CABLES, WIRING & FUSES

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Main issues

- Codes / Regulations
- Cable thermal ratings
- Voltage drop
- Fuses & miniature circuit breakers (MCBs)
- Earthing
- Accessories
- Residual current devices (RCDs)
- Planning

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Wiring Codes / Regulations

- The IEE Wiring Regulations (UK) BS 7671:2001 **do apply** to off-grid systems
  - **Chapter 55** applies specifically to installations
    - not connected to the public supply
    - alternative to the public supply
    - operating in parallel with the public supply
    - and combinations thereof
- The National Electrical Code in the USA also deals with off-grid systems

Photovoltaic Power Systems
And the
2005 National Electrical Code:
Suggested Practices

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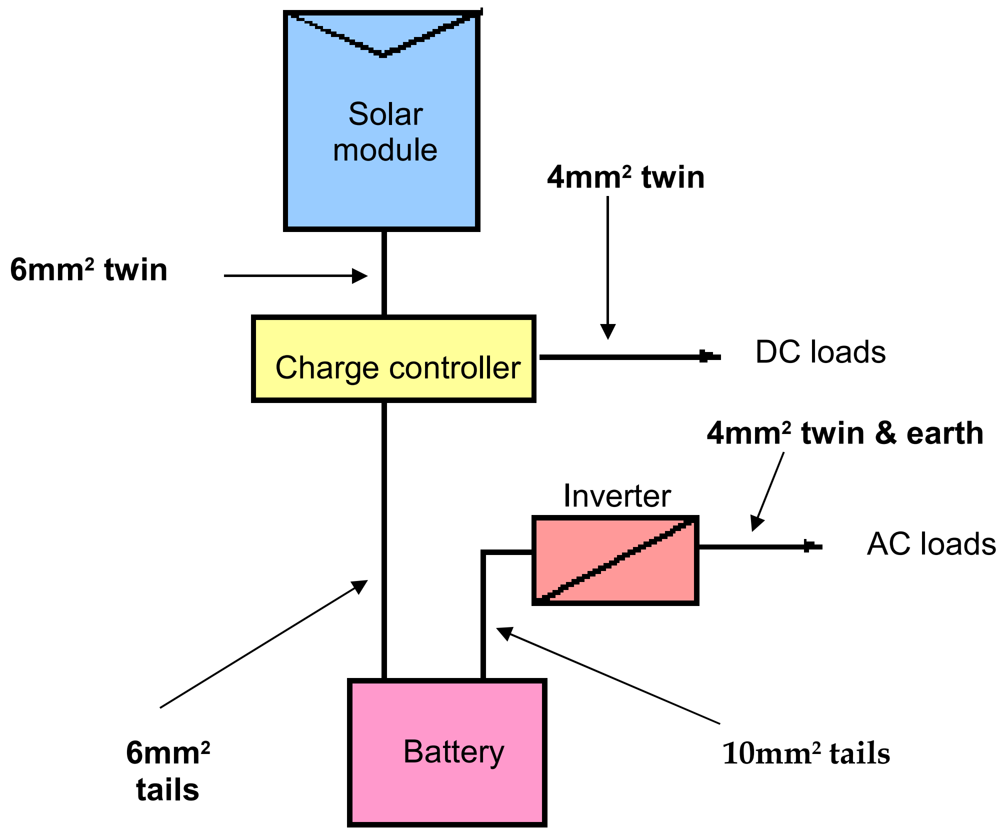
One of the first things to do when designing a system is to make a cable plan



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Cable thermal ratings

Maximum current carrying capacities for more common copper cables, for both AC and DC
Complete tables can be found in Appendix 4 of the IEE Wiring Regulations (UK)

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Array cables

- UV resistant (conduit, tape)
- High temperatures possible
- Refer to standards

External cables must be specifically adapted to outdoor exposure according to the international standard IEC 60811 or to the national standard for cables used by the relevant country.

From *Universal Technical Standard for Solar Home Systems*

Cables routed behind a PV array must be rated for a minimum temperature of 80°C.

From *Photovoltaics in Buildings (DTI, UK) – a standard for grid-tied*

What is voltage drop?

Voltage drop along a conductor from the source to the load wastes energy and can damage appliances. And the module may not charge the battery properly.

Voltage drop is a function of the current in the cable and the resistance of the cable.

Current is determined by the load and resistance is determined by the cross sectional area and lenght of the conductor.

$$V_{drop} = I \times R_{cable}$$

Permissible cable voltage drops

Battery to charge controller - <1%

Battery to inverter - <1%

Solar module to charge controller - <3%

Charger controller to loads - <5%

Inverter to loads - <5%

Voltage drop tables

- Tables giving maximum allowable voltage drop can be used
- Or voltage drop can be calculated using IEE tables.
- Cables energised at 24VDC can be twice as long as those in a 12VDC system
- 230VAC can be 20 times as long

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Wiring and Fittings

Increasing system voltage decreases voltage drops in long runs.

Voltage drop tables

Table 8.2: 12 Volt System Maximum Wire Length in Metres (0.6 V max voltage drop, or 5%)

Wire Size (mm²)	Load Current								
	1 amp	2 amp	3 amp	4 amp	5 amp	6 amp	8 amp	10 amp	14 amp
1.5	22	11	7	6	4	4	3	2	2
2.5	38	19	13	9	8	6	5	4	3
4.0	60	30	20	15	12	10	8	6	4
6.0	88	44	29	22	18	15	11	9	6
10.0	150	75	50	38	30	25	19	15	11

Table 8.3: 24 Volt System Maximum Wire Length in Metres (1.2 V max voltage drop, or 5%)

Wire Size (mm²)	Load Current								
	1 amp	2 amp	3 amp	4 amp	5 amp	6 amp	8 amp	10 amp	14 amp
1.5	44	22	15	11	9	7	6	4	3
2.5	75	38	25	19	15	13	9	8	5
4.0	120	60	40	30	24	20	15	12	9
6.0	176	88	59	44	35	29	22	18	13
10.0	300	150	100	75	60	50	38	30	21

From *Solar Electric Systems for Africa*

Estimating voltage drop using resistance values

Resistances for metric size cable cores

Conductor cross-sectional area (mm^2)	Resistance in ohms per metre (Ω / m)
2.5	0.0074
4	0.0046
6	0.0031
10	0.0018
16	0.0012
25	0.00073
35	0.00049

The above cable is based on metric copper cable sizes and practice. The following formula can be used: Voltage drop per metre = I × R, where I is the current in the circuit and R is the resistance of the conductor. So, for a 4 mm^2 cable, 90 m long, carrying a current of 15 A, the voltage drop = 15 A × 0.0046 V = 0.069 V per metre of cable core. To calculate the voltage drop for a 90 metre cable run, multiply by 180 (feed and return) to get the total voltage drop of 12.42 V.

From *Photovoltaics for Professionals*

IEE voltage drop tables

- The IEE Wiring Regulations BS7671:2001 provide tables for voltage drops of all types of cables
- Values are given in mV per ampere per metre [mV/A/m]
- These are for single core cables carrying

CABLE SIZE	SINGLE CORE CABLES (in conduit)
1.5mm^2	29mV
2.5mm2	18mV
4mm2	11mV
6mm2	7.3mV
10mm2	4.4mV
16mm2	2.8mV
25mm2	1.75mV
35mm2	1.25mV
50mm2	0.93mV

Voltage drop - worked example

If a PVC insulated single core copper 25mm^2 cable is carrying a current of 100A at 24VDC and the length of the cable is 12 metres, what will the voltage drop be?

The IEE tables give a voltage drop for this type of cable of 1.75mV per amp per metre
(1.75mV /A/m)

So the the voltage drop will be

1.75mV x 100A x 12m = 2100mV or 2.1V

This is 8.75% of 24V, which is not acceptable.

Fuses and MCBs

- Fuses and MCBs protect against fire caused by
  - Short circuits
  - Overheating of cables
- Against electric shock
  - by preventing metalwork rising to > 50V
  - and/or cutting off the supply with 0.4 seconds for socket outlets and/or 5 seconds for lights and fixed equipment under earth fault conditions
- AC distribution from inverters: MCBs will usually be of a lower rating than in a similar mains supply
  - e.g. 1000 W socket circuit with 2.5 mm^2 cable can be protected by a 5A MCB

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Main battery fuse

- DC rated
- In positive cable as near as possible to positive terminal of battery
- Rating in A to be less than thermal rating of battery cables
- Breaking capacity in kA to be greater than battery short circuit current

Outback inverter-battery fuse

ESSENTIAL SAFETY PRECAUTION

Reasons for earthing

- To keep all metalwork associated with the electrical system and which could become "live" under fault conditions at the same "electrical potential" as the general mass of the earth. The earthing system should ensure that metalwork will never have a voltage of above 50V
- Ensuring that all fuses and circuit breakers will blow or trip quickly in the case of a live conductor coming into contact with metalwork
- To provide lightning protection which can damage equipment such as inverters
- Functional earthing to enable correct operation of some electronic equipment

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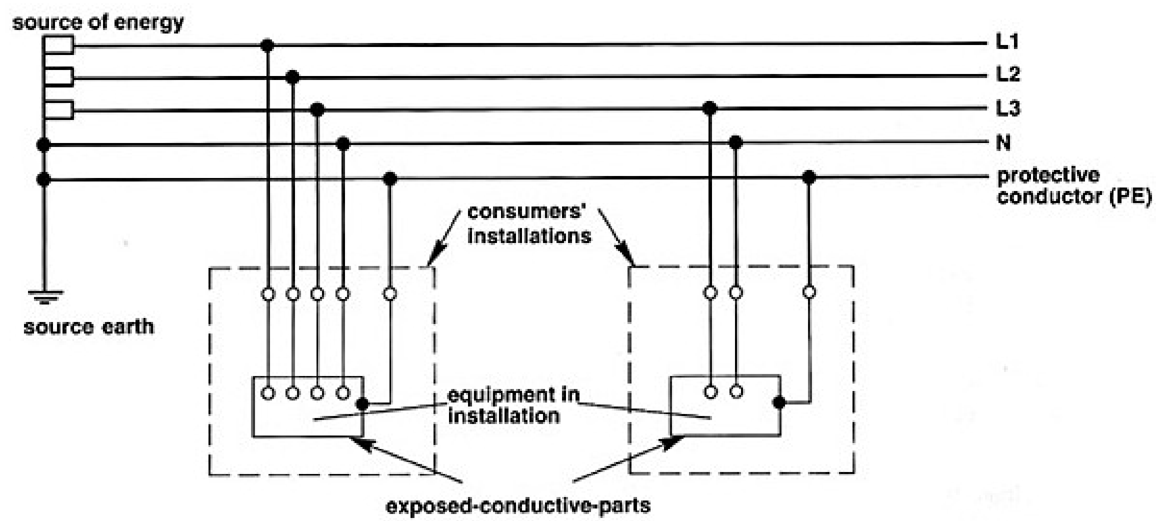
Earthing system

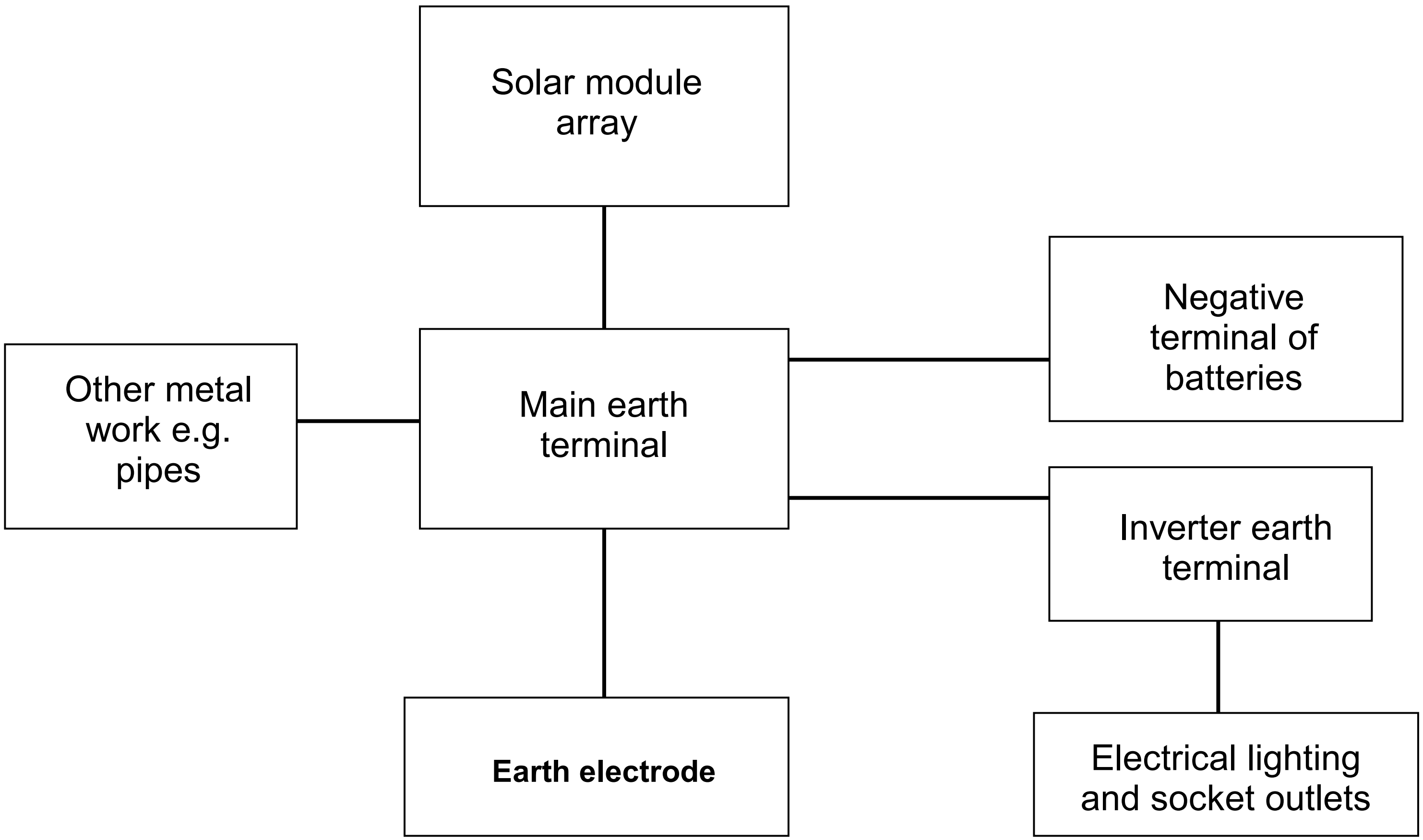
Most off-grid renewable energy systems will be considered TN-S systems as defined by the *IEE Wiring Regulation (UK)*

Earth electrode resistance needs to be verified – local practice?

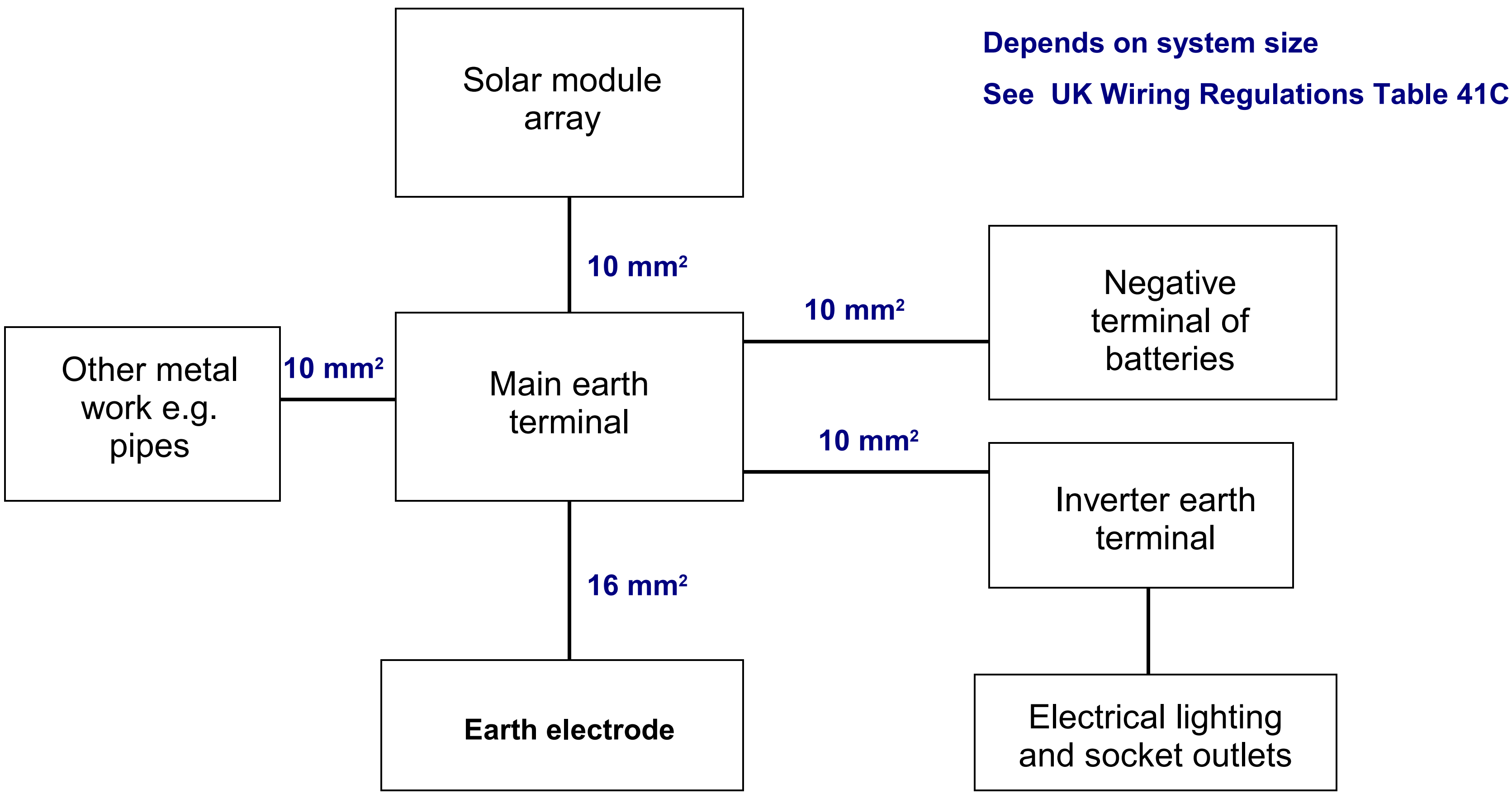
The impedance (function of size) of final circuit distribution cables - refer to Table 41C (IEE UK Regulations) – should ensure that in fault conditions voltage does not raise above 50V



Components of earthing system



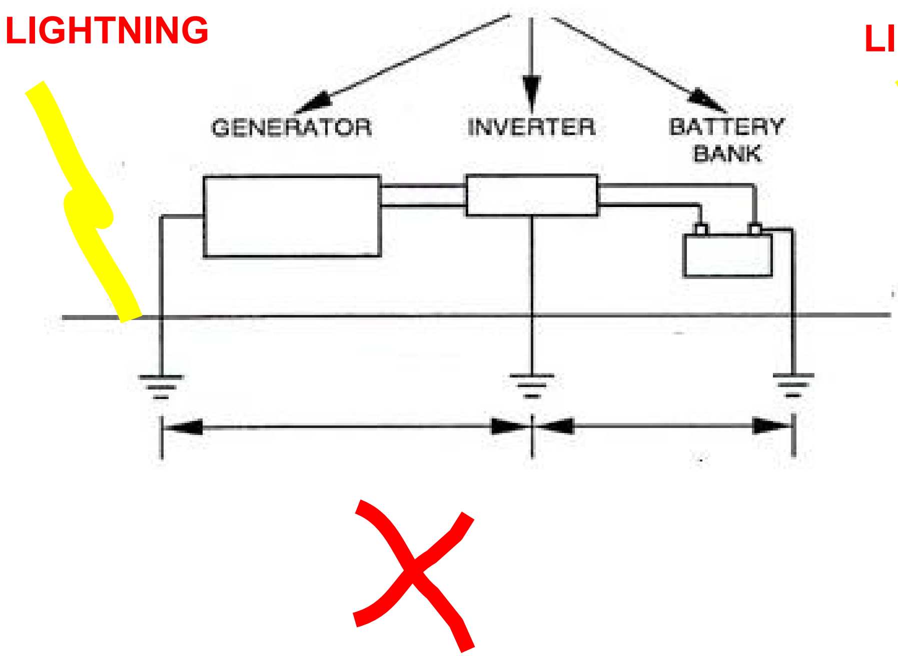
Earthing cables - minimum sizes

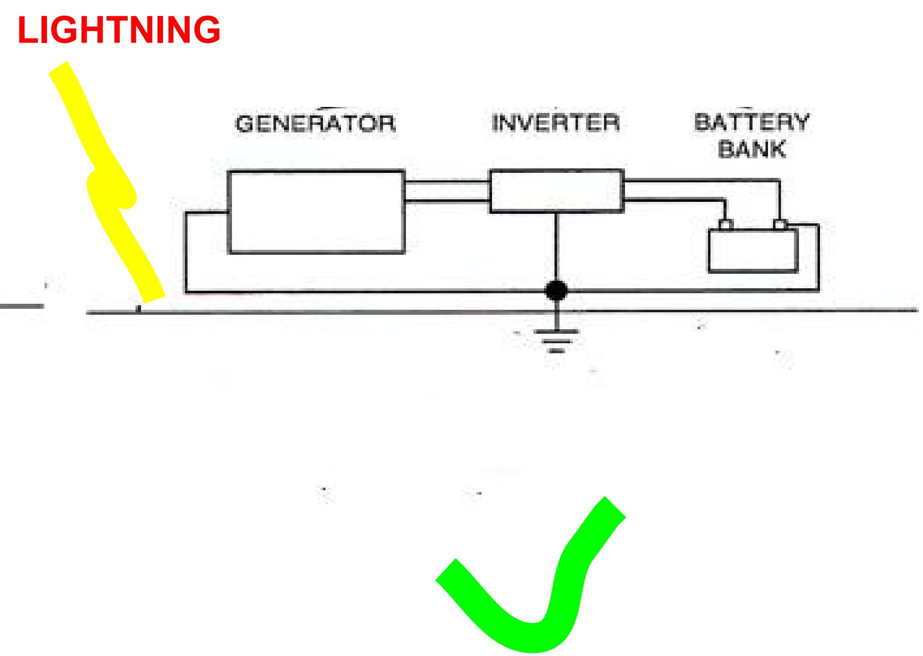


Number of earth electrodes

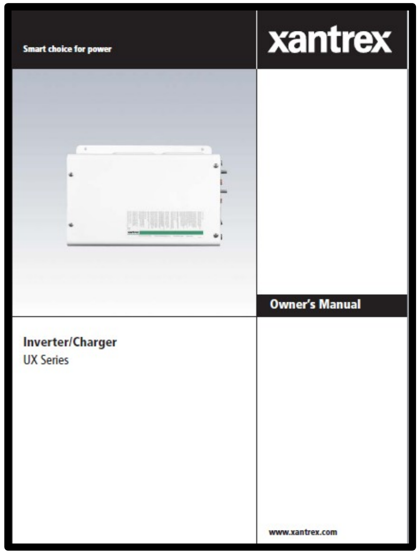
System components act as conductor (current flow) because of voltages between earth electrodes

All system components connected to single earth electrode. No current flow between system components





Inverter manuals can be a good good to earthing



www.xantrex.com

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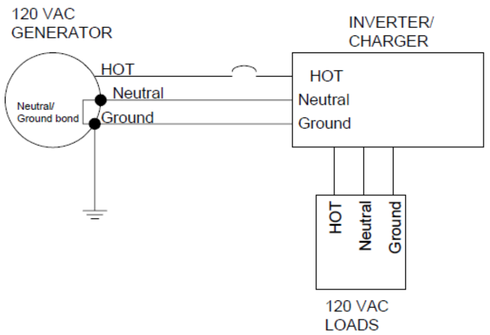
Generators

Basic 120 Vac Generator Hookup (Off-Grid applications only)

NOTE: The ground and neutral must be bonded at one place, and only one place, in the system. If the generator is the main source of power, (i.e., no utility grid power) then the neutral and ground connections are bonded at the generator. If the generator is acting as a backup for the utility grid, then the bond should be at the main utility breaker box. In this case, ensure that no bond exists at the generator output.

1. Connect the ground wire on the generator to the GROUND terminal on the inverter.
2. Connect the generator neutral wire to the NEUTRAL terminal on the inverter.
3. Connect the generator HOT wire to the HOT input on the inverter.
4. Bond the neutral to the ground on the output of the generator (only if used in non-utility installations) *or* in the main utility breaker box (not both).
5. Drive a ground rod 6–8 feet (1.8 - 2.4 meters) into the ground and connect the generator's ground to the ground rod.
6. Start the generator and check for proper operation of the inverter (i.e., the inverter transfers from battery to generator power).



From XANTREX UX Series Owners Manual

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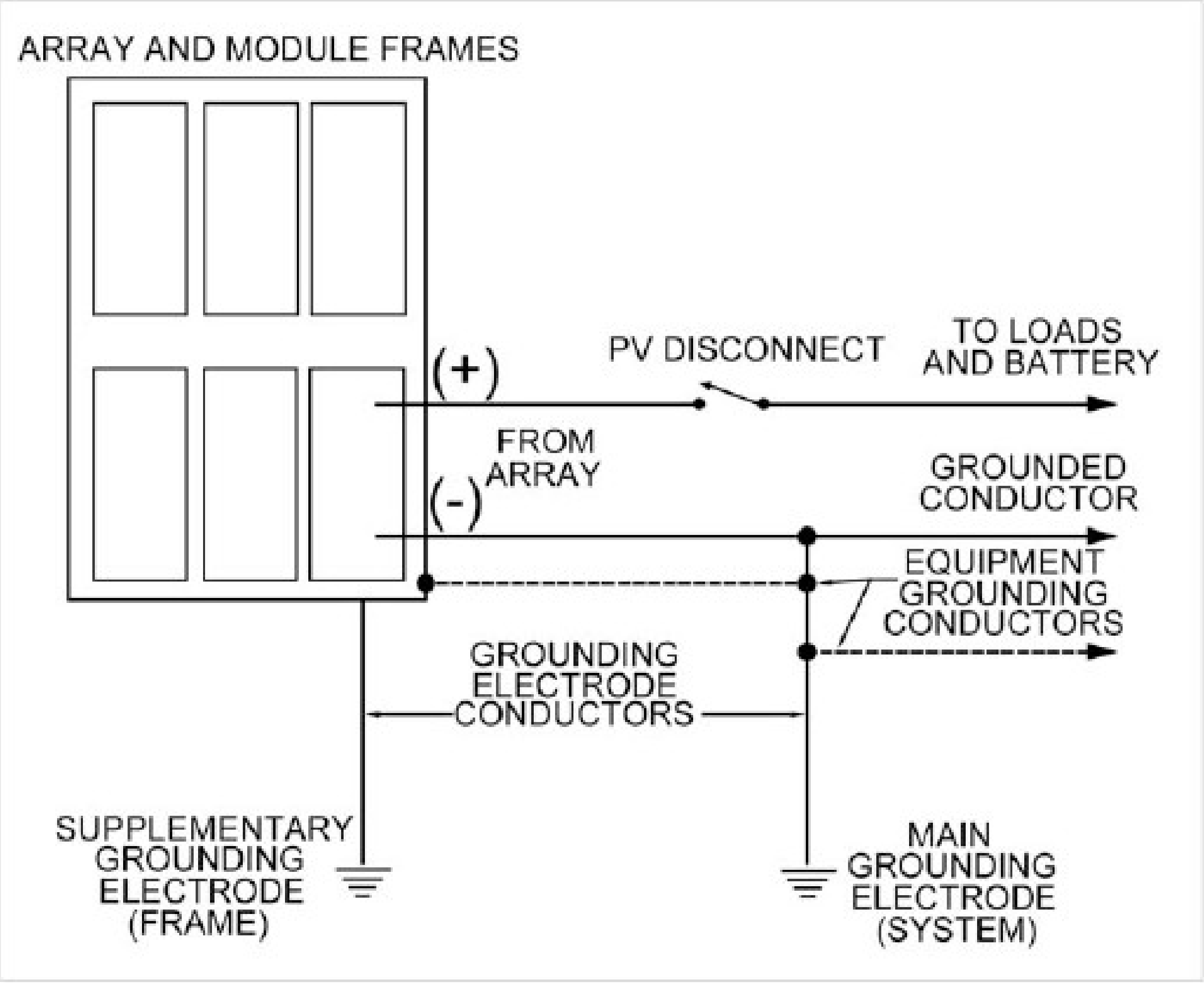

Figure 13. Example Grounding Electrode System

Photovoltaic Power Systems
And the
2005 National Electrical Code:
Suggested Practices

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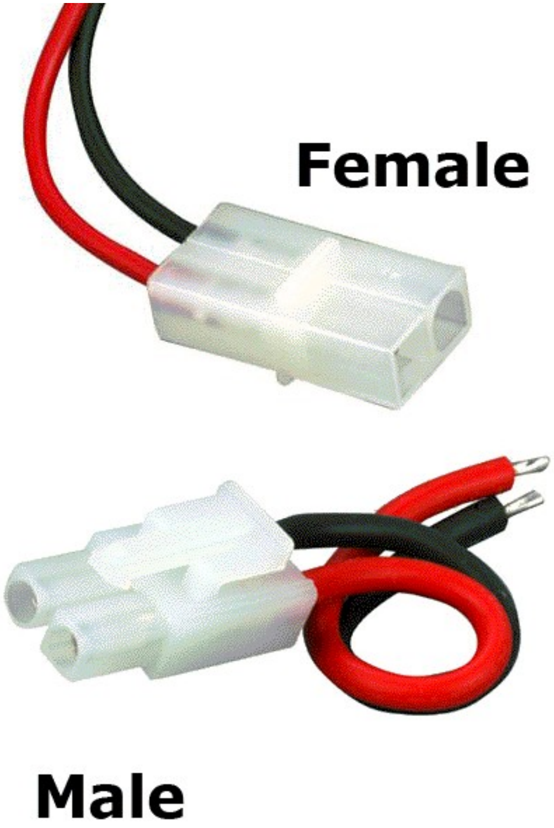
Las Cruces, NM 88003

Recommend reading

Switches

- Ideally DC-rated
- But AC can also be used, especially on distribution circuits (AC rating needs to be twice the max. DC current)
- Some will be both AC and DC rated, but at different currents
- With more than 2 module an isolator is needed between modules and charge controller
- Change over switches in inverter-charger – generator systems

DC plugs & sockets



Residual current devices (RCDs)

- Designed to cut off power in the case of an earth leakage current of 30 mA in 200 ms
- Incorporated in consumer unit
- Designed for mains supplies mainly
- Refer to local codes and inverter manuals
- Should be tested before use

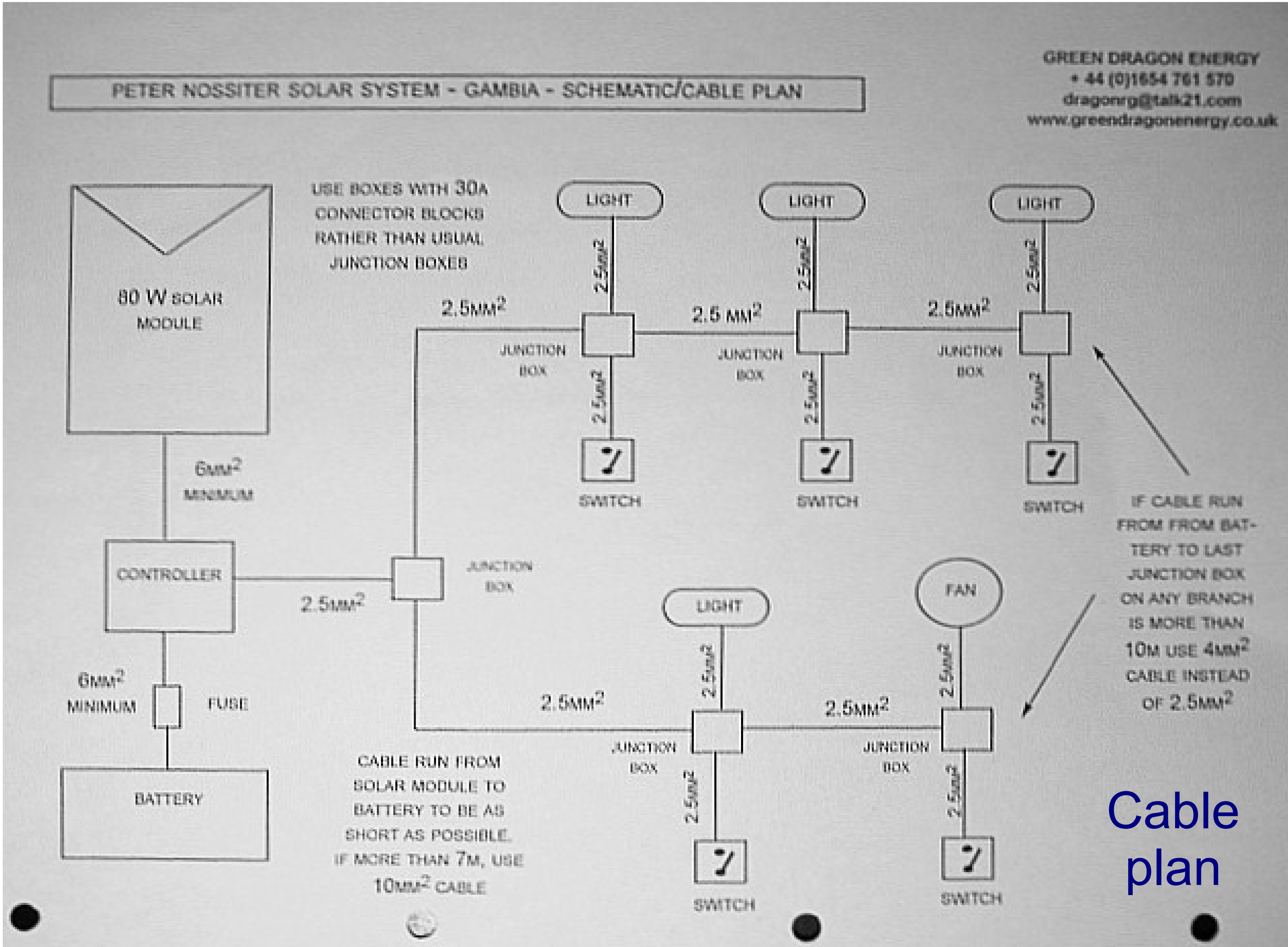
Junction boxes

- Array
  - Appropriate IP rating
  - Need to be sealed
- DC distribution wiring
  - Correct rating in amps
  - However cables maybe be larger (because of voltage drop requirements) than they are designed for, boxes with connector blocks may be a better option
  - Need to be sealed

Inter-building distribution

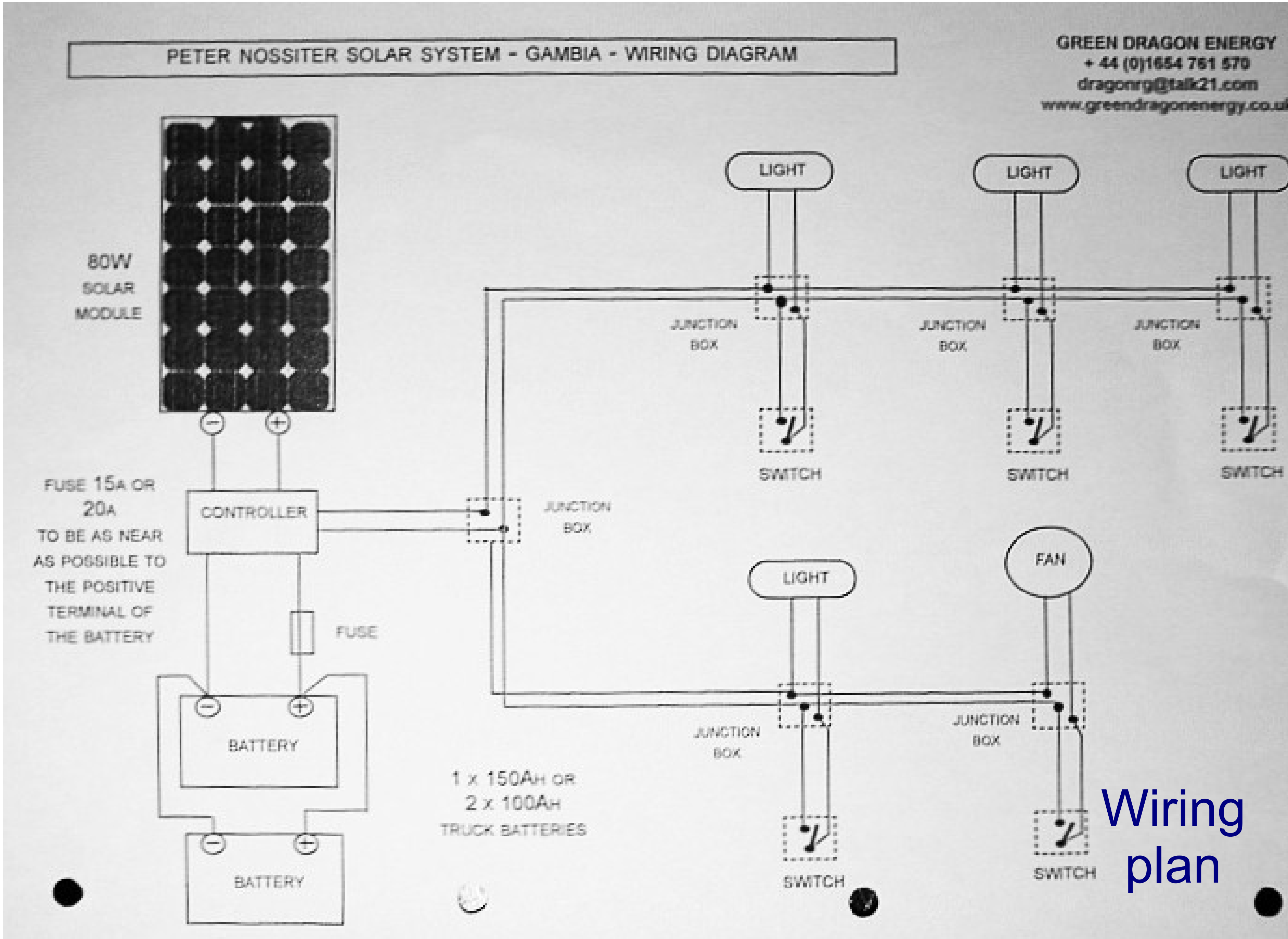
- Overhead (with catenary)
  - UV resistant
- Underground
  - Armoured cables
  - Separate earth
  - Tape / sand

STAND-ALONE SYSTEMS
- PLANING & WIRING IN THE CORRECT SEQUENCE


PETER NOSSITER SOLAR SYSTEM - GAMBIA - SCHEMATIC/CABLE PLAN
GREEN DRAGON ENERGY
+ 44 (0)1654 761 570
dragonrg@talk21.com
www.greendragonenergy.co.uk
80 W SOLAR MODULE
USE BOXES WITH 30A CONNECTOR BLOCKS RATHER THAN USUAL JUNCTION BOXES
LIGHT
LIGHT
LIGHT
2.5MM2
2.5 MM2
2.5MM2
JUNCTION BOX
JUNCTION BOX
JUNCTION BOX
SWITCH
SWITCH
SWITCH
6MM2 MINIMUM
CONTROLLER
2.5MM2
JUNCTION BOX
IF CABLE RUN FROM FROM BATTERY TO LAST JUNCTION BOX ON ANY BRANCH IS MORE THAN 10M USE 4MM2 CABLE INSTEAD OF 2.5MM2
LIGHT
FAN
6MM2 MINIMUM
FUSE
2.5MM2
2.5MM2
JUNCTION BOX
JUNCTION BOX
BATTERY
CABLE RUN FROM SOLAR MODULE TO BATTERY TO BE AS SHORT AS POSSIBLE. IF MORE THAN 7M, USE 10MM2 CABLE
SWITCH
SWITCH

Cable plan

Wiring plan

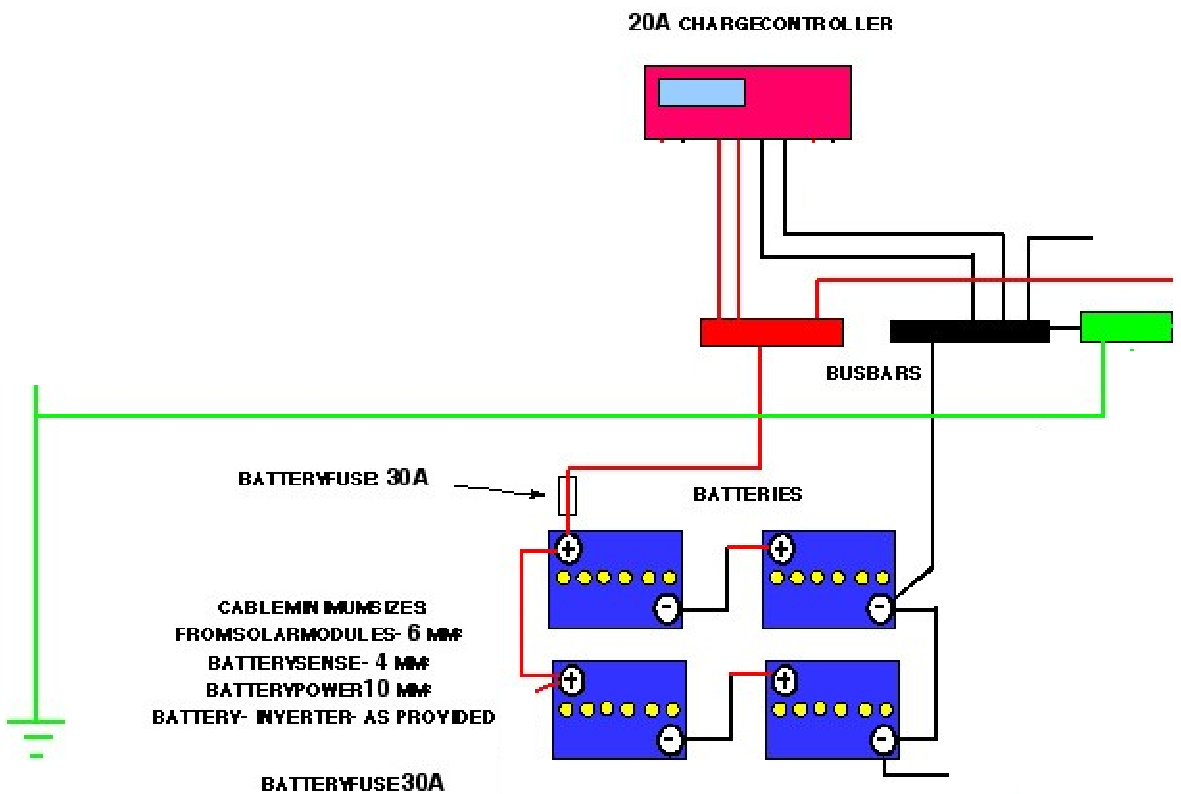


PETER NOSSITER SOLAR SYSTEM - GAMBIA - WIRING DIAGRAM
GREEN DRAGON ENERGY
+ 44 (0)1654 761 570
dragonrg@talk21.com
www.greendragonenergy.co.uk
80W SOLAR MODULE
LIGHT
LIGHT
LIGHT
JUNCTION BOX
JUNCTION BOX
JUNCTION BOX
SWITCH
SWITCH
SWITCH
FUSE 15A OR 20A TO BE AS NEAR AS POSSIBLE TO THE POSITIVE TERMINAL OF THE BATTERY
CONTROLLER
JUNCTION BOX
FAN
LIGHT
FUSE
BATTERY
BATTERY
1 x 150AH OR 2 x 100AH TRUCK BATTERIES
JUNCTION BOX
JUNCTION BOX
SWITCH
SWITCH

Connection and disconnection sequences

- The wiring of the different parts of a stand-alone electrical system should be carried out in the correct sequence
- The work should be planned
- All manuals should be referred to and instructions followed
- Systems should also be dismantled in the correct sequence
- Not following the correct sequence can damage equipment
- The following is a example only

Connect batteries to charge controller



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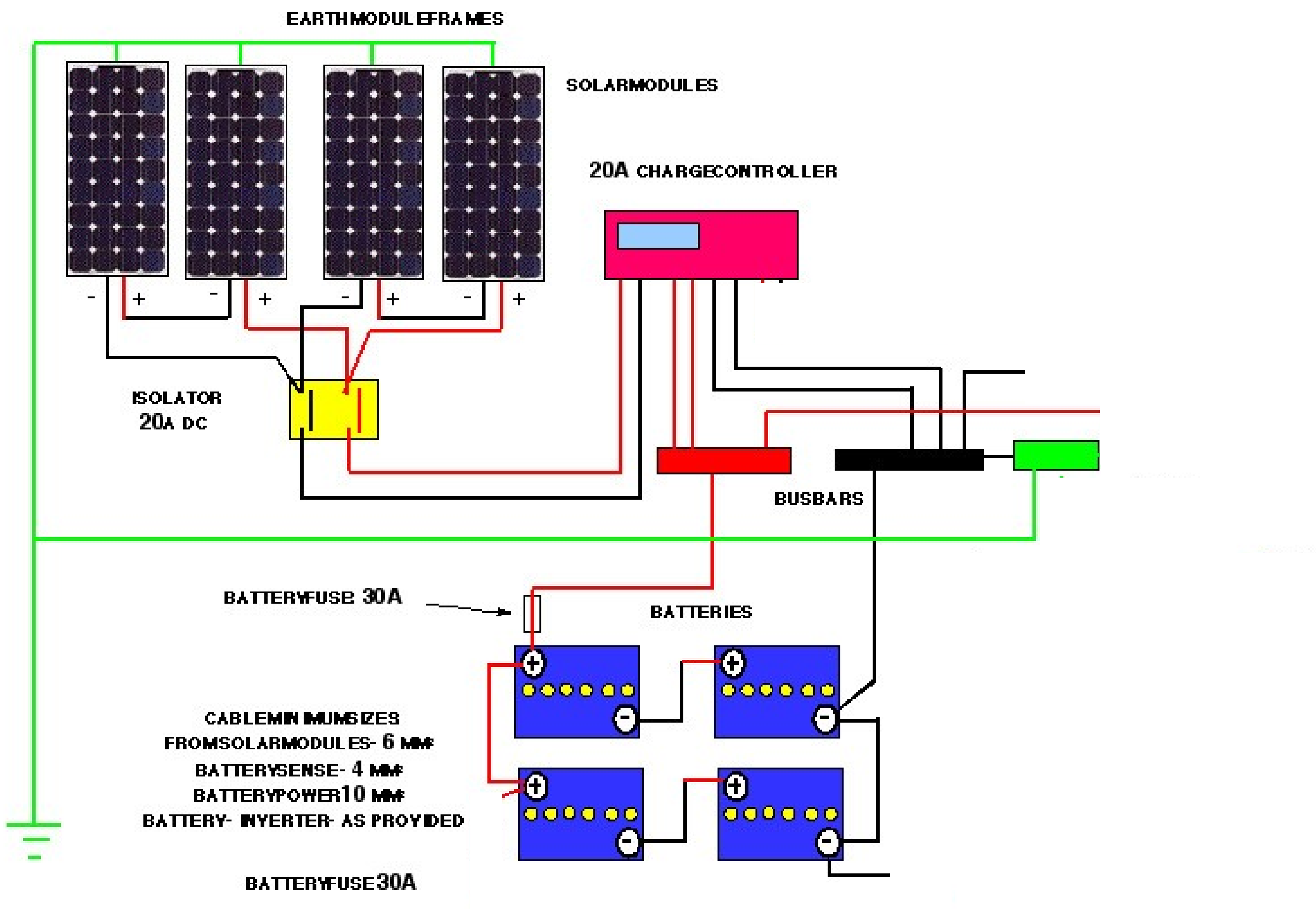
Connect solar modules to charge controller



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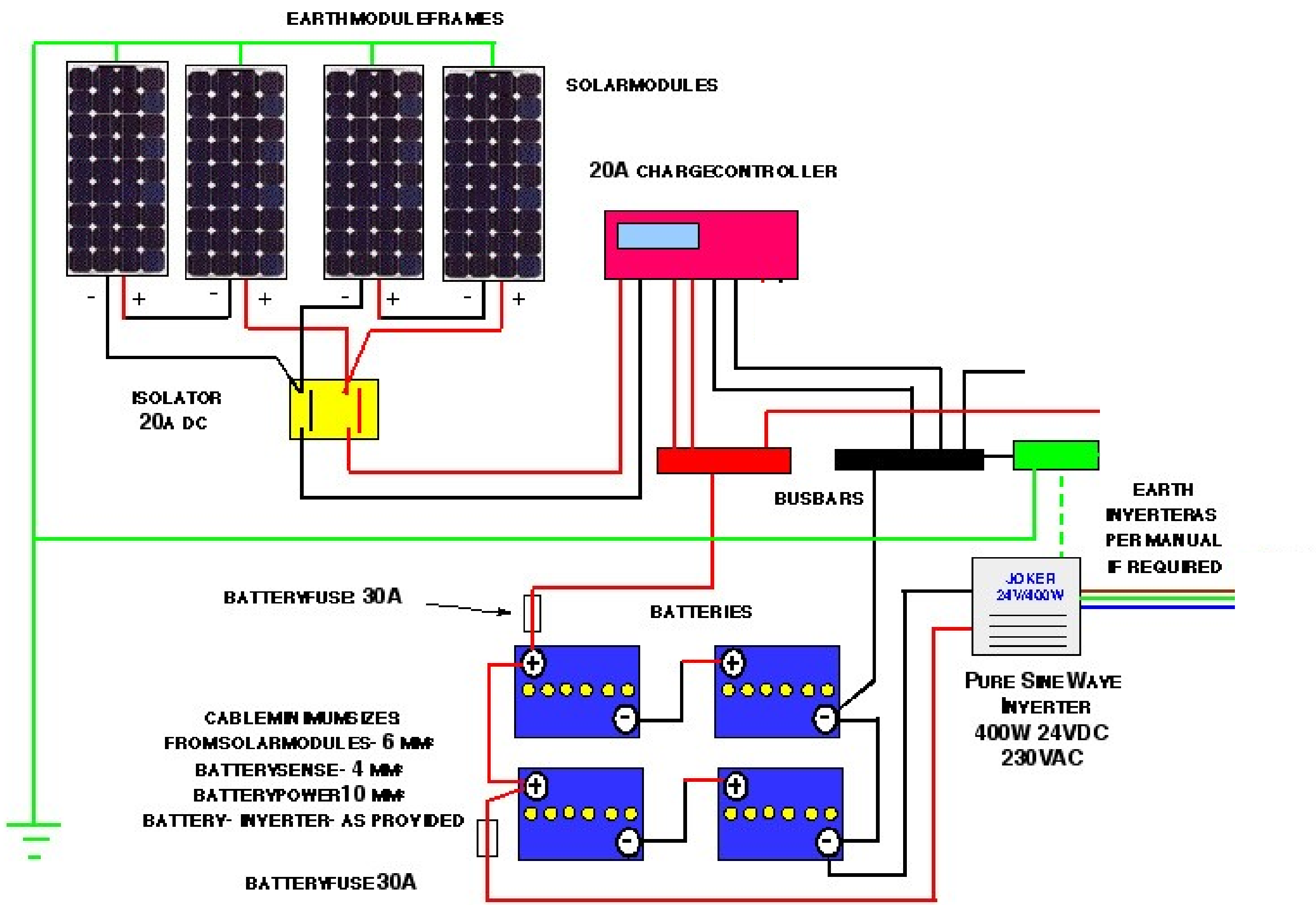
Connect inverter to batteries



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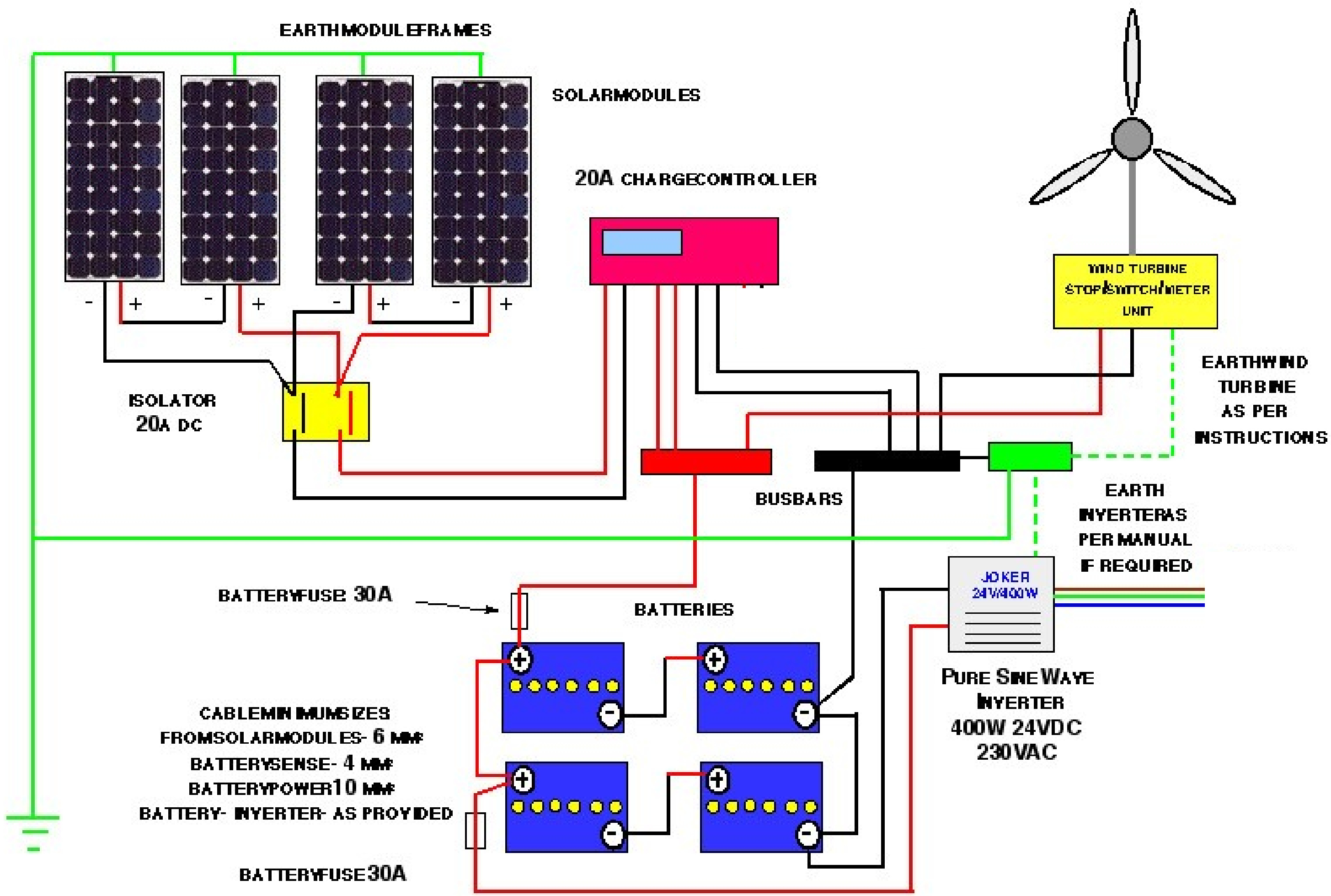
Connect wind turbine



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Connect final distribution circuits