding failure risk is dominated by the risk of incorrect installation or tampering, assuming the inverter meets the detection test
  - P(anti-islanding failure) = $1x10^{-3}$

==

  - P(PVrisk) = $2x10^{-14}$ (1 in 50 trillion)

Comparison to Other Acceptable Risks

- The risk of death is 1/74 each year (at age 55-64 yrs)
- For imposed (non-voluntary) risks, the threshold of tolerance is 10^{-4}
- Minimum acceptable target is 10^{-6}
- Risk as an electric utility customer: 2.5×10^{-6}
- Risk as a network operator
  - 4×10^{-6} due to electric shock, (without live line practices)
  - 8×10^{-5} due to physical injury

IEA Conclusion

- The risk from islanding is so much smaller than other hazards, it should be secondary to other efforts.

- The data from the Netherlands should:
  - be analysed in each country's context (not necessarily repeated)
  - be interpreted with each countries unique set of probabilities

Questions ???

- Next:

  Metering of micropower systems

How does net metering work?

- how the solar power system owner's sees it

Energy Retailer, Wire Service Provider

Exported electricity is carried to neighbour without extra carriage fees, and displaces the electricity that would have been otherwise provided by the Energy Retailer.

Wire Service Provider's Distribution System

3

1 kWh

Electricity paid in full

1

Import

1 kWh

2

PV system owner runs the meter backwards, sending the previously imported electricity back for full credit. In effect, the PV system owner stores the Energy Retailer's electricity but without charging any storage fee.

Export

kWh

Ordinary kWh meter (goes both ways)

PV system owner

1 kWh

4

Neighbour pays the ER and the WSP full fees for the electricity and its delivery.

kWh

Ordinary kWh meter

Neighbour

1 kWh supplied, 1 kWh paid for

How does net metering work?

- how the Wire Service Providers see it

Energy Retailer, Wire Service Provider

Wire Service Provider's Distribution System

1 kWh

The Wire Service Provider "stores" in its wires the PV electricity produced in the daytime.

3

4

1 kWh

1 kWh

Electricity paid in full

1

2

PV system owner runs the meter backwards, reversing the full charges for the same amount of previously imported electricity.

The Wire Service Provider "re-delivers" the exported electricity back to the PV system owner at night, offsetting the amount exported in the daytime.

Import

Export

kWh

Ordinary kWh meter (goes both ways)

PV system owner

1 kWh supplied, 1 kWh paid for

How does 1-way metering work?

- how the micropower system owner's sees it

Energy Retailer, Wire Service Provider

Wire Service Provider's Distribution System

The Energy Retailer contracts the Wire Service Provider to deliver the energy to neighbours for full fees but without taking custody of it!

1 kWh

Electricity paid in full

1 Import

1 kWh

2 Energy is supplied to the AESO for free.

Export

3

1 kWh

4 The AESO gives the energy to the Energy Retailer to sell to neighbours, but without having to pay for it!

kWh

Latched (one-way) kWh meter

kWh

Ordinary kWh meter

PV system owner

Neighbour

1 kWh supplied, 2 kWh paid for!

Questions ???

- Next: Example systems

Cold Climate Solar House, Edmonton

2 kW ARISE GX 5000 inverter.

205 VDC, 240 VAC, 2.3 kW PV

Installed in 1995

Cost now $26,000

Electricity generation: ~$200 per year

Supplies ~100% of annual electricity needs

Sponsored by EPCOR, NRCan, City of Edmonton, HME in 1995.

2.3 kW solar PV

Sells excess to the Alberta Electric System Operator's Energy Trading System

Buys from EPCOR

EPCOR Centre

- 13 kW
- Roof-integrated
- On EPCOR's HQ in Edmonton
- Installed in 1996

+Eric Steeden
Edmonton's Solar Garden

2.5 kW Sunny Boy inverter

Installed in 2003

Cost $26,000

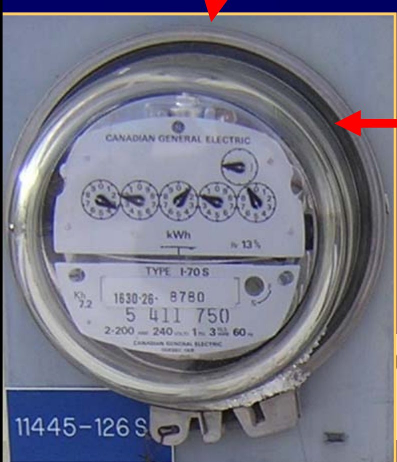
Electricity generation: ~$180 per year

Annual electricity export value: $100

2 kW solar PV

Photo Credit:
Steve Wiebe

Gives his excess to
the Alberta Electric System Operator's
Energy Trading System for free



Buys from EPCOR

Solar meter

Avalon "Discovery II"
Net Zero Electricity Home, Red Deer

3.7 kW grid-dependent solar power

2 collector, solar domestic water heating

Direct gain passive solar space heating windows

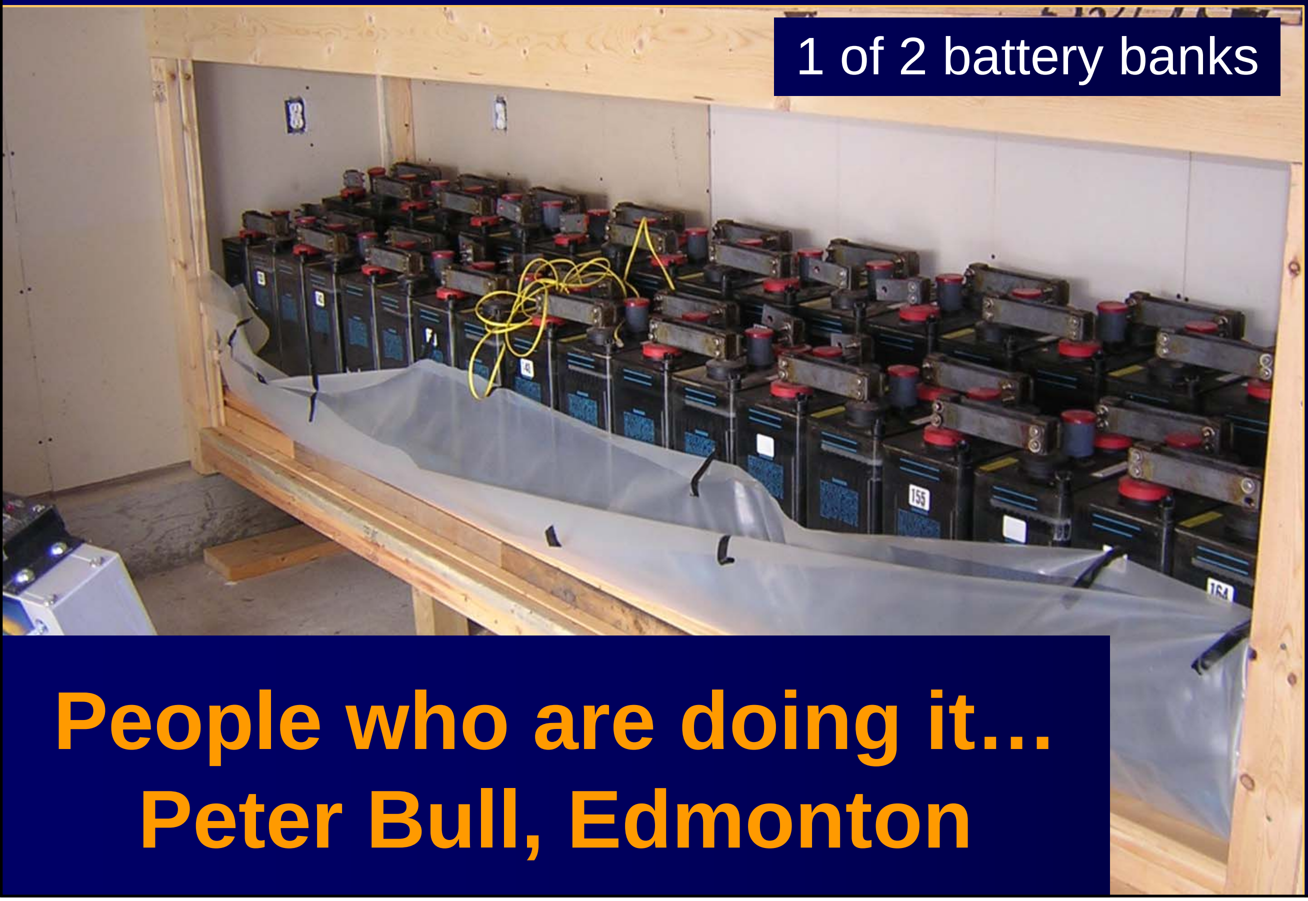
Solarwall ventilation air pre-heating system

Energy efficiency rating: Alberta Built Green Gold – EnerGuide rating of 84.


2.9 kW solar PV
Solar DHW, to come
Solar PV
People who are doing it…
Peter Bull, Edmonton

Inverter, charge controllers, DC switches, meters

Inverter
/charger



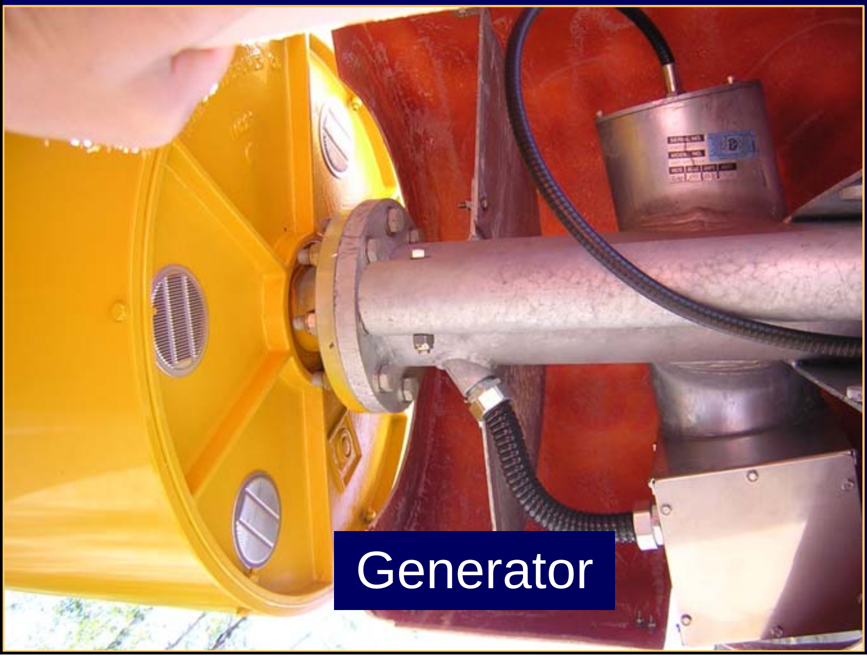
1 of 2 battery banks

Visible break disconnect

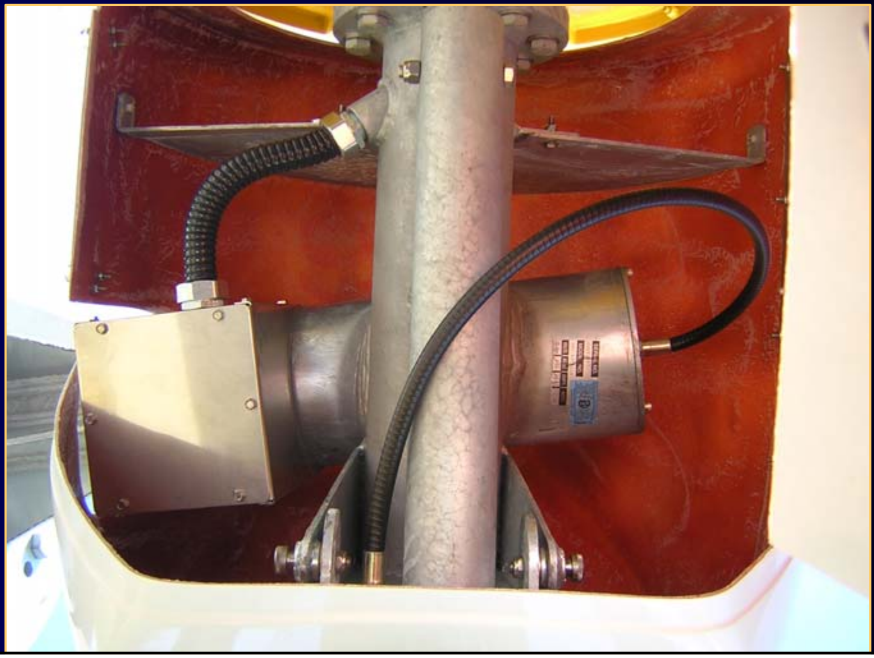
People who are doing it…
Peter Bull, Edmonton

Joe Waldowski Microwind Turbine Onoway

- 10 kW Bergey
- Grid-dependent connection, no battery bank
- $65,000 or so for the cost of turbine and its installation



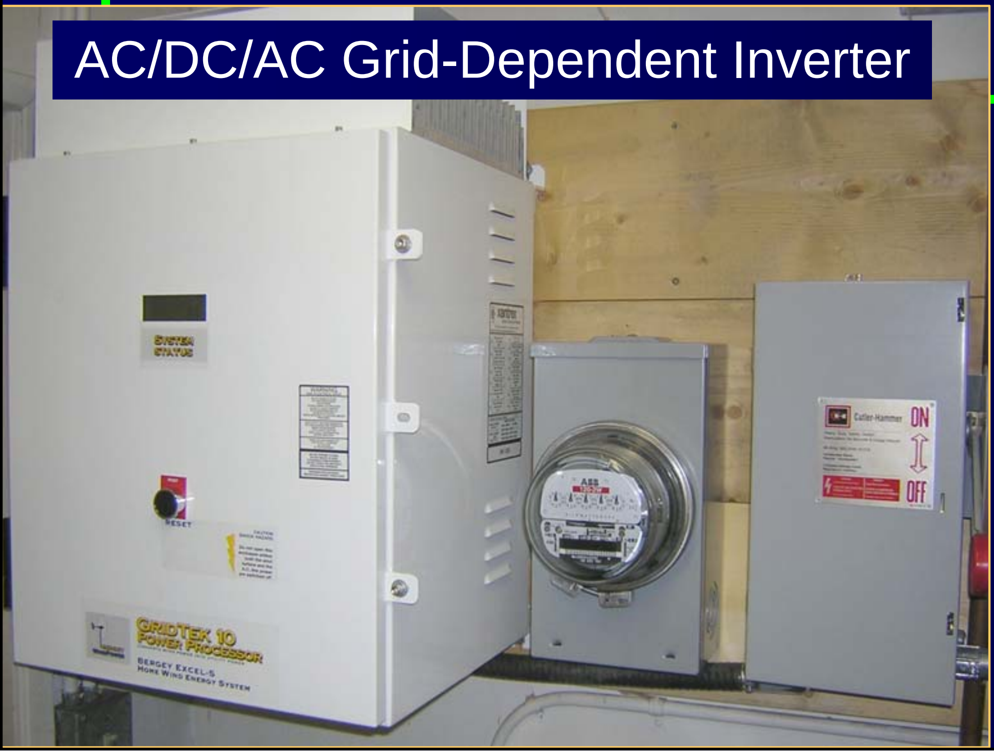
Generator



Joe Waldowski
Microwind Turbine, Onoway

- Generates ~5000 kWh of electricity per year
- Worth $400 per year. $110 is exported for free

- Wire Service Provider increased his service fees ($180 per year for a switch)



AC/DC/AC Grid-Dependent Inverter

Example: Grid-Connected Fees in Alberta

1.	Wind turbine cost, installed		~$42,000
2.	Engineering consulting fees for grid-connection		$6,000
3.	WSP fees to apply for grid-connection		$1,400

4.	Generates 5060 kWh of electricity per year	@ 8.65 ¢/kWh = $438 /year	$438
5.	Doesn't get paid for his 1300 kWh of excess	@ 8.65 ¢/kWh = $112 /year	Net = $326
6.	WSP added a $180+GST per month fee to service an existing disconnect switch	= $193 per year	Net = $133

The New Urban Guerrilla! Edmonton's Guerrilla PV Systems

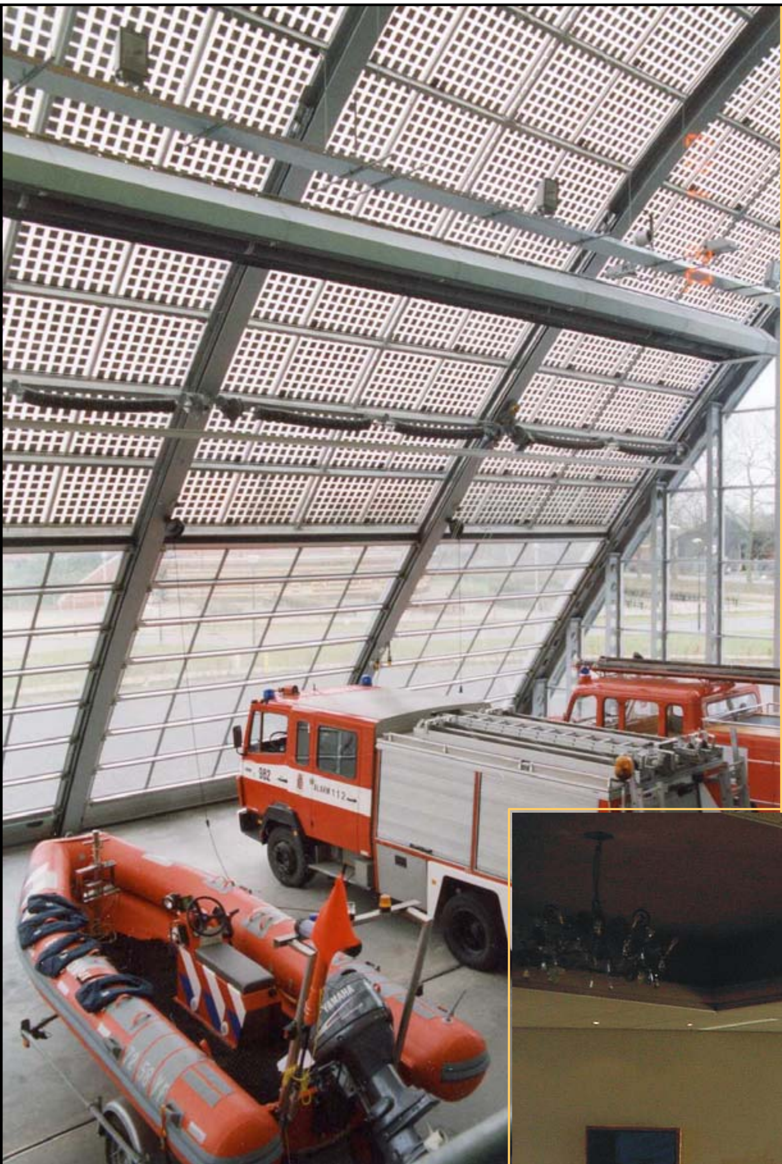
These systems were installed by average homeowners who wanted to be responsible for their electricity bills but found the regulations far too complex and onerous, so they simply installed the solar system themselves, which is easy to do…

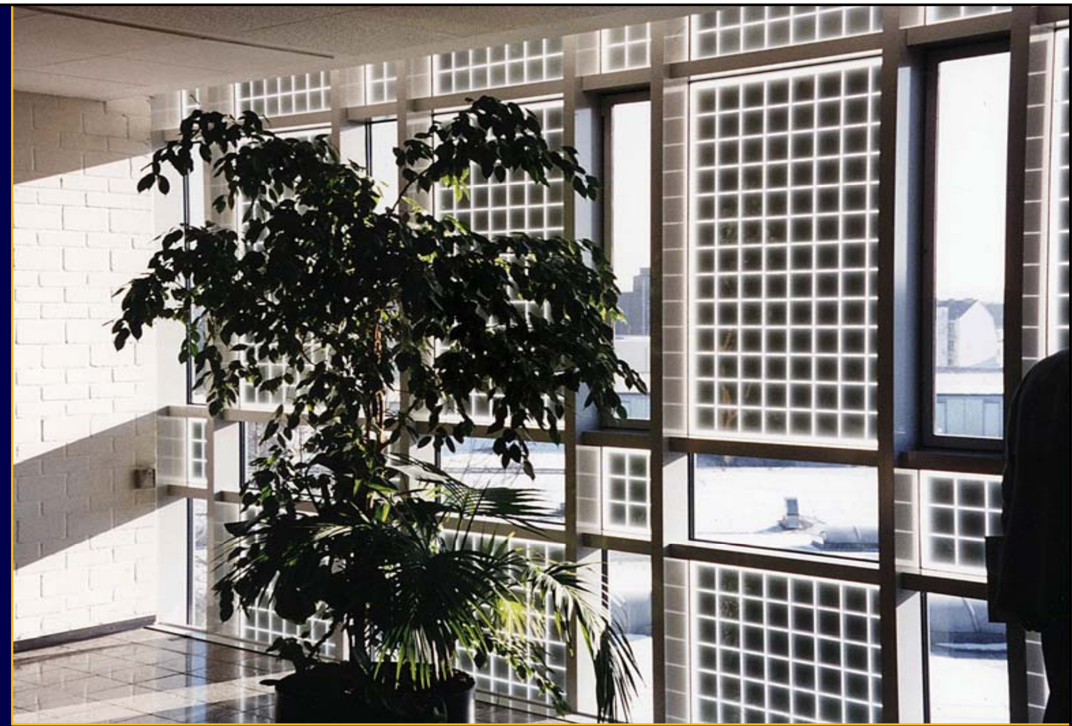
Integration into Unused Land

rights-of way, highways, railways

100 kW PV, Switzerland

California





Integrated into Glazing for Natural Lighting

30 kW, Netherlands

45 kW (340 m²), Netherlands. ©Saint-Gobain Glass Solar.

Toronto

Photo Credit:
Per Drewes

Queens University, Kingston

Integrated into Shading Structures

Photo Credit:
Anton Driesse

Integrated into Roofing Materials

With concrete roof tiles

With metal roofs

As shingles

With slate tiles

2.8 kW,
BCIT
Technology
Place,
Burnaby, BC

RWE Solar
Frankfurt

Integrated into Window Films

30% transparency

Q2

1 MW, Munich

Aachen, Germany

5 kW, Ontario

6000 kW, Germany

Buildings are becoming Solar Power Plants!

Neighbourhoods are becoming Solar Power Plants!

1000 kW community PV project on 500 houses in the Netherlands

Questions ???

Gordon Howell, P.Eng.
Howell-Mayhew Engineering

Edmonton
Phone: +1 780 484 0476
E-mail: ghowell@hme.ca

Photo credits: Gordon Howell and several others