

Emergency Power for Ham Radio W0TLM Amateur Radio Club

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This presentation focuses on emergency power for ham radio systems but the same approaches and equipment generally apply to home emergency power preparation

Presenter Background

- **Relatively new to ham radio: amateur extra license received April 2014**
- **37 yrs experience working as an electrical engineer in RF and uwave integrated circuit development and design**
- **Currently with Analog Devices Inc. developing ultra-wideband (<40 GHz) microwave samplers for high speed A/D converters and ultrawideband microwave amplifiers**

Emergency Power for Ham Radio Presentation Overview

- **Power need assessment**
- **Power source types**
- **Fuel types and characteristics**
- **Key power sources**
 - **Batteries and Chargers**
 - **Inverters**
 - **Generators**
 - **Solar cell systems**
- **Example Ham Shack Emergency Power Configuration**

Grid-Down Scenario

- **This talk focuses on a power “grid-down” situation**
 - **Variety of possible natural and man-made causes for a 3 day to 1+ year grid-down scenario**
 - **Longer duration outages created by loss of key power system transformers**
 - **These transformers are huge, specialized equipment, typically foreign-made, with very long manufacturing and delivery lead times up to 1 yr+**
 - **Experts unanimously agree that our aging power grid is at some risk for extended grid-down scenarios**

Power Need Assessment

Equipment to be Powered

- **What equipment might you want to power?**
 - ✓ **Handheld transceiver (HT)**
 - ✓ **HT and HF bench radio**
 - ✓ **Radio system accessories (tuners, rotors, etc)**
 - ✓ **Radio bench lighting**
 - ✓ **Other household equipment**
 - ✓ **Flashlights, headlights, portable room lighting, battery chargers**
 - ✓ **Portable electronic devices, AM/FM radios, computers**
 - ✓ **Basic refrigeration capability**
 - ✓ **Cooking (usually best powered by non-electric fuels)**

Power Need Assessment

What Duration of Emergency Power is Needed?

- 3 days – 3 weeks (batteries, car powered recharge systems)
- 3 weeks – 3 months (batteries, moderate-volume fuel storage, liquid or gaseous fuel generators, solar)
- 3 months – 3 years+ (batteries, large volume fuel storage, gaseous fuels, solar)
- Simple way to measure electrical power consumption of equipment: Consider buying a Kill-a-Watt Measurement tool
 - Measures total energy consumption (KWhrs) from an AC outlet over an arbitrary duration
 - Invaluable for emergency energy planning, very reasonably priced for the value you get from it, several models available at Amazon

Example Simple Battery Bank Calculation for Ham Shack (3 day – 3 week scenario)

- **Ham Shack Deep Cycle Battery Amp-Hour (AH) Capacity**
 - Elecraft K3 HF radio operating in receive mode 4 hours/day, with ~10% transmit duty cycle (24 minutes/day transmit). Assume 1.5A receive current, 20A transmit current, Ah Requirement = 6(receive) + 8(transmit)=14 Ah/day, (Marine battery ~ 100Ah @12 V, GC2~220 AH @6V)

Total Time (Days)	Total Consumption (Ah)	Required Battery Capacity (Ah) @ Discharge To:		Required Battery Bank
		70%	50%	
3	42	140	84	1-2 marine or 2 GC2(6v)
21	294	980	588	5-10 marine or 6-10 GC2(6v)

Some Key Types of Electrical Power Sources

Power Source	Input	Output	Comments
Small batteries	-	1.5 – 9Vdc	Limited life, Alkaline, Li Ion
Small NiMH batteries (rechargeable)	Battery Charger	1.5 Vdc, 9 Vdc	Available in AAA, AA, C, D, 9V Excellent value/# recharge cycles
Storage battery	12 Vdc	12 Vdc	Battery bank workhorse (banks @ 12V, 24V or 48V common)
Battery chargers	120 Vac	1.5 – 48	Essential for battery preparedness
Inverter	12 Vdc	120 Vac	Essential for max power flexibility Premium inverters: 12, 24, 48V input
Generators	Fossil fuels, Wind	120 Vac 12 Vdc	Fuels: Gasoline, diesel, natural gas, propane - Essential for longer term operation. Wind typ not competitive.
Solar cell system/arrays	Sunlight	12-96V	Charge controller sets exact voltage Ideal for small - moderate power tasks (ham station power)

Key Types of Generator Fuel Sources

(fuels have similar energy content/weight!)

Fuel Source	Energy Content		Available in Grid Down?	Storage Attributes
	(kWh/gal)	kWh/kg		
Gasoline	34	12	few days	Somewhat dangerous and difficult to store for long periods. Best long term storage additive is PRI-G (11 yrs, add once/yr).
Diesel	37.6	12	few days	Safer storage than gas and has longer natural storage life (few years). Best long term storage additive is PRI-D (11 yrs).
Liquid Propane	24.7	14	few days	Large quantities can be stored nearly indefinitely and safely
Natural Gas	21.9 (LNG)	13	few weeks- few months	No easy consumer storage but most NG sys. can operate without electricity using underground reserve NG storage reservoirs and NG pumps

PRI-G, PRI-D are new state-of-the-art fuel storage additives, add once per year for up to 11 yrs

Underground Propane Tank Footprint



100 lbs (23.7 gal) Propane Cylinder



Small Batteries (AAA, AA, C, D, CR123 Li Ion)

- Use in HTs, radios, flashlights, headlights
 - Get conventional AA battery adapter for your HT as backup to internal battery
- NiMH rechargeable batteries have reached an advanced state and are cost effective in AAA, AA, C, D sizes (Best brand is Panasonic Eneloop)
 - Up to 2000 charges with very low self-discharges rates (several years)
 - For long life:
 - Use high quality chargers that have 4-8 independent charging banks (Ex:Powerex MH-C800S 8 cell charger).
 - These chargers can be run off 12V or inverters running off larger storage batteries (recharged from solar or generator). Gives nearly infinite supply of small batteries!
 - NiMH batteries need occasional maintenance for long life
 - Consider getting a NiMH battery charger/analyzer to check Ah capacity, refresh, and deep cycle batteries to maintain capacity and obtain the longest lifetime
 - Battery analyzer is well worth the cost to maintain batteries and obtain max lifetime
 - Ex: Powerex Wizard One MH-9000
 - Ex: La Crosse Technology BC1000

Lead Acid Storage Batteries

- Everyone has at least one in their car. Can use with inexpensive inverter and extension cord in an emergency. (But you must have the inverter ahead of time!)
- Key types of lead acid storage batteries
 - Flooded (water caps - need occasional maintenance, also have maintenance free)
 - Starter batteries (like in your car)-optimized for high current but not deep cycling- Use the one in your car if necessary but AVOID as a dedicated backup unit!
 - Deep cycle marine batteries – better optimized with thicker plates for deep cycling
 - Golf cart (6V GC2 batteries) –very thick plates highly optimized for deep cycling- relatively inexpensive, PREFERRED
 - L16 Batteries – Very high Ah ratings (400+ Ah) in 6 V form, Ex: Rolls Surette
 - Sealed Lead Acid (SLA)
 - Absorbed Glass Mat (AGM), sealed, Ex: Optima brand–very high quality-PREFERRED for indoor use and if you can afford them!
 - Gel batteries, sealed
- Battery Ratings: Ah (usually 20 hr rating), reserve capacity = #min @ 25A current

L16 Size Rolls Surette FLA Battery (430Ah)

Rolls



Surette / Rolls S550 Flooded Battery
(#9900153)

Lead Acid Battery Care

- **Battery Charging**
 - Always keep batteries charged!
 - Only use 3 or 4 stage charger
 - Bulk charging stage <80%
 - Absorption charging stage 80-97%
 - Float charging 97-100%
- **Battery Use (Discharging)**
 - Ideally only discharge to >70%
 - Discharge to 50% OK but reduces life somewhat
 - If it's a crisis go ahead and discharge to low levels -just know that battery life is significantly reduced

Battery	Approx. # Recharge Cycles after Discharge to:		
	<u>100-0%</u>	<u>100-50%</u>	<u>100-70%</u>
GC2 Deep Cycle	200	500-1000	1K – 2K

Charge State	SG	Battery Type		Ref. 4
		<u>12V</u>	<u>6V</u>	
100%	1.265	12.7	6.3	
75%	1.225	12.4	6.2	
50%	1.190	12.2	6.1	
25%	1.155	12.0	6.0	
Dischg	1.120	11.9	6.0	

SG=specific gravity (hygrometer)

Inverters

- Converts 12 Vdc to 120 Vac (Modified Sine and True Sine Wave)
- Inexpensive brands: Whistler (superb surge capability), Cobra
 - Modern inverters provide 120 Vac and 5 Vdc USB outputs
 - Inverters have some standby current even when unloaded
 - Inverters have ~ 85% conversion efficiency when loaded
 - Maximum efficiency for various loads is obtained by having a few inverters of different powers tailored for specific load levels
 - Try not to use a bigger inverter than you need for the specific job
 - 12V Inverters utilize large DC input currents-must use BIG cables

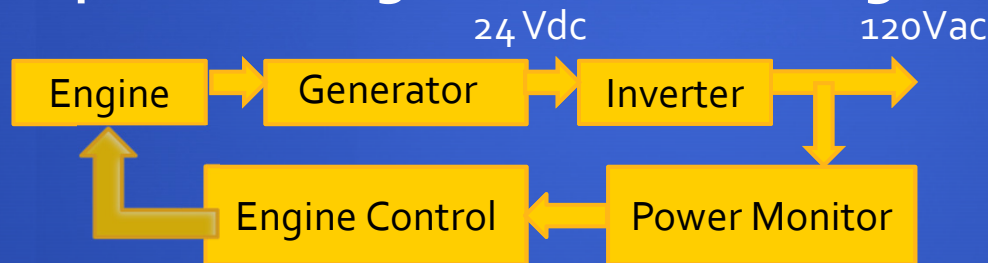
Whistler Model	Max CW Output (W)	Standby Current (A)	Standby Power (W)	Input Current (A) at 12V @ Full Output
XPi800	800	< 0.5	< 6w	80
XPi1600	1600	< 1	< 12	160
XPi3000	3000	< 1.3	< 15.6	300

Generators

- A generator is needed for longer term power independence and flexibility (unless you have an expensive whole house solar system)
 - Fill in the gaps on days when a solar system is not producing
 - A generator, coupled with fuel storage will usually be the most cost effective method to achieve a moderate power capability for > few days duration.
- Most efficient generators are diesel and inverter generators
 - Good diesel generators tend to be expensive
 - Tri-fuel inverter generators are very efficient and a great choice (gasoline, NG, or propane)
 - All generators need to be power derated 1 - 3% per 1000 ft elev.
 - In Monument that's a derating of about 14%.
 - Generators with tri-fuel capability often are easily air-mixture-optimized for altitude.
 - Small quantity of acetone can be added to the fuel (< 3 oz/10gal) to lower flash point temperature – enhances altitude performance.

Tri-Fuel Inverter Generators

- Tri-fuel capability: gasoline, natural gas, propane
 - Can take advantage of the likely natural gas availability during initial period of an extended grid-down (unless earthquake)
 - Propane storage is an effective fuel solution for longer term
 - Inverter generator is very efficient and maximizes fuel life
 - Example inverter generator block diagram:



- Inverter generators are typically very quiet (~53 dBa, voice level!)
- Some excellent inverter generators (Ref. 6)
 - Honda EU2000i (1600 W continuous, 2000 W peak, very portable)
 - Yamaha EF2000is (1600 W continuous, very portable)

Honda EU2000is Tri-Fuel Inverter Generator 1600 W (CW)



Honda EU7000is Tri-Fuel Inverter Generator 5500 W (CW)



Honda EU7000is Tri-Fuel Inverter Generator (next to random power generator)

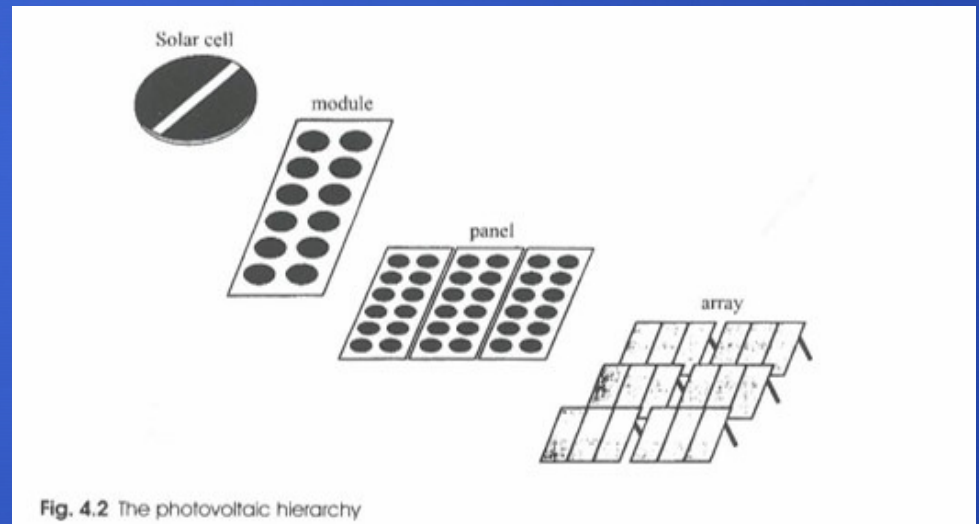


Generator Shed Natural Gas and Propane Entry



Solar Cells, Modules and Panels

- 3 Key Types of Solar Cells
 - Monocrystalline (eff ~ 15-22%)
 - Polycrystalline (eff ~ 13-16%)
 - Amorphous Thin Film (eff~ 6-14%)
- Solar cell produces ~0.5 – 0.6 V
- Solar Module typically contains 36 solar cells in series to achieve ~ 18 V into open circuit (for “12 V” module)
- Solar Panels created by parallel and series connections of modules
- Higher cell efficiency reduces panel area/W
- Panel behaves as a current source over a large voltage range
 - Charge batteries with this current
 - Charge controller controls voltage (MPPT type best)



Key Solar Panel Electrical Characteristics

- Key Parameters to Know to Design/Size Your System
 - Power rating of the panel (watts) at I_{mx} and Max Power Point ($\sim 17V$)
 - I_{mx} maximum output current (A)
 - Open circuit voltage (typically $> 18V$ for "12 V" panel)
 - Output voltage at the maximum power point ($\sim 17V$ for "12 V" panel)

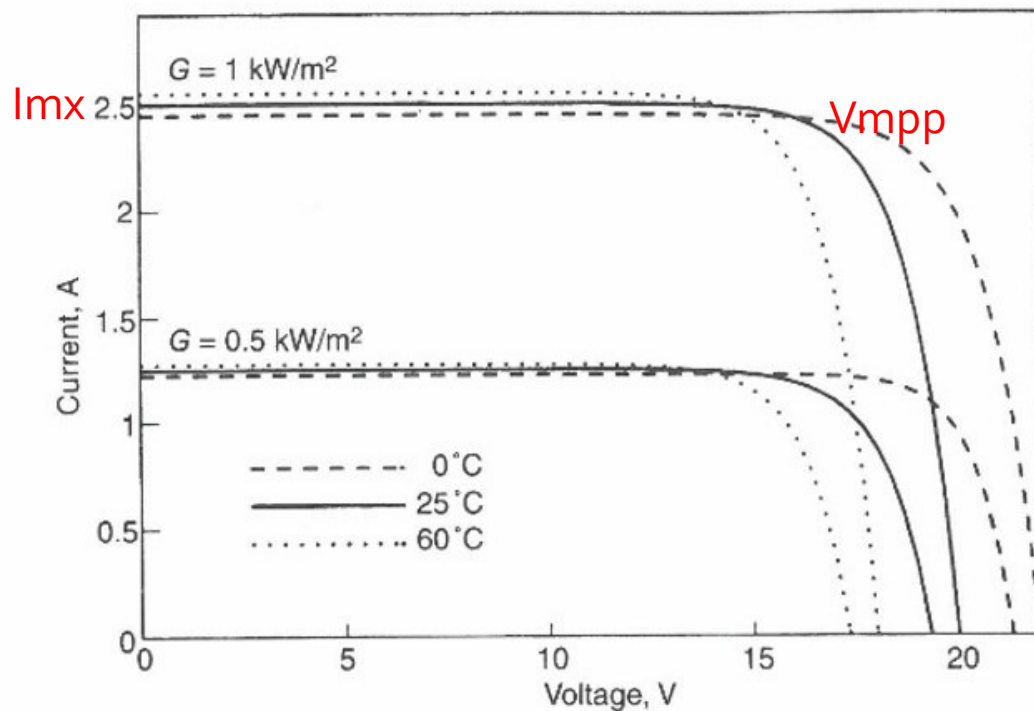


Fig. 4.4 The temperature and irradiance dependence of the module $I-V$ characteristic

Two key types of battery charge controllers:

1) On/off or proportioning controllers ($I_{chg} \sim I_{mx}$)

2) Maximum power point tracking controllers (MPPT)
 $I_{chg} \sim \text{Panel Power}/13.5V$
This extracts max power from the solar cell

Ref. 7

Solar Charge Controllers

- Why do we need a solar charge controller?
 - Solar panel voltage can be too much or too little for the battery/battery bank
 - Either scenario can damage battery
- What does a solar charge controller do?
 - Maintains the battery charging voltage at the right voltage for a large range of solar panel operating conditions/voltages
 - Premium units also automatically handle optimized battery charging and maintenance activities

Two Key Solar Charge Controller Types

- **Conventional charge controller**
 - On/off, duty cycle modulation, or analog type of voltage regulator
 - Output charging current ~ Input charging current
 - Output voltage always $<$ (or $=$) input voltage, not as efficient as MPPT
 - System design sizing calculations most easily performed using Amp-hour computations
- **Maximum power point tracking controller**
 - This is essentially a power efficient DC-to-DC converter/"transformer"
 - Extracts maximum power from solar array using $\sim I_{mx}$ at V_{mpp}
 - Usually handles a wide range of input and output voltages
 - Output current can be bigger than input current
 - Can support serial connections/higher voltage of both solar panel and battery array
 - System design sizing calculations most easily performed using Watt computations (because power is nearly conserved within controller efficiency)

Solar System Sizing: How much power will I really get?

- All panels are typically rated at standard test conditions (STC) of an illumination intensity of 1 kW/m² "one standard mid-day sun" and 25 deg C temperature
 - Irradiation tables show the kW.h/m² for the average day over a month
 - kW.h/m² = Number of average hours of mid-day sun-equivalent you can expect
 - Solar system needs to be sized from these irradiance averages over the year

- Example for Colorado: Assume our simple ham shack at 14.8 Ah/day with optimal solar panel tilt
 - Minimum irradiance = 4.58 kW.h/m² or 4.58 standard sun hours (panel tilt adjusted each month)
 - Assume 100 W panel and MPPT controller: this gives 100W x 4.58 hours
 - Ichg~ = 100 W/13.5 V = 7.4 A for 4.58 hours average or 33.9 Ah per day
 - Compare to our prior calc Ah for an HF radio with 4 hours receive, 24 min transmit/day: 14 Ah/day
 - Controller inefficiency(90%), shading, electrical losses will reduce this somewhat
 - A 100 W panel has sufficient margin to keep the batteries charged in a typical ham station with margin for lights, few accessories, etc. under worst case winter conditions

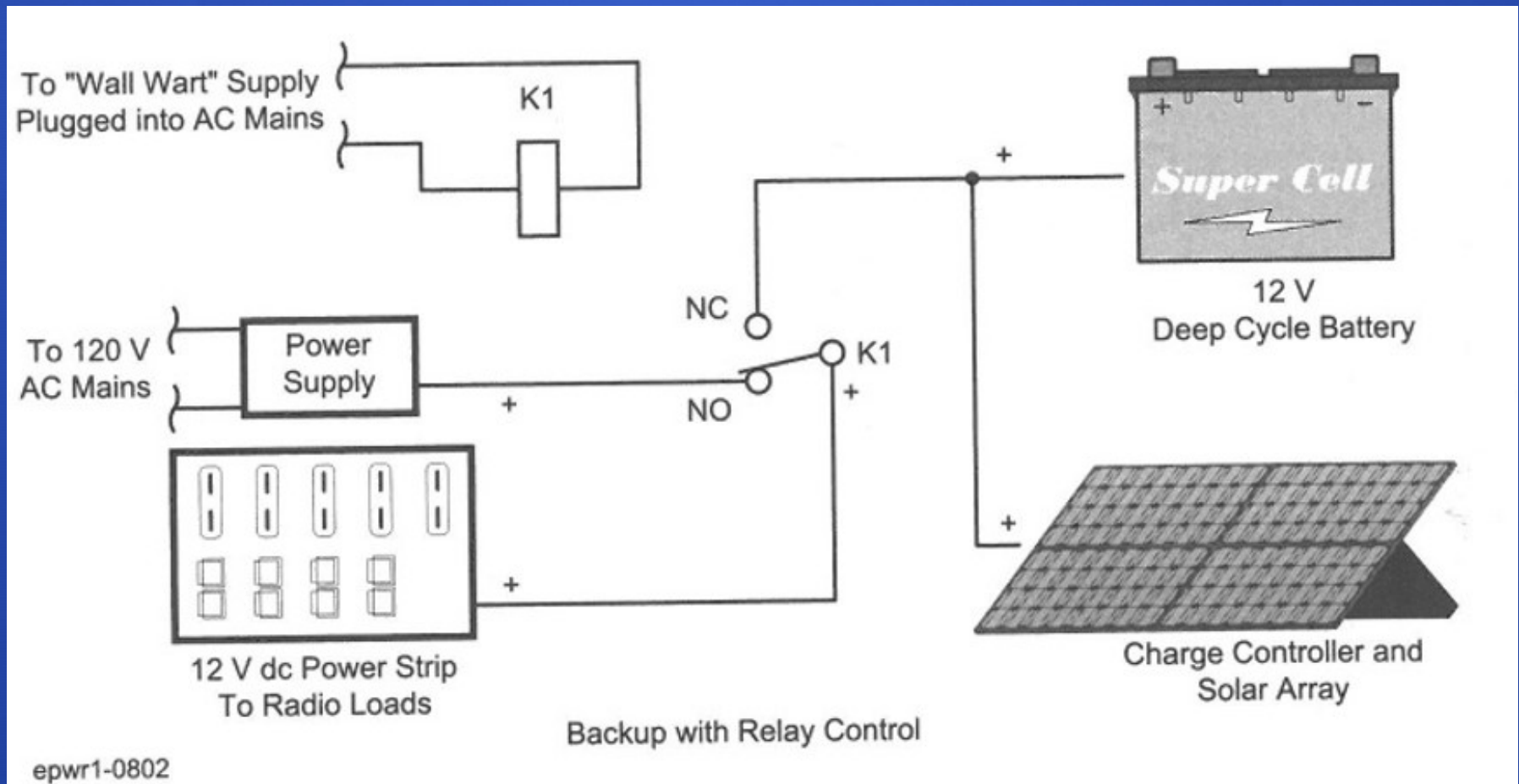
Ref. 8

<u>Colorado</u>	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flat - 90°	2.41	3.27	4.49	5.42	6.28	6.70	6.35	5.68	5.03	3.90	2.67	2.18
Upright - 0°	4.20	4.18	4.05	3.25	2.80	2.60	2.64	2.99	3.90	4.66	4.30	4.21
50° angle	4.27	4.85	5.58	5.62	5.81	5.90	5.72	5.60	5.87	5.60	4.52	4.12
Year-round tilt												
34° angle	4.58	4.99	5.47	5.17	5.10	5.05	4.96	5.05	5.63	5.71	4.79	4.47
Best winter tilt												
66° angle	3.72	4.43	5.39	5.78	6.24	6.47	6.21	5.87	5.79	5.17	3.98	3.53
Best summer tilt												
Tilt adjusted	4.58	4.99	5.58	5.78	6.24	6.73	6.21	5.89	5.87	5.71	4.79	4.56
each month	34°	42°	50°	58°	66°	74°	66°	58°	50°	42°	34°	26°

Continued

Ham Station Battery Backup with Solar Battery Charging

- Sizing/irradiance analysis shows that a 100 W panel with MPPT controller in typical CO sunlight can provide ~ 34 Ah/day charging
- Compare with our previous HF radio usage of 14 Ah/day



Higher Capacity Systems: Overview (to be continued in next presentation)

- Battery Banks and Advantage of Higher Voltage
- MPPT Solar Controllers
- MPPT Inverter/Chargers
 - Invaluable for battery backup and generator systems
- Typical Key Component Efficiencies
- A Typical Higher Voltage Solar and Battery Array System

Conclusions/Summary

- **Minimum Prep: Everyone has a generator and a battery bank already in their car**
 - Buy an inverter, extension cord, and store spare car fuel to achieve minimal power prep
 - Stock NiMH rechargeable batteries and charger for the HT receivers, flashlight, headlights, etc.
- **A properly-sized, battery/(battery bank) is essential for emergency power in the ham station or for the larger power tasks of the household**
- **Solar is ideal for the small power tasks of the ham station**
- **Generator, with fossil fuel storage is most cost effective for scenario durations longer than 3 weeks.**
 - Consider diesel or inverter generators for max efficiency
 - Tri-fuel inverter generator takes advantage of the likely natural gas availability and longer term trouble-free propane storage options
- **Questions? : Feel free to contact Mike at acoustiman@comcast.net**

Emergency Power for Ham Radio References

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