W0TLM Amateur Radio Club
Emergency Power for Ham Radio

Mike Hoskins, W0MJH

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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

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

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-PREFERRED
  - 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

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:		
	100-0%	100-50%	100-70%
GC2 Deep Cycle	200	500-1000	1K – 2K

Ref. 4

Charge State	SG	Battery Type 12V	6V
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)

Ref. 5

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 approx. 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

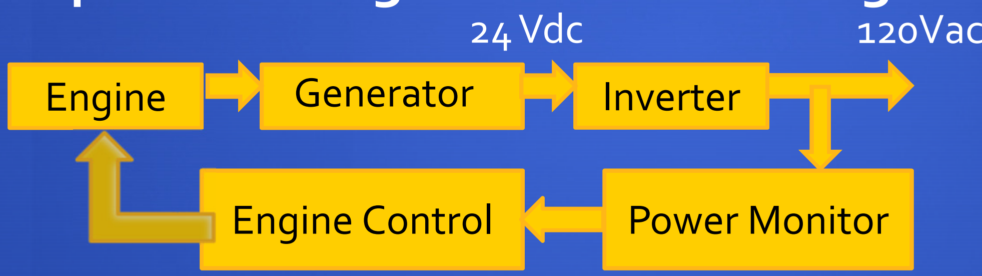
Whistler Model	Max CW Output (W)	Standby Current (A)	Standby Power (W)	Input Current (A) at 12V @ Full Output
XPi800	800	< 0.5	< 6w	80
XPi1600	1600	< 1	< 12	160
XPi3000	3000	< 1.3	< 15.6	300

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)

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)

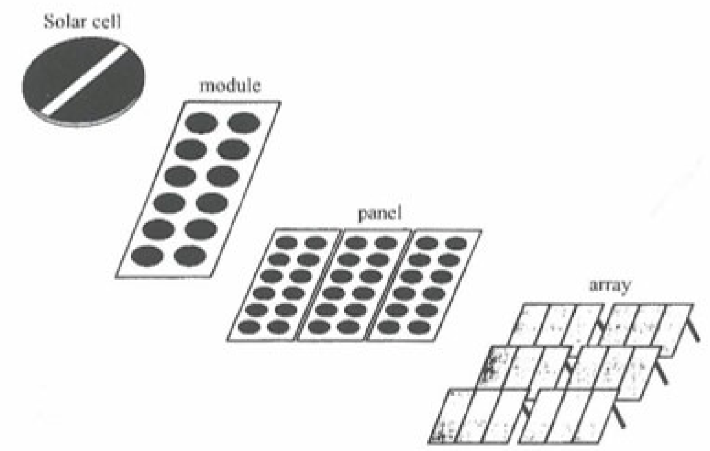


Fig. 4.2 The photovoltaic hierarchy

Ref. 7

Key Solar Panel Electrical Characteristics

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

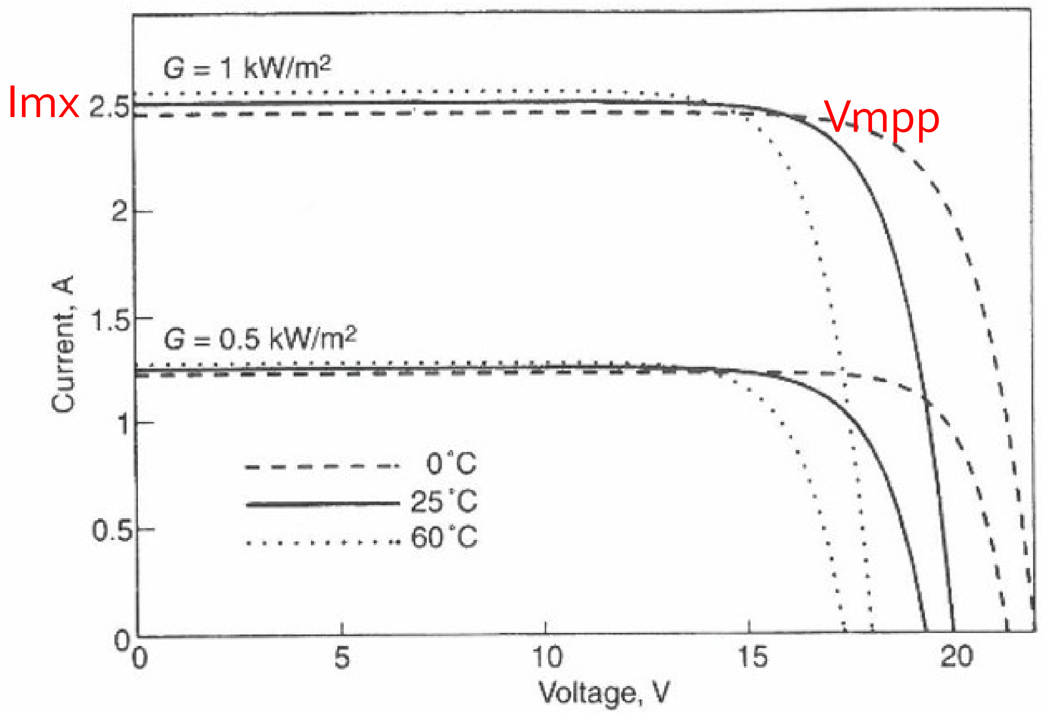


Fig. 4.4 The temperature and irradiance dependence of the module *I*–*V* characteristic

Two key types of battery charge controllers:

1)On/off or proportioning controllers (Ichg ~Imx)

2) Maximum power point tracking controllers (MPPT) Ichg~ 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 ~Imx at Vmpp
  - 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 optimal tilt adjusted through seasons
    - 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

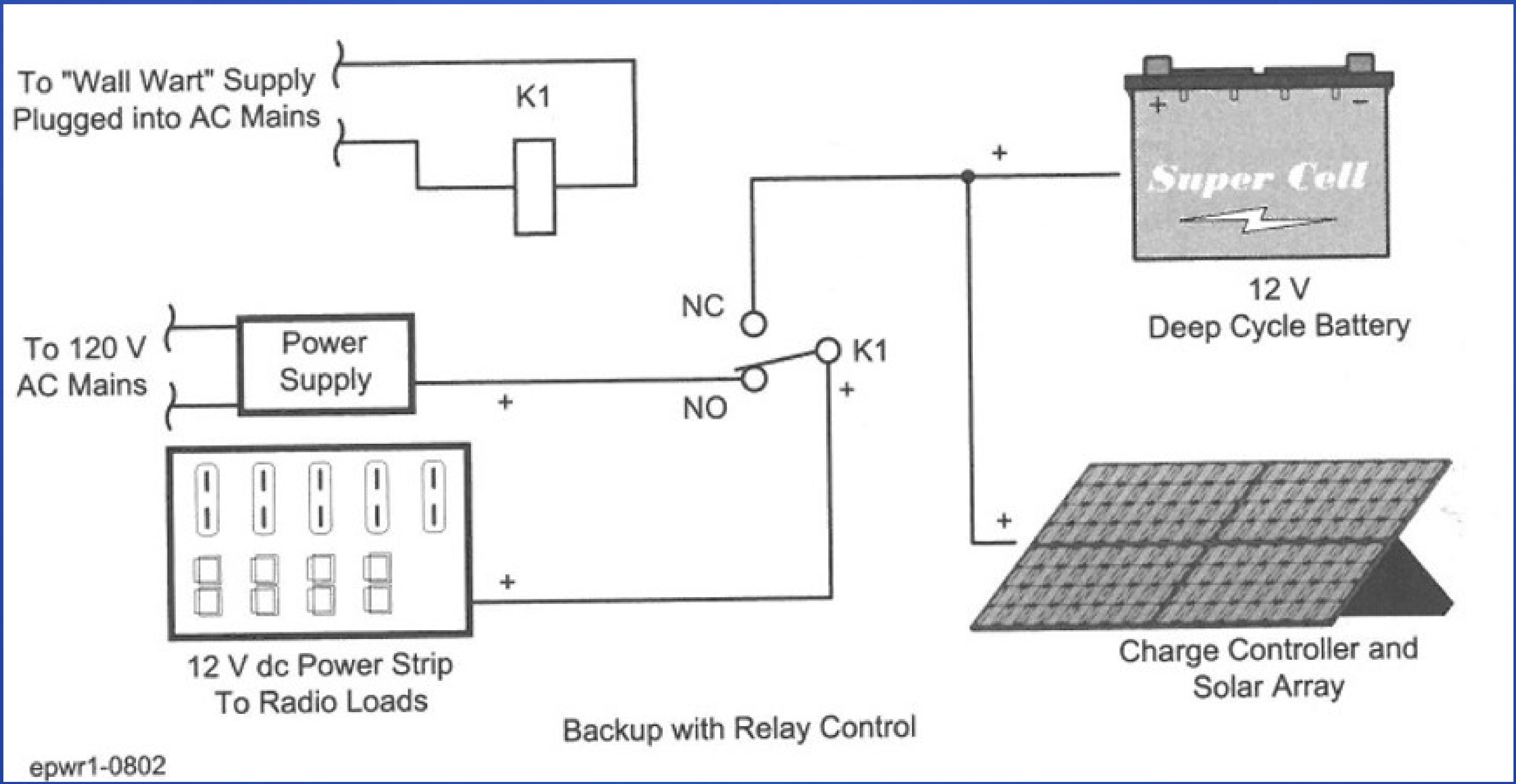
Ref. 8

Colorado

	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 Year-round tilt	4.27	4.85	5.58	5.62	5.81	5.90	5.72	5.60	5.87	5.60	4.52	4.12
34° angle Best winter tilt	4.58	4.99	5.47	5.17	5.10	5.05	4.96	5.05	5.63	5.71	4.79	4.47
66° angle Best summer tilt	3.72	4.43	5.39	5.78	6.24	6.47	6.21	5.87	5.79	5.17	3.98	3.53
Tilt adjusted each month	4.58 34°	4.99 42°	5.58 50°	5.78 58°	6.24 66°	6.73 74°	6.21 66°	5.89 58°	5.87 50°	5.71 42°	4.79 34°	4.56 26°

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



Ref. 9

Emergency Power for Ham Radio References

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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

Addendum Info on Higher Capacity Systems: Overview

- 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

More Power: Battery Banks

- Some scenarios for more power
  - I'd like my ham station power to have enough reserve power for :
    - A whole week of cloudy conditions (it does happen occasionally!)
    - Auxilary equipment (for example: spectrum display, dual HF receivers, VHF/UHF base station in addition to HF, etc)
    - AND serve as a central charging station in the long term for all my NiMH battery usage
  - I have a split phase 240V generator capable of powering critical items in my house through the electrical panel/transfer switch
    - I need a battery bank to buffer my generator power so I can run generator efficiently for 2 – 4 hours/day and run silent/run deep off batteries at all other times
  - I want to take advantage of solar energy and use several solar panels to generate all the power I need to get through a crisis

Battery Banks

- Larger Battery Banks Benefit From Higher Voltage Series Connections
  - Higher voltage reduces cable/connection resistance losses at high currents
  - The improvement is a double effect: lower $I = P/V$, $Ploss = I^2 \times R_{loss}$
  - Typical arrangement is parallel connection of series sub-banks
  - The same interconnect loss principles apply to solar panel arrays as well

- Battery Bank Disadvantages
  - Larger investment in battery banks demands diligent care of batteries – neglect or mistakes can ruin an entire bank which is very costly
  - Multiple batteries accumulate individual differences in charge state that must be periodically "equalized" for longest lifetime.
    - Equalization is a slight "overcharge" at higher than normal charge voltage to bring all batteries to essentially identical charge states
    - Equalization is typically performed once/month or so
    - Equalization can be done manually or automatically (best) by charge controller or inverter/chargers

MPPT Solar Controllers and Inverter/Chargers for Battery Banks

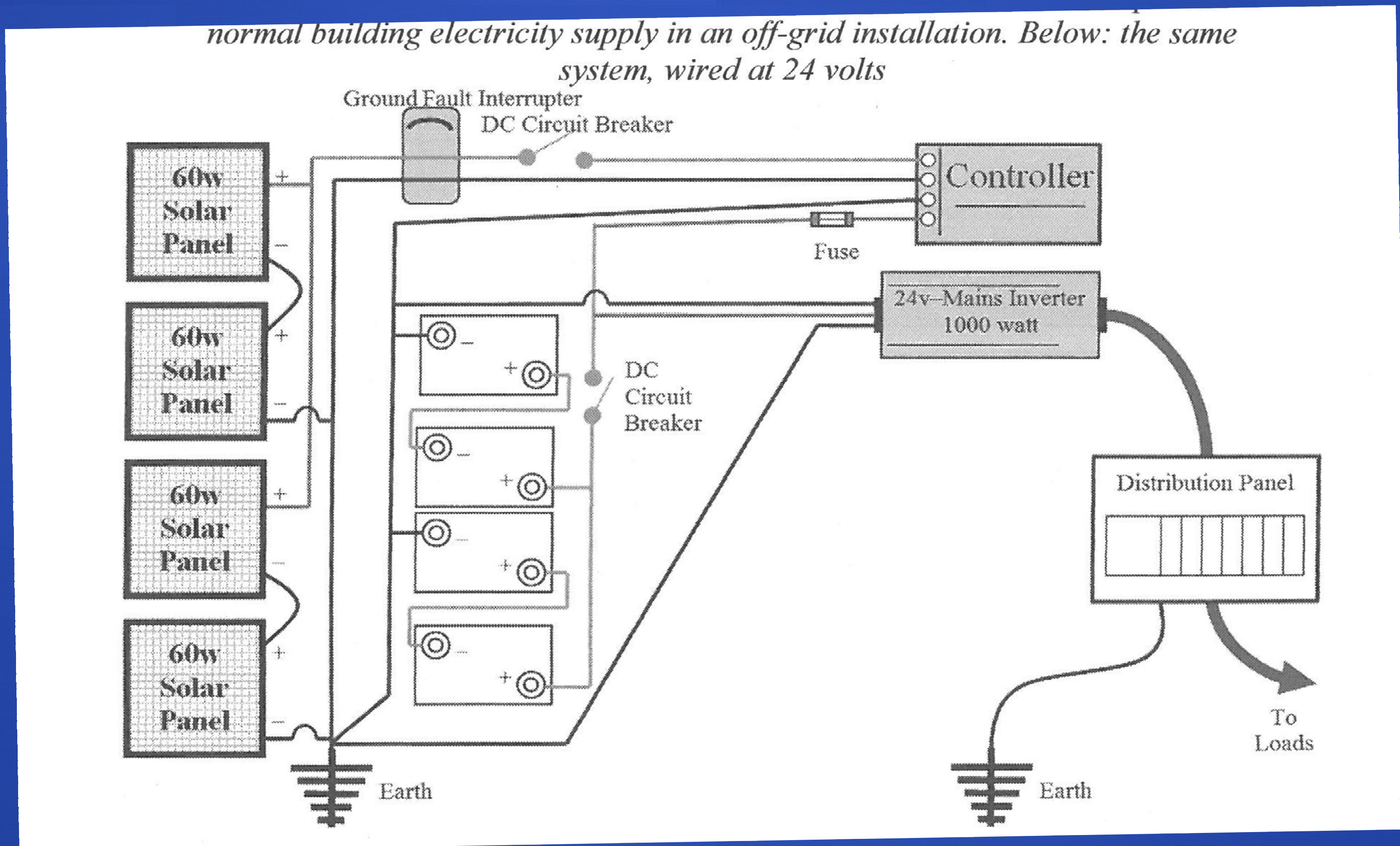
- Inverter/Charger has two key functions in one unit
  - 120VAC to DC conversion for charging battery bank
  - DC to 120VAC conversion for operating house electrical panel or specific transfer switch circuits off batteries
  - Inverter/charger particularly useful when you don't have a solar panel(s)
  - AC for charging batteries can be from generator and/or the power panel
  - This unit is very helpful for keeping your battery array in top shape regardless of whether you're running off your utility power or your generator.

- Larger power MPPT controllers and inverter/generators often have:
  - Wide range of input and output voltage compatibility
    - Choice of 12, 24, 48, 72, 96 VDC are common for solar panel and battery arrays
  - Battery temperature sensing for precise charging regimen (long battery life)
  - Programmable/customizable charge routines for optimization of specific battery brands (long battery life)
  - Automatic or manual equalization of battery arrays
  - Troublefree battery array auto-maintenance reduces chance of damaging batteries
  - Pure sine wave, low interference, inverted AC outputs

Typical Efficiencies of Key Components

Component	Typical Efficiency (%)	Comments/Impact
Solar Array Temperature Coefficient (Affects Power Output Efficiency)	-0.5/degree C	Relative to 25C test condition Hot arrays reduce power output
Charge Controller Efficiency	Conv.: 75 MPPT: 90-95	Affects required size of solar array
Battery Charge Cycle Efficiency	Marine: 90 GC2: 95	Affects required size of solar array Caused by higher voltage for charging
Inverter Efficiency	85-90	Affects battery array size
120VAC to 13.8VDC Switching Supply	80	Affects battery array size if inverting to 120VAC
Total Solar-to-Battery Energy Eff. (MPPT)	~80	
Total Battery to Inverted AC	85-90	Must add power supply ineff.

Typical Solar Series/Parallel Array Setup
24V Solar and Battery Configuration



Ref. 8