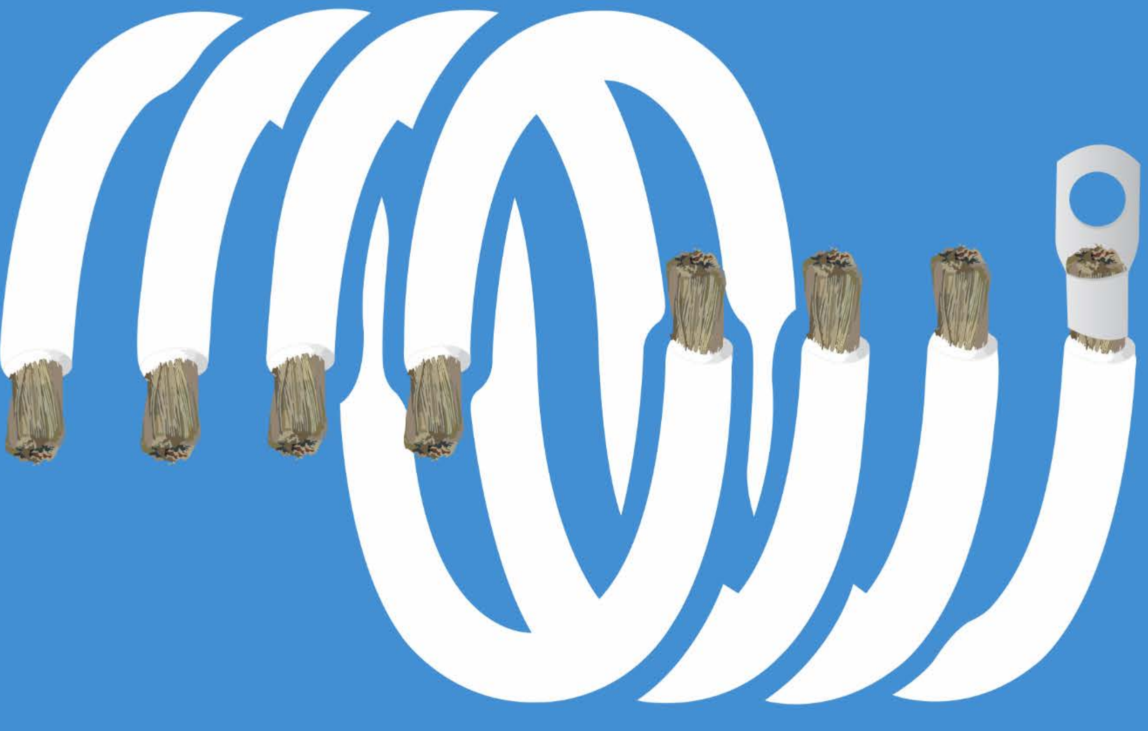
Wiring Unlimited



victron energy
BLUE POWER

Wiring Unlimited

Contents

1. Introduction and Disclaimer

For a trouble-free operation of a system containing inverter/chargers and batteries, it is essential that the wiring in the system is done correctly. Many system problems are due to bad wiring. A system might underperform due to sub-standard wiring on both the DC or the AC side.
In this document we aim to explain about wiring, the importance of getting it right and assist the installer in making the correct choices.

We would like to acknowledge that electrical wiring regulations are different based on where you are in the world. Local electrical regulations can differ from the wiring advice given in this document. It is your responsibility to always seek professional advice and instruction form local authorities and/or licensed electricians prior to commencing any electrical work.

The sole purpose of this document is to aid in the understanding of basic principles behind certain electrical concepts. This document is intended as a guide only.

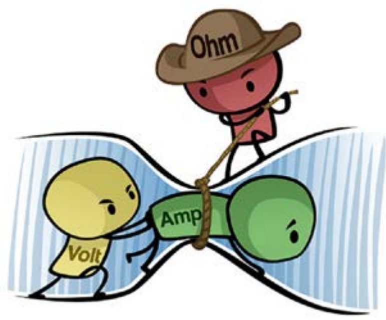
2. Theory

To be able to understand the underlying factors are that determine wiring thickness and fuse ratings. You do need to know some basic electrical theory. You might already know this and can perhaps skip this chapter, but we highly recommend that you at least have a read.

2.1 Ohm's Law

This basic electrical law allows you to be able to calculate the current that runs through a cable or a fuse at different voltages.

Electricity is movement of electrons. When you pass electricity through a material it meets a certain resistance. When the resistance is low the elections move easily, and the current is high. When the resistance is high the electrons move slow or do not move at all and the current is low.



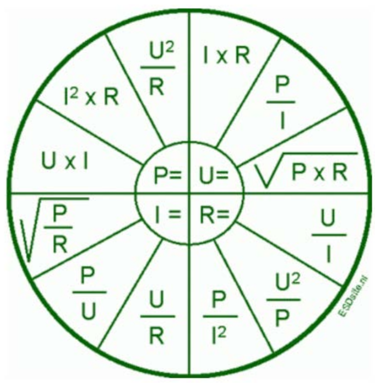
The resistance determines how much current runs through a material at a given voltage. This can be represented in a formula. The formula is called Ohm's Law:

Current (A) = Voltage (V) / Resistance (Ω)

I = V/R

2.2 Power

Ohms law can be used to derive other formulas. All possible formulas are listed in the image on the right. Please note that there are two symbols in use in the world that represent Voltage. These are U or V.



Some of these formulas are very useful when calculating current in cables.

One often used formula is this formula. **I = P/V**

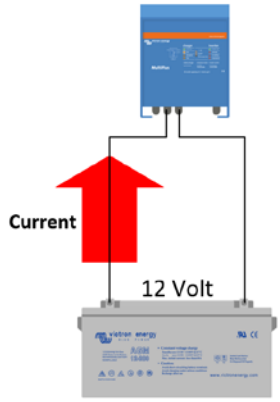
It calculates the current through a cable when the voltage and the load is known:

An example of how this formula can be used:

Question:
If we have a 12V battery that is connected to a 2400 W load.
How much current is running through the cable?

Answer:
V = 12V
P = 2400W

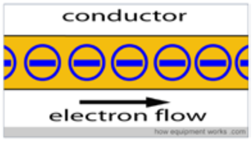
I = P/V = 2400/12 = 200 A



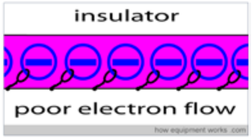
2.3 Conductivity and resistance

Some materials conduct electricity better than other materials. Materials with a low resistance conduct electricity well, and materials with a high resistance conduct electricity poorly, or not at all.

Metals have a low resistance and they conduct electricity well. These materials are called conductors. This is the reason they are used in electrical cables.



Plastic or ceramics have a very high resistance, they do not conduct electricity at all. They are called insulators. This why, for example, plastic or rubber is used on the outside of cables. You will not get an electrical shock when you touch the cable. Insulators are also used to prevent short circuit when two cables touch each other.



Each material has its own specific resistance. This is written down as rho (ρ). In Ω.m. The table on the right on the right lists various conducting materials, their electrical conductivity and their specific resistance. You can see in this table that copper conducts electricity well and has a low resistance. This is the reason why electrical cable is made from copper. But, for example, titanium, does not conduct electricity well and therefor has a higher specific resistance.

TIBTECH	Electrical conductivity (10.E6 Siemens/m)	Electrical resistivity (10.E-8 Ohm.m)
Silver	62,1	1,6
copper	58,5	1,7
Gold	44,2	2,3
Aluminium	36,9	2,7
Molybden	18,7	5,34
Zinc	16,6	6,0
Lithium	10,8	9,3
Tungsten	8,9	11,2
Brass	15,9	6,3
Carbon (ex PAN)	5,9	16,9
Nickel	14,3	7,0
Iron	10,1	9,9
Palladium	9,5	10,5
Platinium	9,3	10,8
Tin	8,7	11,5
Bronze 67Cu33Sn	7,4	13,5
Carbon steel	5,9	16,9
Lead	4,7	21,3
Titanium	2,4	41,7

There are two more factors that determine cable resistance. These are the length and the thickness of the conductor (cable):

- A thin cable has a higher resistance than a thick cable
- A long cable has a higher resistance than a short cable

The resistance of a length of cable can be calculated:

Resistance = Rho x $lenght/Area$

R= ρ x l/A

As you can see there are 3 factors that determine cable resistance. Namely:

- The electrical resistance of the used material
- The length of the cable (longer cable = more resistance)
- The diameter of the cable (thinner cable = more resistance)

It is important to know the resistance of a cable. Cable resistance creates two effects when a current is passed through a cable:

- There will be a voltage loss over the cables
- The cables heat up

If the current is increased these effects will be worse. The voltage loss increases, and the cable heats up more.

This is how to calculate the resistance of a cable:

Question:
What is the resistance of a 1.5-meter-long, 16 mm^2 cable?

Given:
ρ copper = 1.7 x 10-8 Ω/m
l = 1.5 m
A = 16 mm2 = 16 x 10-6 m^2

Answer:
R = ρ x l/A
R = $1.7 \times 10^{-8} \times 1.5/(16 \times 10^{-6})$
R= $1.7 \times 10^{-2} \times 1.5/16$
R = $0.16 \times 10^{-2} = 1.6 \times 10^{-3}$
R = 1.6 m Ω

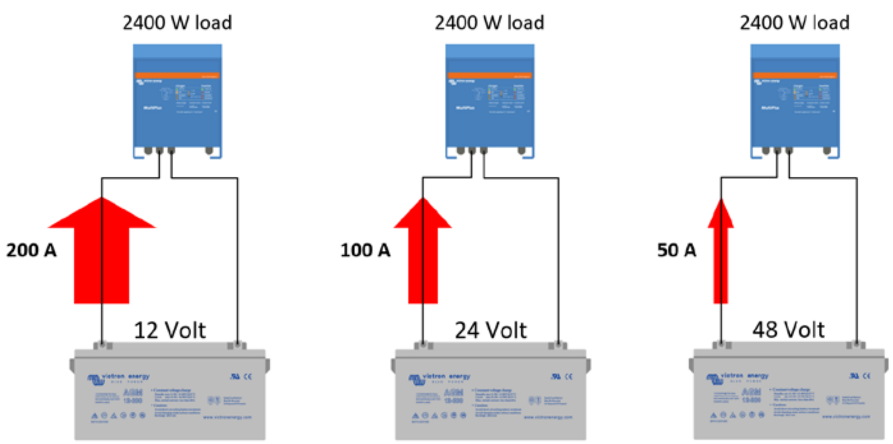
The effect of cable length:
Let's take above example and now calculate for a 5m long cable. The result will be that the resistance is 5.3 mΩ. If you make the cable longer the resistance increases.

The effect of cable thickness:
Let's take the original example and now calculate for a 2.5m^2 cable. The result will be that the resistance is 10.2 mΩ. If you make the cable thinner the resistance increases.

Conclusion:
Both cable thickness and cable length have a big impact on cable resistance. Please read next chapter what the effect of a high cable resistance is.

2.4 Current, cable resistance and voltage drop

To be able to select the right cable thickness and you will need to know how to much current runs through that cable. The current that flows through a system varies depending on the system voltage. The higher the voltage the lower the current is.
Below is an overview of the amount of current that run in 3 systems where to load is the same, but the battery voltage varies:



As we have seen before, a cable has a certain amount of resistance.

When current flows through a resistor, the resistor heats up. These are called cable losses. Power is lost in the form of heat. The lost power can be calculated with the following formula:

Power = Resistance x Current^2

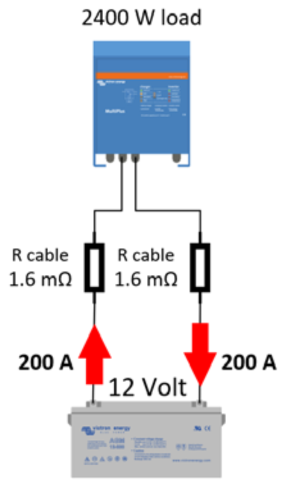
$P = R \times I^2$

Another effect of cable losses is that a voltage drop will be created over the cable. The voltage drop can be calculated with the following formula:

Voltage = Resistance x Current

$V = R \times I$

We now will add cable resistance to the system we used previously. In the circuit diagram on the right we have added two cables with a 1.6 mΩ resistance.



The current that flows through each resistive element in a series electrical circuit remains the same while there will be a voltage drop over each element of which the sum equals the total voltage. This is called the Law of Kirchhoff.

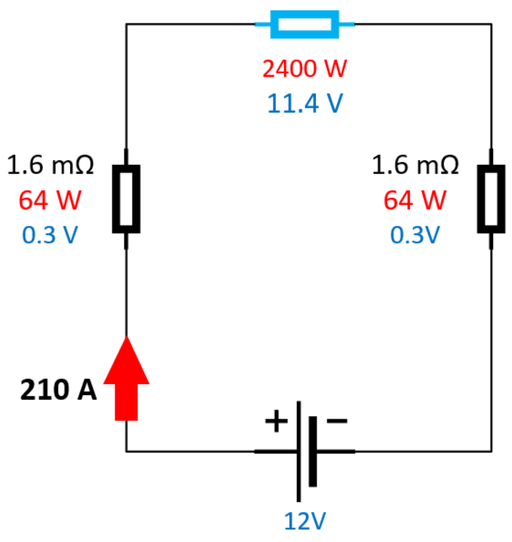
Knowing this we can calculate the voltage drop over one cable:

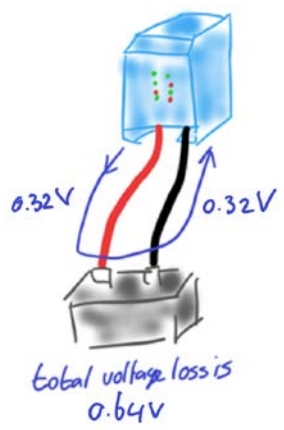
- A 2400W load at 12V creates a current of 200 A
- The voltage drop over one cable is: V = I x R = 200 x 0.0016 = 0.32 V

Because we have two cables, the total voltage loss in this system is 0.64 V

This also means that the inverter does not get 12V anymore, but 11.4V

The load is a constant in an inverter system, so the battery needs to deliver more current to compensate for the losses.
In this example this means that the current will increase to 210 A.





When designing a system, you will always keep in mind that voltage drop varies for different battery voltages.

If we look at the same 2400 W load, but now in a 24V system:

- The 2400 W load @ 24V will create a current of 2400/24 = 100A
- The total voltage drop will be 2 x 100 x 0.0016 = 0.32 V (= 1.3%)

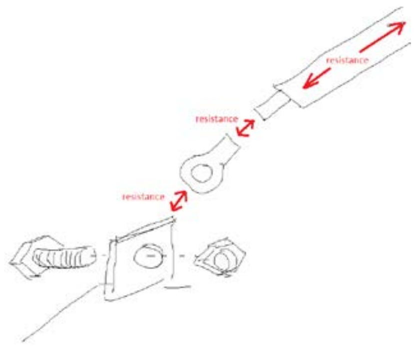
And at 48V the current is 50A. The voltage drop is 0.16 V (= 0.3%)

Battery voltage	Percentage drop	Voltage drop
12 V	2.5 %	0.3 V
24 V	2.5 %	0.6 V
48 V	2.5 %	1.2 V

This leads to the next question; how much voltage drop is allowed? The opinions vary somewhat, but we advise to aim for voltage drop no bigger than 2.5 %. For the different voltages this is indicated in the table on the right.

It is important to realize that resistance does not only occur in the cable itself, but additional resistance is created by any items in the path of the current. This is a list of possible items that can add to the total resistance:

- Fuses
- Shunts
- Switches
- Cable lug crimps
- Connections



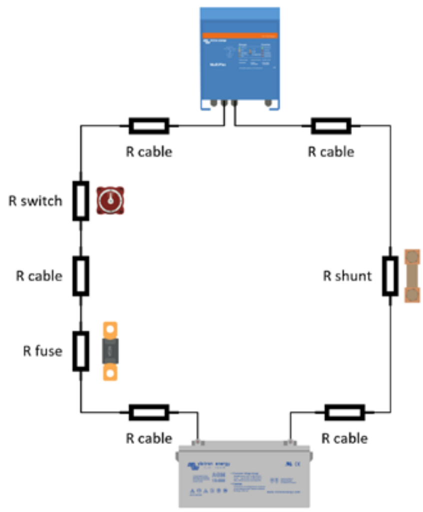
And especially watch out for:

- Loose connections
- Dirty or corroded contacts
- Bad cable lug crimps

Each time a connection is made, or something is placed in the path between battery and inverter resistance is added.

To give you some idea how much these resistances can be:

- Each cable connection: 0.06 mΩ
- 500A shunt: 0.10 mΩ
- 150A fuse: 0.35 mΩ
- 2m 35mm² cable: 1.08 mΩ



2.5 Negative effects of cable voltage drop

We now we know that we need to do to keep resistance down to prevent a voltage drop. But what are the negative effects of a high voltage drop in a system?
This is a list of the negative effects of a high voltage drop:

- Energy is lost and therefore the system efficiency is reduced
- All devices connected to the system have a shorter lifetime because of DC ripple.
- The system current will increase. This can lead to DC fuses blowing prematurely.
- High system currents can lead to premature inverter overloads.
- Voltage drop during charging will cause batteries to get undercharged.
- The inverter receives a lower battery voltage. This this can potentially trigger low voltage alarms
- The battery cables can heat up.

This is how to prevent voltage losses:

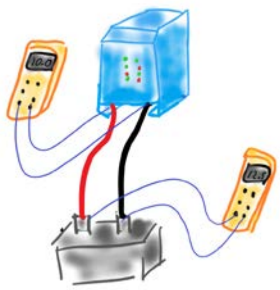
- Use as short as possible cable lengths
- Use cables with sufficient cable thickness
- Make tight connections (but not too tight, follow torque recommendations in the manual)
- Check that all contacts are clean and not corroded
- Use quality battery isolator switches
- Reduce the amount of connections within a cable run
- Use DC distribution point or busbars

It is good practice to measure the system voltage drop. But Remember that a voltage drop only occurs at high current events. This is when an inverter is loaded with maximum load or when a battery charger is charging at full current.

This is how to measure voltage drop:

- Load the DC system with maximum power.
- Measure with a voltmeter in the negative cable between the connection inside the unit and the battery pole
- Repeat this for the positive cable

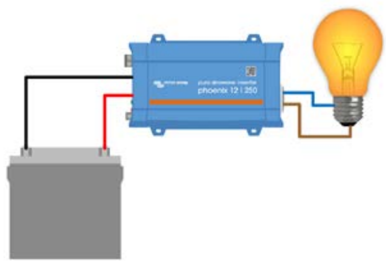
In case of the battery and the unit being too far away or in a different room or enclosure:



- Load the DC system with maximum power.
- Measure with a voltmeter across the DC connections inside the unit
- Measure arcos the battery poles
- Compare these readings

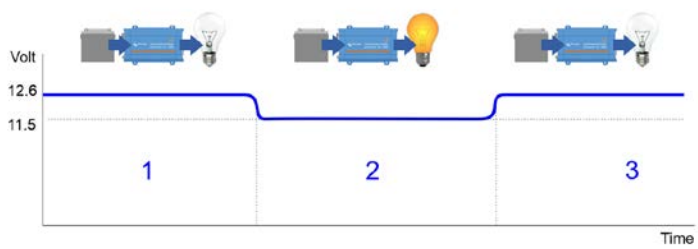
2.6 DC ripple

One of the negative effects of high voltage drop in a system is ripple. Ripple appears in a system were the power source is a battery (DC) and the load is AC device. This is always the case in a system with an inverter. The inverter connects to batteries, but it powers an AC load.
Ripple is directly related to the voltage drop over the DC cables when a system is under load and the battery currents are high. A high current causes a high voltage drop and this means that there will be a high ripple in the system.



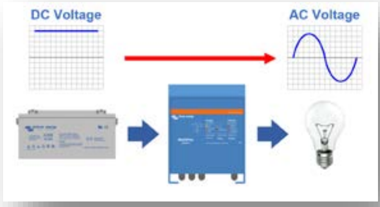
The mechanism that causes ripple is an alternating voltage drop. The voltage drops when the system is feeding a load. And once the load is turned off the voltage recovers. And then drop again, recovers, drops and so on and on….
The voltage drop can be made worse if lead acid batteries are used, especially when these are too small or when they are too old or when they are damaged.
This process is depicted in the drawing on the right.

1. The voltage measured at the inverter is normal. In this example 12.6V
2. When a large load is turned on the battery voltage drops to 11.5 V
3. When the load is turned off, the battery voltage usually recovers back to 12.6V

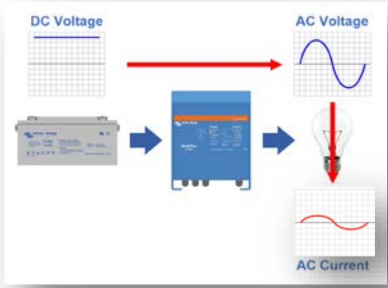


How is ripple created?

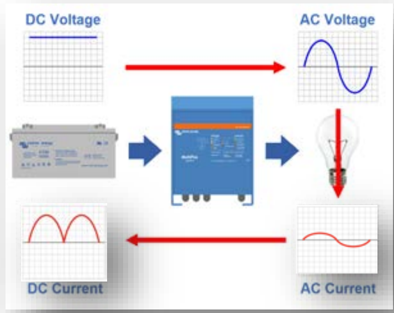
1. The inverter converts DC voltage into an AC voltage.



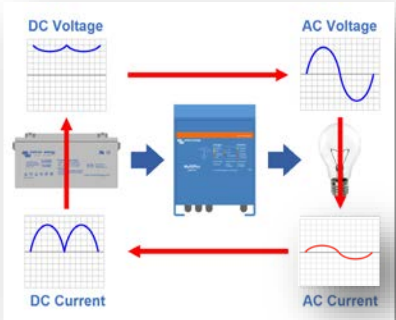
2. The load connected to the inverter creates an AC current in the inverter.



3. This AC current causes (via the inverter) a fluctuating DC current on the battery.

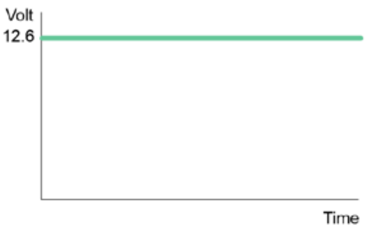


4. The result of this fluctuating DC current is the following
   - When the DC current peaks the battery voltage will drop.
   - When the DC current drops the battery voltage recovers
   - When the DC current peaks the battery voltage will drop again
   - And so on.

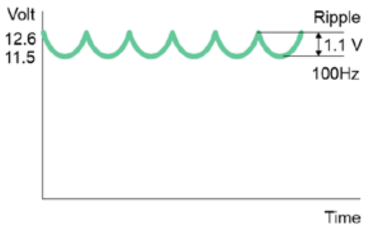


The DC voltage will keep going up and down and is not constant anymore.
It now is fluctuating. It will go up and down 100 times per second (100Hz). The amount the DC voltage fluctuation is called ripple voltage.

Normal DC looks like this:



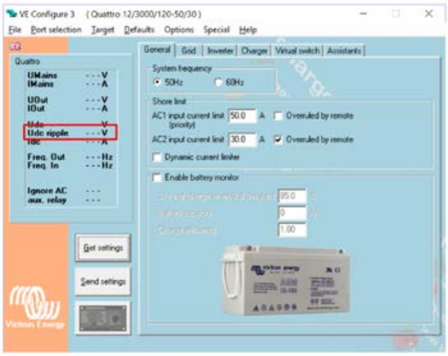
DC voltage with ripple looks like this:

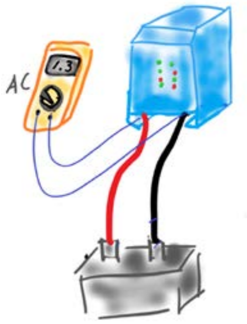


It is possible to measure ripple. There are two ways:

- Use a Multi meter. Put multimeter in AC mode and measure the DC close to the inverter.
- Use VE Configure, it keeps track of ripple

When measuring remember that ripple only occurs when the system is under load. The same as for voltage drop, it can only be detected when the system is under full load or is when it is charging at full current.





A small amount of ripple can exist with no measurable impact. However, an excessive ripple can have a negative impact:

- The lifetime of the inverter will be reduced. The capacitors in the inverter will try to flatten the ripple as much as possible and as a result the capacitors will age faster.
- The lifetime of the other DC equipment in the system will be reduced as well. They too suffer from ripple
- The batteries will age prematurely, each ripple acts a mini cycle for the battery. Due to the increase in battery cycles the battery lifetime will reduce
- Ripple during charging will reduce the charge power

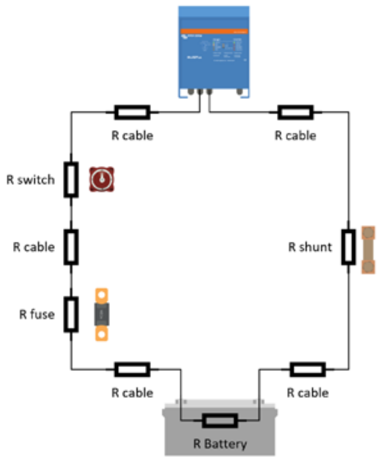
Inverters or inverter/chargers have a built-in ripple alarm. There are two ripple alarm levels:

- Ripple pre-alarm: Both the overload and the low battery LEDs blink and the unit will turn of after 20 minutes.
- Full ripple alarm: Both the overload and low battery LEDs are on and the unit powers down.

These are the ripple alarm levels for the different voltages:

	12V	24V	48V
Ripple pre-alarm	1.5V	2.25	3V
Full ripple alarm	2.5V	3.75	5V

The only reason ripple exits is when there is a voltage drop in a system. To fix ripple you will have to reduce the resistance in the path from battery to inverter and back to the inverter. For more seen chapter 2.5.



To fix high ripple in a system do the following:

- Reduce Long battery cables
- Use thicker cables
- Check Fuses, shunts and battery isolator switches
- Check for loose terminals and loose cable connections
- Check for dirty or corroded connections
- Check for bad, old or too small batteries

3. Battery bank wiring

3.1 Battery bank

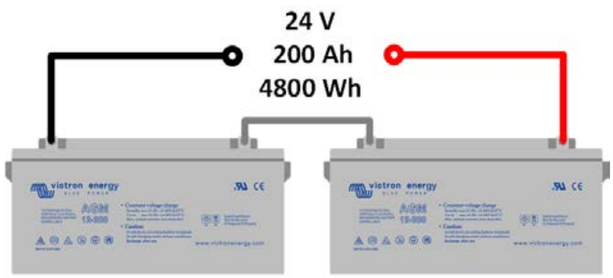
At the heart of any Victron system is the battery. A battery bank can consist out of a single battery but can also consist out of multiple batteries that are connected to form a battery bank. Commonly referred to as the house battery. The reason for doing this is to either increase the battery voltage, increases the battery capacity or both.

A battery bank is when:

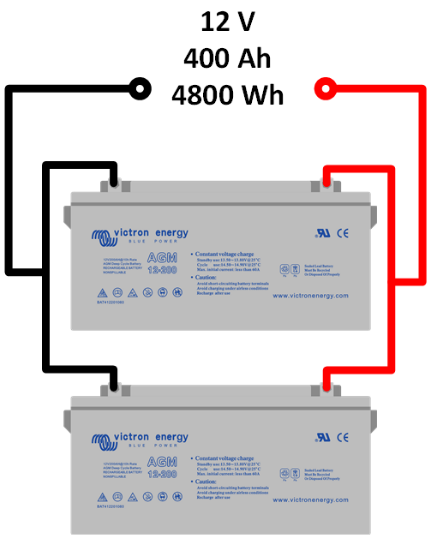
- When two batteries are connected in series their voltage increases.
- When 2 batteries are connected in parallel their capacity increases.
- Series/parallel combinations are also possible.

Some examples:

Single battery

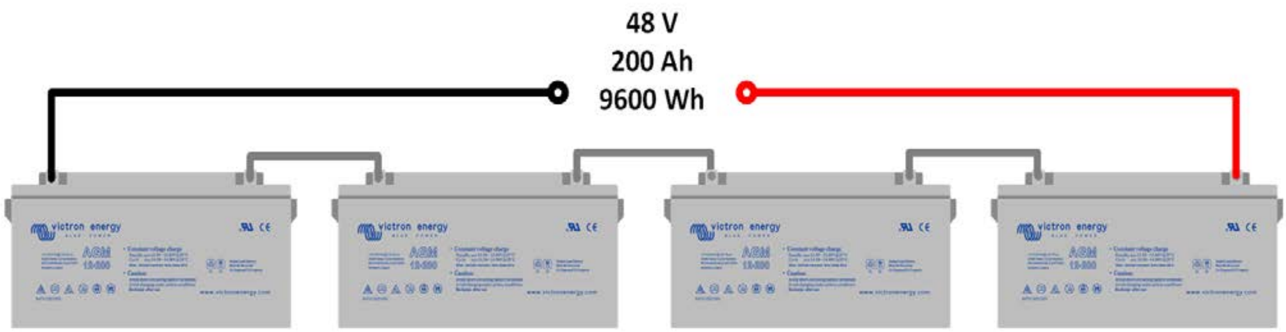


Two batteries in series



Two batteries in parallel

Four batteries in series/parallel



Four batteries in series

3.2 Large battery banks

When a large battery bank is needed try to avoid numerous series parallel battery banks constructed out of 12V AGM or Gel batteries. In these cases, consider using 2V lead acid batteries, Victron lithium batteries, smart Lithium batteries or smart other chemistry batteries.

2V lead acid batteries

2V OPzV or OPzS batteries are available in a variety of large capacities. You only have to pick the capacity you want and connect them in series. They are supplied with dedicated connection links exactly for that purpose.

Basic Lithium batteries

With internal or external BMS.

Smart Lithium batteries

Each battery has their own battery management system.

Together they will generate a total state of charge value for the whole battery bank. A Venus monitoring device is needed in the system.

More info on what brands can work with Victron see:
https://www.victronenergy.com/live/battery_compatibility:start

Other chemistry batteries

Flow batteries and other chemistries. Commonly available in 48V. Multiple batteries can connect in parallel without any issues. Each battery has their own battery management system. Together they will generate a total state of charge value for the whole battery bank. A Venus monitoring device is needed in the system.

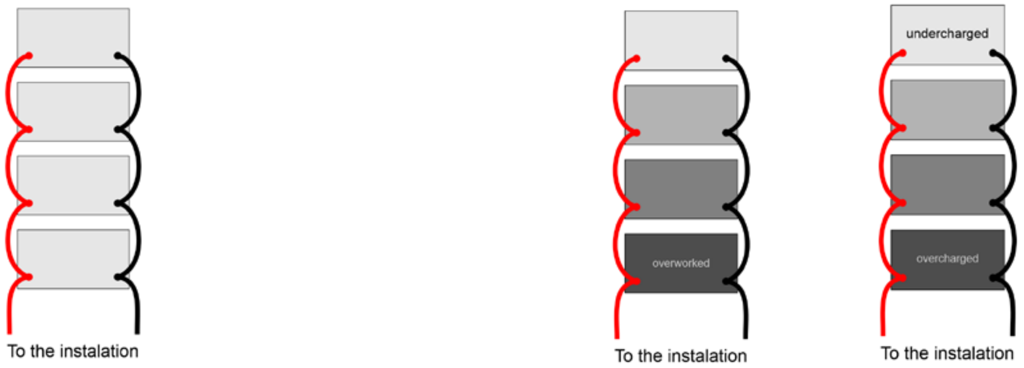
More info on what brands can work with Victron see:
https://www.victronenergy.com/live/battery_compatibility:start

3.3 Parallel battery bank wiring

It matters how a battery bank is wired into the system. It is easy to make a mistake. One of the most common mistakes is to parallel all the batteries together and then connect one side of the parallel battery bank to the installation. As indicated in below image.

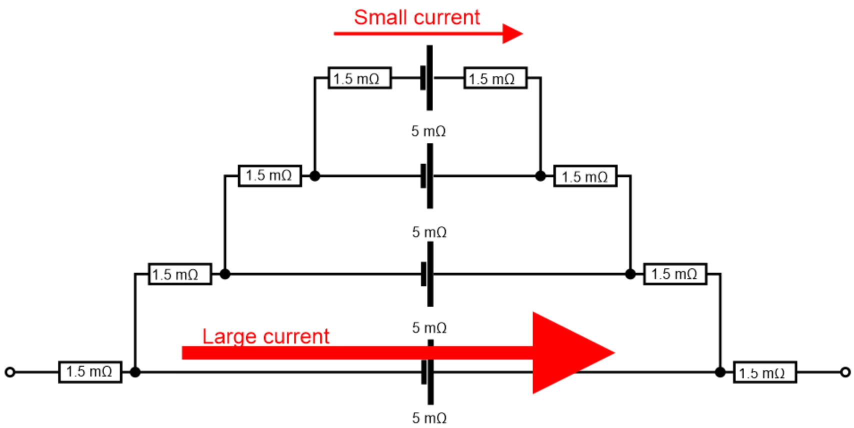
What happens when a load is connected? The power coming from the bottom battery will only travel through the main connection leads. The power from the next battery has to travel through the main connection and through the 2 interconnecting leads to the next battery. The next battery up has to go through 4 sets of interconnecting leads. The top one has to go through 6 sets of interconnecting leads. The top battery will be providing much less current than the bottom battery.

What happens if the battery bank is being charged? The bottom battery gets charged with a higher current than the top battery. The top battery gets charged with a lower voltage than the bottom battery. The result is that the bottom battery is worked harder, discharged harder, charged harder. The bottom battery will fail prematurely.

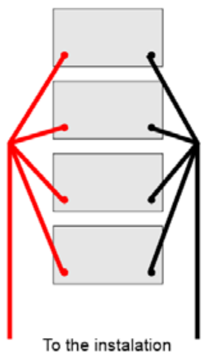


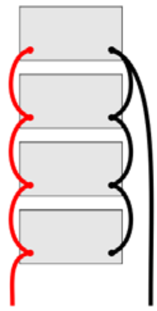
Why is cable resistance important when wiring battery banks? Remember that a cable is a resistor. The longer the cable, the higher the resistance. And cable lugs and battery connections also add to this resistance.

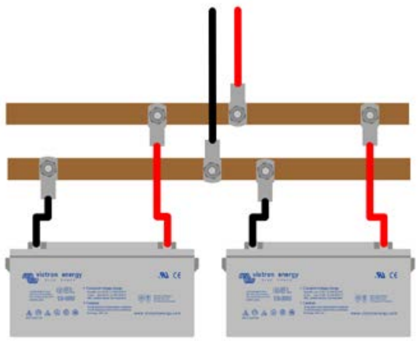
To give an indication of this, the total resistance for a 20cm 35 m^2 cable together with its cable lugs is about 1,5 mΩ. You might say that 1.5 mΩ is not much. But the internal resistance of the actual battery is also low. Therefore, it does matter a lot! The internal resistance of a battery is typically between 10 to 3 mΩ. If you construct an electrical diagram it will look like this:
Current always chooses the path of least resistance. Most of the current will travel through the bottom battery. And only a small current will travel through the top battery.



The correct way of connecting a multiple parallel battery bank is indicated in below drawings. Use a positive and negative post, connect diagonally or use busbars. The main aim is to make sure the total path of the current into each battery is equal.

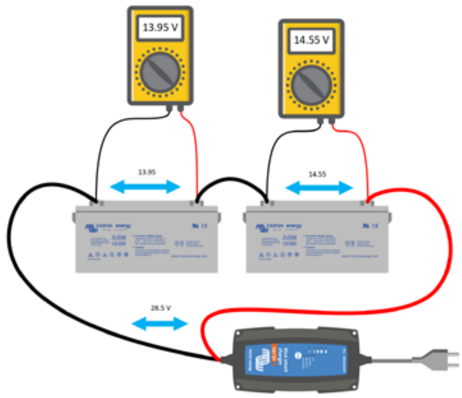






3.4 Battery bank balancing

Multiple 12V batteries can be connected in series to create a higher voltage like 24V or 48V. Only batteries are not completely identical and have minute differences in internal resistance. When a series string of batteries is charged you can end up with a variance in terminal voltages on each battery. This will cause the batteries to become unbalanced over time, and one of the batteries in a string will fail prematurely.

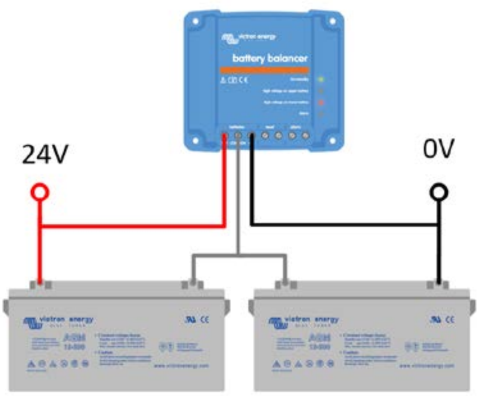


To check if cell unbalance is happening in your system:

- Charge the battery bank.
- Measure at the beginning of the bulk charge stage. This is when the charger is charging at full current.
- Measure the individual battery voltages of one battery.
- Measure the individual battery voltages of the other battery.
- Compare the voltages.
- If there is a noticeable difference between these voltages, then the battery bank is unbalanced.

To prevent initial battery unbalance you will need to fully charge each individual battery prior to connecting them in series (and/or parallel). to prevent unbalance in the future as the batteries are aging use a Battery balancer.

The battery balancer balances measures, warns and corrects battery imbalance. When a 24V battery bank is charged, and the voltage has reached 27V, the Battery Balancer will turn on. It will compare the voltage of both batteries and if it detects that the voltage of one battery is higher than the other battery it will draw a current of up to 1 A from the battery until the voltages are the same again.



For a 24V system a single battery balancer is needed. And for a 48V system 3 battery balancers are needed, one between each two batteries.

For more info see:
https://www.victronenergy.com.au/batteries/battery-balancer

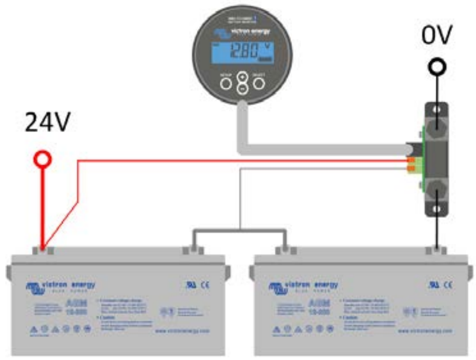
3.5 Battery bank midpoint

Battery unbalance can be detected by looking at the midpoint of a battery bank. If the midpoint is monitored it can be used to generate an alarm.

A midpoint alarm can mean the following:

- An individual battery has failed, like an open cell or short-circuited cell
- End of battery life due to sulfation or shedding of active material
- Equalization is needed (only for wet cells)

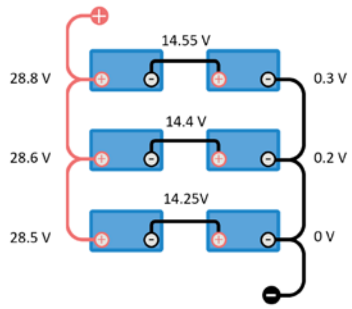
Both the battery balancer and the BMV 702 and 712 can generate a midpoint alarm.



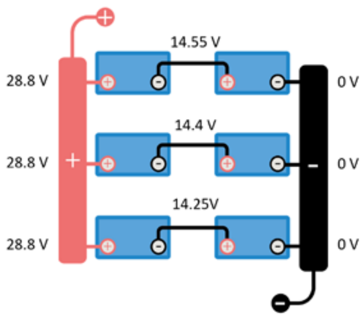
The BMV 702 and 712 have a second voltage input that can be used for midpoint monitoring. It can be wired to the mid-point of the battery bank. The BMV will display the difference between the two voltages or as a percentage. For more info see: https://www.victronenergy.com.au/battery-monitors/bmv-700

In series/parallel battery banks it can be helpful to connect the midpoints of each parallel series string. The reason to do is to eliminate unbalance within the battery bank.

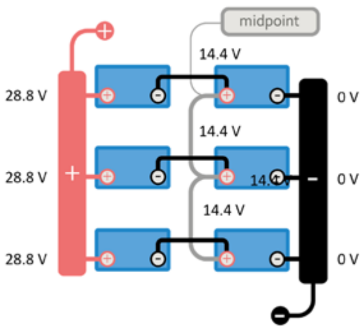
If you connect batteries in series/parallel, like the image on the right, you will see that the individual voltages will vary per series string and they will also vary within the string.



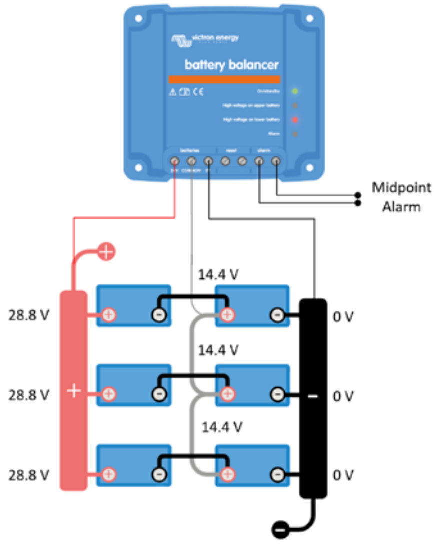
First make sure that each string has the same voltages by using a common negative and positive connection point or busbar



Once each string voltage is equal the midpoints can be connected.
Make sure that the midpoint cabling is able to carry the full current between the batteries.

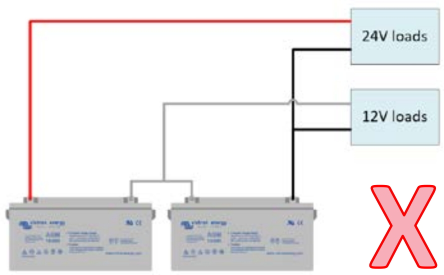


Once the midpoint of the battery bank is connected one battery balancer can be used, instead of using 3 battery balancers (one for each string). Also, a single BMV can be used for midpoint monitoring of the entire batetry bank.

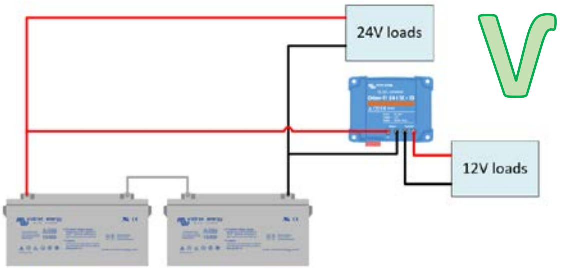


But please be aware, that the only reason to use the midpoints of a battery bank is for balancing and/or monitoring purposes. It is not allowed to connect loads to the midpoint of a battery bank in order to be able to run loads that require a lower voltage. Doing so will create a large imbalance in a battery bank. This imbalance is bigger than a battery balancer can rectify (larger than 1A). The battery that is used to provide the lower voltage will fail prematurely.

For example, do not do this:



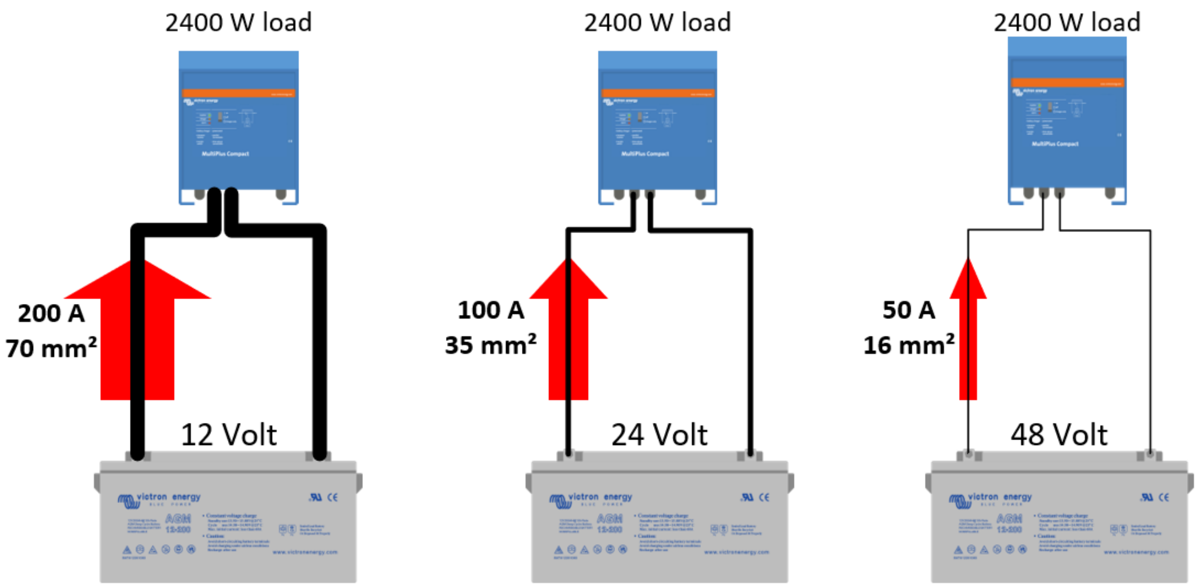
But instead use an Orion DC /DC converter:



4. DC wiring

4.1 Select the right cable

It is important to use the correct cable thickness in a system. The correct cable can only be selected once you know the currents in a system. This is an example of what cable size belong to these currents. Providing the cable distance is less than 5 meters.



In order to avoid very thick cables, the first thing you should consider is to increase the system voltage. Large systems mean large currents. If you increase the system voltage the current will drop. The preferred upper inverter power limits per system voltage are:

- 12V: up to 3000VA
- 24V: up to 5000VA
- 48V: 5000 VA and up

Remember, that in case you have some loads or charge sources that only can deal with 12V, you can use DC/DC converters, rather than to choose a low voltage for the entire system.

As explained already, it is very important to always use the right cable thickness. The correct cable thickness as mentioned in the product manual. Using too thin cabling has a direct effect on system performance.

Generally, cable core thickness is indicated in mm². This indicates the surface area of the cable core. But other annotations are used as well. Like AWG (American Wire gauge) is used. In that case see here for a conversion table.

To find out the core dimeter of a stranded core cable, look on the cable insulation. There will be markings on the cable that indicate cable core thickness. Be aware that some cables can have very thick insulation and they may appear thicker than they are.

In a solid cable you can calculate the surface area if you measure the diameter of the cable core, but in a stranded cable this might not possible. (Please note that we do not recommend using solid core cables).

Surface area = π x raduis²

Surface area = π x (diameter/2) ²

A = π x (d/2)²

$$\text{Surface area} = \pi \times \text{raduis}^2$$

$$\text{Surface area} = \pi \times (\text{diameter}/2)^2$$

$$A = \pi \times (d/2)^2$$

If you cannot find the right cable, double up. Use two cables per connection, rather than one very thick one. But the combined surface area of both cables has to be equal to the recommended surface area. For example, 2 x 35 mm^2 cables equals a 70mm^2 cable. Our bigger inverter/chargers have 2 connections for positive and negative in our larger units. It is okay to double up cable

Use as short as possible cable lengths
Avoid these mistakes:

- Don't use cable with course strands
- Don't use non-flexible cable
- Don't use AC cable
- For marine use marine rated cable. This is cable with tin coated copper strands

Marine cable

Calculating cable thickness, yourself is hard, so we help you with selecting the correct cable thickness. There are several options:

- Look in the product manual
- The Victron toolkit app
- The rule of thumb
- Recommended battery cables document

Product manuals
All our manuals recommend the battery cable size (and fuse size) that needs to be used for the product.

	12/3000/120	24/3000/70	48/3000/35
Recommended battery capacity (Ah)	400–1200	200–700	100–400
Recommended DC fuse	400A	300A	125A
Recommended cross section (mm^2) per + and - connection terminal			
0 – 5 m	2x 50 mm^2	50 mm^2	35 mm^2
5 – 10 m	2x 70 mm^2	2x 50 mm^2	2x 35 mm^2

Victron toolkit app

This App helps you calculate cable size and voltage drop. You can select:

- voltage
- cable length
- current
- cable cross section
-

And the app will calculate the voltage drop over both cables.

The app can be downloads from here.

Recommended battery cables document

This document contains a table that shows the maximum current for a number of standard cable where the voltage drop is 0.259 Volt.

The document can found here.

cable diam mm	cable section mm²	L(+) + L(-) tot 5 meters I max A	L(+) + L(-) tot 10 meters I max A	L(+) + L(-) tot 15 meters I max A	L(+) + L(-) tot 20 meters I max A
0.98	0.75	2.3	1.1	0.8	0.6
1.38	1.5	4.5	2.3	1.5	1.1
1.78	2.5	7.5	3.8	2.5	1.9
2.26	4	12	6	4	3
2.76	6	18	9	6	5
3.57	10	30	15	10	8
4.51	16	48	24	16	12
5.64	25	75	38	25	19
6.68	35	105	53	35	26
7.98	50	150	75	50	38
9.44	70	210	105	70	53
11.00	95	285	143	95	71
12.36	120	360	180	120	90

Rule of thumb

For a quick and general calculation for cables up to 5 meters use this formula:

Current / 3 = cable size in mm²

Example:

Current is 200A

Then the cable needs to be: 200/3 = 66mm²

4.2 Busbars

Busbars are like cables only the are rigid copper bars. They are used in large systems where larger currents flow. They are used as a common positive and common negative point between the batteries and multiple inverters. But busbars are also used in smaller systems, especially when there are a lot of DC equipment. A busbar in this case provides a nice location to connect all the various DC cables to.

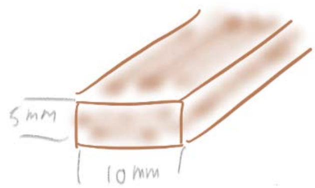
To calculate busbar thickness, simply use the recommended cable surface area and apply that to the bus bar cross section area.

surface area = with x depth

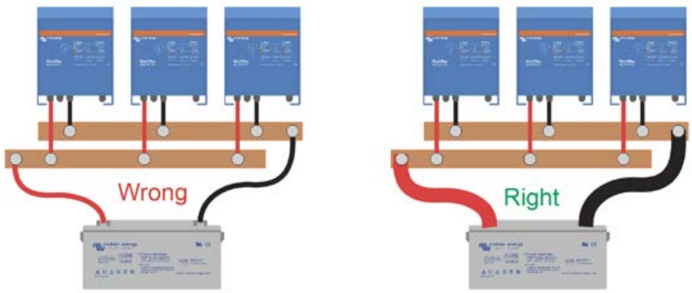
For example:

A busbar of 10mm x 5mm

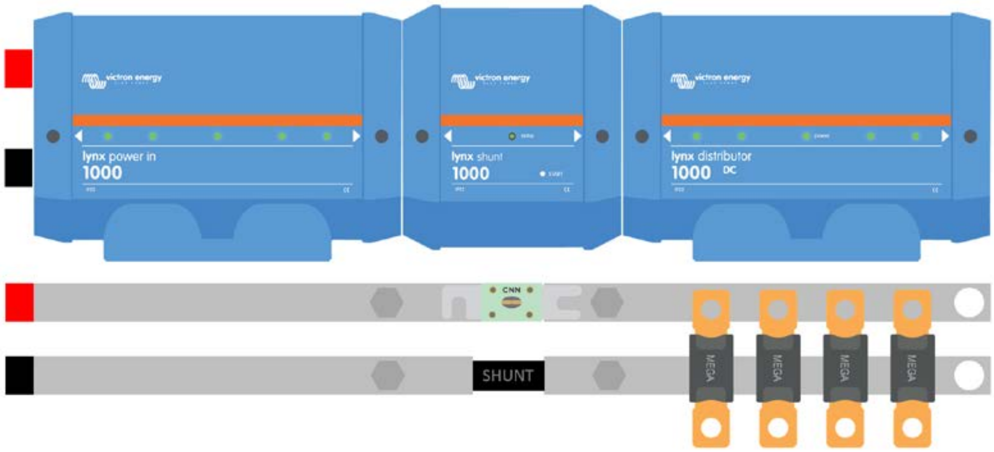
The surface area cross section is 5 X 10 = 50 mm²



When wiring the system please make sure that the cross-section of the connection between the batteries and the DC distribution point equals the sum of the required cross-sections of the connections between the distribution point and the DC equipment



We also have a product range that can be used as a bus-bar. This is the Lynx range. The lynx consists out of 3 products that can be connected to each other to form a bus-bar. It is rated up to 1000A.



- Lynx Power in - to connect batteries
- Lynx shunt - This unit houses the main fuse, the shunt and battery monitor electronics. (CCGX needed to read out the battery monitor)
- Lynx distributor – to connect the DC loads and their fuses and indication light per fuse.

For more info on the Lynx see here.

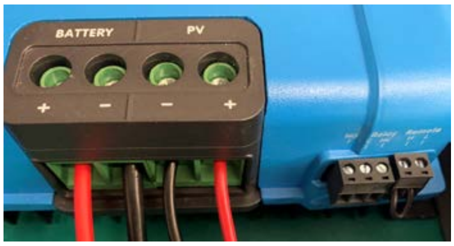
4.3 Cable connections

There are several ways to connect cables to batteries or to Victron products. Connections are made is a variety of ways:

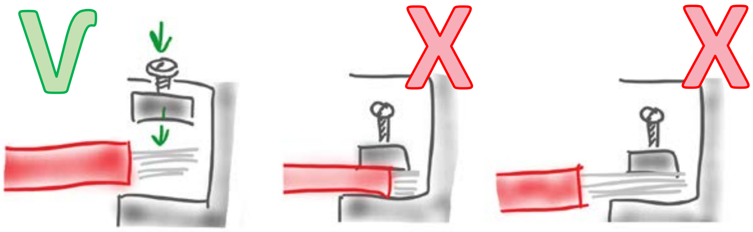
Nuts and bolts

- These usually come in M5, M6, M8 or M10.
- To fit a cable onto a bolt, the cable needs to have an eye cable lug.
- The cable lug needs to match the cable thickness.
- A special crimping tool is needed to attach a cable lug onto a cable.
- If the cable lug does not have insulation you will need to add this.
- When connting the cable eye to the bolt, place a washer and spring ring and then the nut.
- Use insulated tools when tightening the nut. An acidental battery short curcuit can be very dangerous and the currents can melt your unisualetd spanner, or the spark can cause a battery explosion.

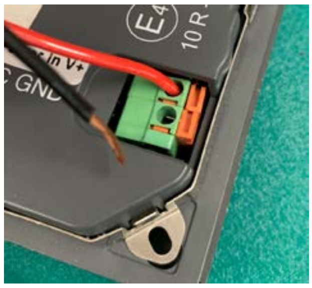
Screw connectors



- These come in all sizes, for thick or thin wires.
- When inserting a wire, the insulation needs to be stripped. Make sure to strip the cable correctly.
- Avoid cable insulation enter the connector. This can lead to too much resistance and the connector will heat up and potentially melt.
- Avoid insolated cable to be visible outside the connector. This is dangerous. Electrocution or short circuit risk.



Push connectors



- Push down the orange part with a flat screwdriver.
- Insert the stripped wire.
- Release the orange part.
- The cable is now locked in place. Give the cable a small tug to check if the cable is securely fastened.

Ferules

- These are sleeves that slide over a stripped cable end.
- A special crimping tool is needed.
- They are used to align the stripped cable strands and to prevent them splaying when inserting a cable into a screw or push connector.
- Use these if you are after a tidy wiring job.

Spade connectors

- A spade crimp terminal needs to be crimped to the cable
- A special crimping tool is needed.

MC4 connectors

- To connect solar panels to MPPTs.
- Male or female connectors.
- Special crimping tool is needed.
- Can be bought as pre-assembled cables.
- MC4 Y-pieces (or Y cables) used to connect solar panels in parallel.

Anderson plugs

- Often used in automotive or mobile applications.
- Available in different current ratings and cable thicknesses.
- Make sure the current rating matches the currents when your system is under load.
- They will add to the cable resistance.
- Limit or avoid their use.

Cigarette plugs

- Used in low-end automotive applications.
- Not capable of carrying large currents.
- Consider that the circuit in the car might only have a low fuse rating
- Take care to insert the plug correctly, and deep enough, if not inserted correctly. the connector can heat up and melt.
- Limit or avoid their use.

Battery clamps

- These are only meant for temporary connections.
- They often do not have a high enough current rating.
- Should never be used as a permeant connection in a system.
- Limit or avoid their use.

Always make sure all connections are tight, but not too tight. Look in the product manuals for the recommended torque moments. Most electrical connections are tinned brass nuts bolts and screws and they can get damaged when applying too much pressure when tightening.

4.4 Fuses

Each product that connects to a battery always needs to be fused. No matter how big or small the load is. The reason behind this is because batteries can potentially produce very high currents capable of cause a fire.

The fuse needs to be situated in the positive battery cable.

Traditionally, a fuse contains a wire that melts as soon as an unacceptable high current passes through this wire. When the wire in the fuse has melted, the electrical circuit has been broken and no additional current will flow.

The fuse protects against:

- Severe overload - when more current runs in the system than normally expected.
- Short circuit - when one conductor accidentally comes in contact with another conductor.

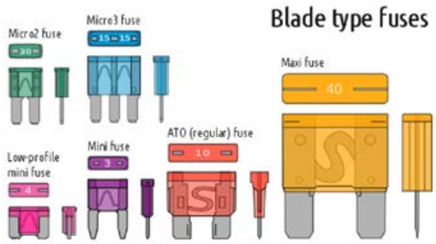
For fuse ratings always see the product manual. Most DC fuses are suitable for 12 and 24V, but they are not necessarily suitable for 48V and higher. Current rating and voltage rating normally is displayed on the fuse, or alternatively look in the fuse datasheet.

In multiple phase systems use one DC fuse per phase. If a big single fuse is not available, use one fuse per unit. Use the exact same fuse per unit.

Some fuse types:

For low currents

Glass fuse + holder



Blade fuse (car fuses) many types

Blade fuse holder

For medium currents

MIDI fuse | MIDI fuse holder | DC MCB

For high currents

MEGA fuse + holder (Victron) | CNN Lynx fuse | ANL fuse + holder | Blade fuse + holder

4.5 Battery isolation

The rules and guidelines for battery isolation vary in different countries, but, it is recommended, that if battery isolation is needed, to only isolate the positive battery cable.
When a battery isolation switch is needed always make sure you use a quality battery isolation switch. A bad switch can cause a voltage drop. The battery switch must be rated to the currents that can be expected in the system under full load.

Type of battery isolator switches

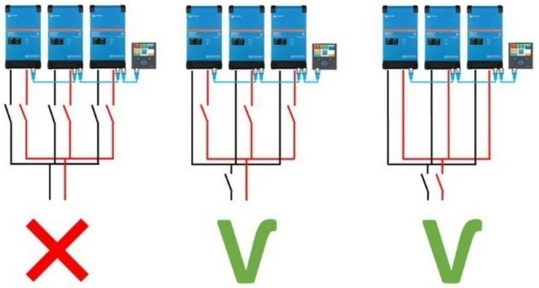
- Marine or automotive systems (usually 12 and 24V) use battery isolators
- Land based systems (usually 48V) din mounted DC MCBs or blade fuses are used

Battery Isolator switch | high current DC MCB | Blade fuse and holder

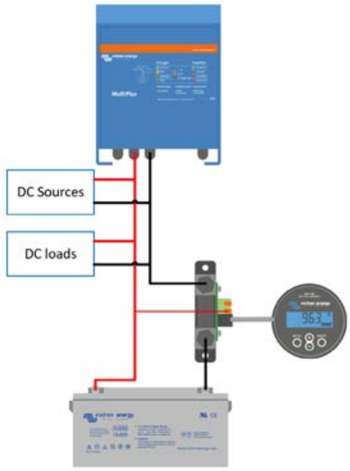
Switching the negative in multiple unit systems

Our inverter/chargers do not have galvanic isolation between the battery and VE-BUS. In a system with more than one inverter/charger it is extremely important to always follow below rules. Not following these rules can lead to damage to the communication chip.

- Each unit’s negative battery connection needs to be connected to the other unit’s negative connections.
- Only when the common negative is in place, the RJ45 VE.Bus cables can be connected to the units.
- When one unit is taken out of the system all the RJ45 cables needed to be disconnected before removing this unit.



4.6 Shunt



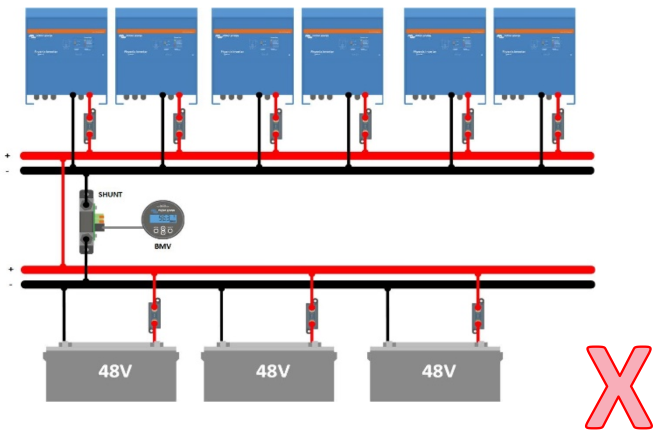
A shunt is needed in a system to measure battery state of charge
The shunt is wired in the negative cable. The shunt measures all the current going in and out of the battery bank. Therefore, the shunt needs to be the last item before the battery bank or battery bank bus bar. All DC loads and DC sources need to be connected after the shunt. See on the right how to wire the shunt into a system:

The shunt needs to be big enough and should be rated to the maximum DC current that potentially can occur in the system. The battery monitor comes with a 500A, 50mV shunt, but in case the shunt is not big enough you need to add a bigger shunt. Shunts are available in the following sizes: 500, 1000, 2000 and 6000A

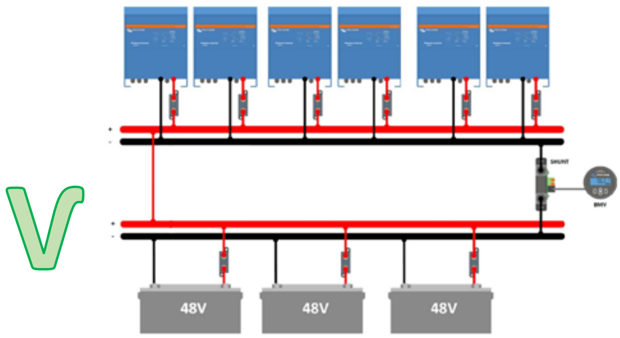
When using a bigger shunt make sure that you change the shunt parameters in the battery monitor.

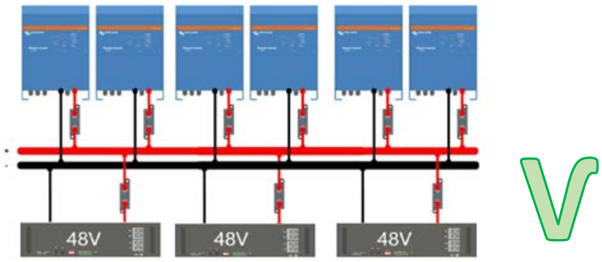


Please be aware that misplacement of the shunt can potentially cause a problem in a system depending how it is wired in. This is especially the case in large systems where there is be a long path between the battery and the inverter/chargers.
When inverting, the inverter/charger near the shunt will “see” a lower DC input voltage than the units far away from the shunt
When charging, the batteries near the shunt will “see” a lower DC input voltage. Than the batteries further away from the shunt. See below image:



To fix this, move the shunt away from the positive cable (not ideal). Or consider not using shunt at all but use smart batteries that generate their own sate of charge or use the VE.Bus battery monitor.





4.7 Parallel and/or 3 phase system DC wiring

In a system with more than one inverter/charger who are connected in a parallel and/or in 3-phase configuration it is essential that each unit has the same DC path from battery bank to each unit, or from the busbar to each unit.

The reason why this is important is, that if there was a difference in cable thickness and length, the resistance between each unit will differ. The internal resistance of an inverter/charger is very low, so a difference in resistance will cause the DC path for one unit, to be much higher or lower than the path of the other unit. Different resistance means different voltages and currents for each unit in the system. Inverter/charger overload is directly related to current. The result will be that, the unit that has more current running through it than the other units, will go into overload before the other units do. The total inverter power of the system will be reduced. As soon as one unit goes into overload, the whole system stops working. The unit with the bad wiring will determine the performance of the whole system.

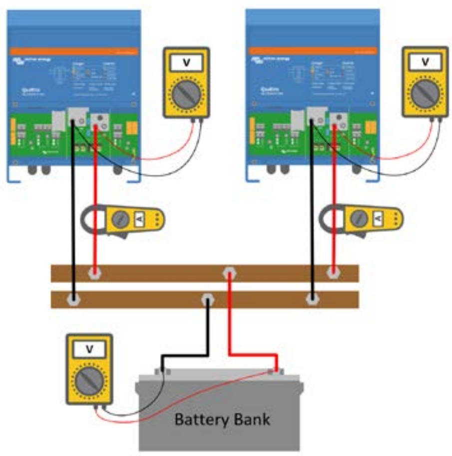
To achieve a balanced system, you will need to use the same cable type, cross section and cable length to each unit from the battery bank or from the busbars. We highly recommend for you to consider using bus-bars or power-posts before and after the inverter/chargers.

A parallel and/or in 3-phase system needs to connect to a single battery bank. It is not allowed to connect the individual units of a 3 phase and/or parallel system to individual batteries.

To check if a system is correctly wired or to trouble shoot wiring follow these steps:

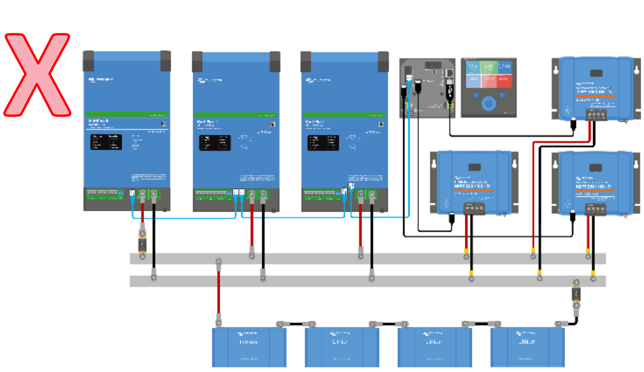
- Load the system to maximum load.
- Current clamp the DC wires to each unit.
- Compare the current readings, each unit should have similar DC currents.

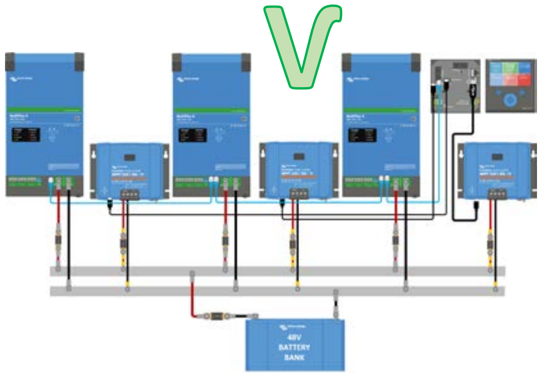
Alternatively, you can measure the voltage on the busbar or battery bank and compare this with the voltages you measure at each unit's battery terminals. These voltages should all be the same.



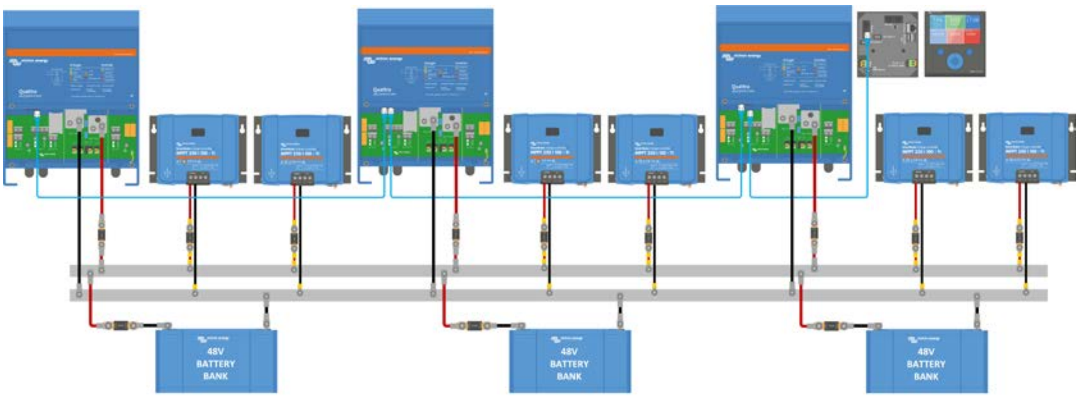
4.8 Large system busbars

In systems that contain inverter/chargers and MPPTs, that all connect to a busbar, it is important to alternately connect the inverter/chargers and MPPT to the busbars. This will reduce the current flowing through the busbars. And all MPPTs should have approximately the same cable length.





If the systems has only one battery bank you should connect the battery bank in the middle of the busbars. But in case of several parallel battery banks, they should also be distributed along the busbars.

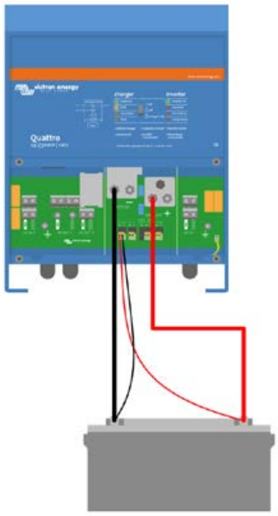
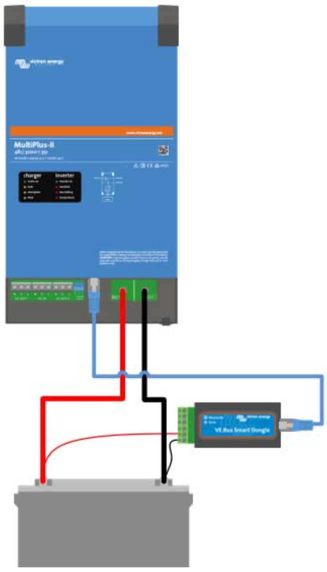
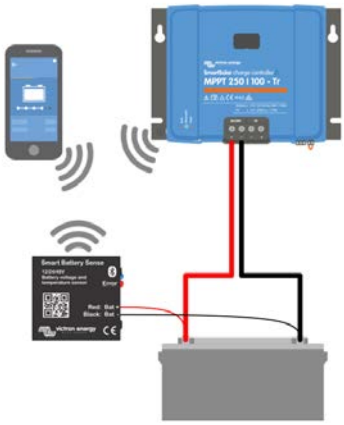


4.9 Voltage sensing and compensation

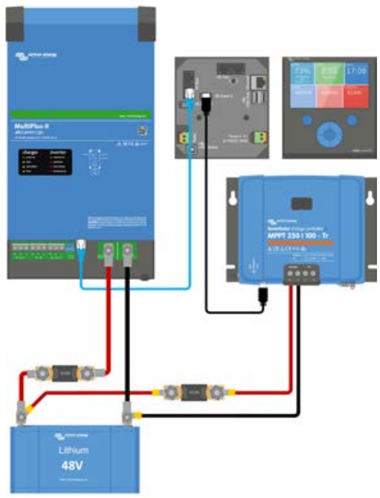
Voltage sense is a feature that will compensate for cable losses during charging. This will ensure batteries are charged with the correct voltage. This feature generally will only compensate for voltage losses up to 1V. If the losses in the system are bigger than 1V (i.e. 1 V over the positive connection and 1 V over the negative connection), the charger or inverter/charger will reduce its charge voltage in such a way that the voltage drop remains limited to 1 V. The reason behind this is, that if the losses are bigger than 1 Volt, the battery cables are too thin and are unable to carry a large current and therefore the charge current needs to be reduced.
Voltage sense also be used to compensate for voltage losses when diode splitters are used. A diode splitter has a 0.3 V voltage drop over the diode.
Some products such as inverter/chargers or large chargers have voltage sense build in. For other products, such additional equipment might be needed such as the smart battery sense or the Smart VE.Bus dongle.

- If the product has a voltage sense terminal two sense wires can be connected from the V-sense terminal directly on the battery positive and negative terminal or distribution. Use wire with a cross-section of 0,75mm².
- In case of the MultiPlus II connect the VE.Bus smart dongle to the battery and connect the dongle via a RJ45 cable to the MultiPlus II.

- In case of a MPPT Connect a Smart battery sense to the battery and match it to a MPPT via the VictronConnect App.

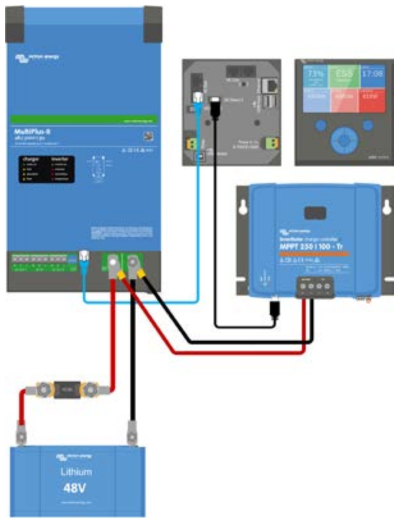




Voltage sensing in an Energy Storage system with DC Solar



In an ESS system with DC solar, the charger of the inverter/charger is disabled. Battery charging and feeding excess solar is taken care of by the MPPT solar charger. This controlled by the CCGX. It will set the MPPT at a higher voltage than the inverter/charger. This will result in a slightly higher DC voltage when the battery is (nearly) fully charged and the inverter/charger will attempt to reduce the “overvoltage” by feeding power back into the grid.
In a 48 V system this overvoltage is set at 0.4 V and in a in a 24 V system it is 0.2 V

But the DC cabling, fuses and connections will cause a voltage drop in the system. The voltage drop can reduce the “overvoltage” the inverter/charger needs before it can feed power into the grid.



Example:
In an ESS system with 100A MPPT with 2x 1m cable 35mm² and a 150A DC fuse the resistance is:

Connections:	0.35 mΩ
150 A fuse	0.35 mΩ
2 m cable	1.08 mΩ

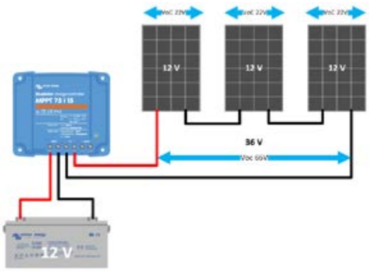
The total resistance is 1.78 mΩ and the voltage drop at 100A is 178 mV

The solution is to use an MPPT with automatic voltage drop compensation this will result in that the output voltage of the MPPT will slightly increase with increasing current. But if the MPPT does not have voltage sensing, then it is best to connect the MPPT directly to the MultiPlus.

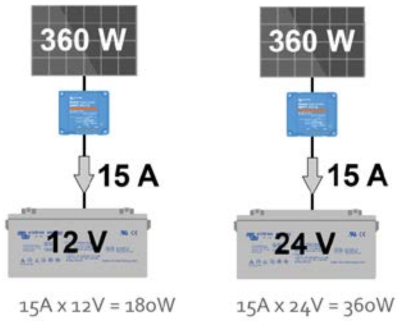
4.10 Solar array design

Multiple solar panels together are called a solar array. If you connect solar panels in series the voltage increases and when you connect them in parallel the current increases. The same as is the case when constructing a battery bank with individual batteries.

An example of panel in series:
If you look at the specs of a 12V solar panel, you will find that the Voc is around 22Volt.
For a 75/15 MPPT the solar voltage can be as high as 75V.
This will allow you to connect up to 3 x 12V panels in series.

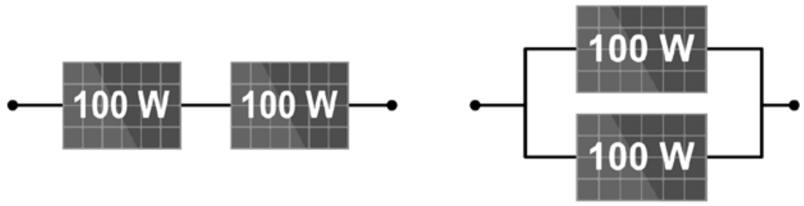


Note on charge current at different battery voltages:
For a 75/15 MPPT the current rating is 15 A. This is the current going into the battery.
This means that with a 12V battery you will get less power into the battery than with a 24V battery.

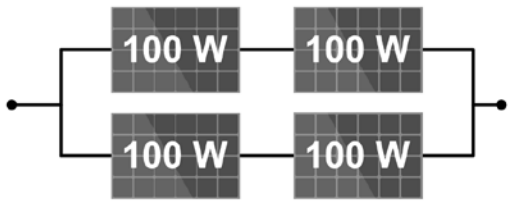


Solar array power
To determine the total power of a solar array, you will have to add the power of each module no matter if they are connected in parallel or in series.

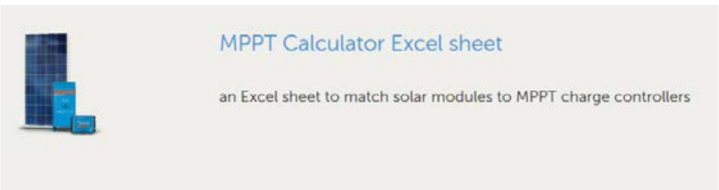
Both these arrays are 200W:



Series parallel arrays are possible as well this is a 400W array:

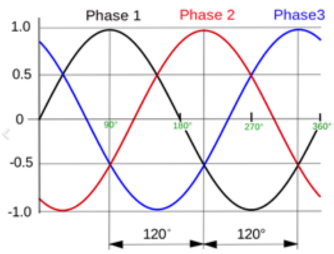


To help you deign a solar array and to match it to the correct solar charger see this calculation sheet [here].



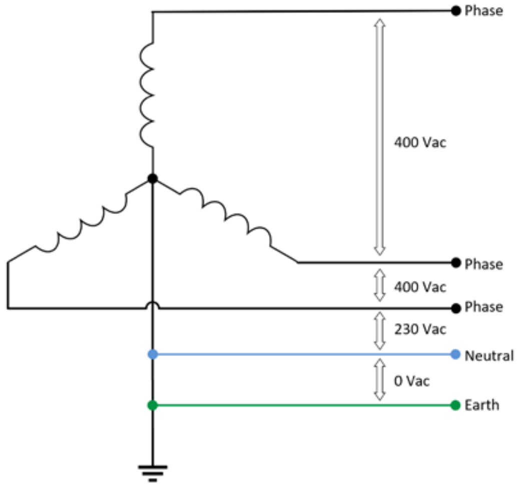
5. AC cabling

5.1 Power generation



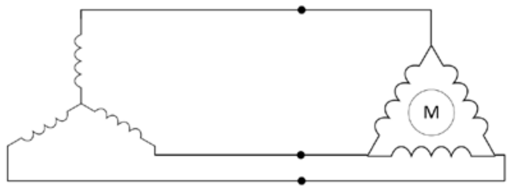
The generator in a power station generates 3 phase electricity. Each of these 3 phases have an alternating voltage of 230 Volt (or a different voltage, depending on the country). The voltage alternates at a frequency of 50 (or 60) Hz. And because the coils in the generator are rotating, there is a 120°-degree phase shift between each phase.

The 3 coils are connected to each other and create a triple circuit, a so-called star configuration. A single coil (phase) has a potential of 230Vac. And a second potential level is created between two coils. Due to the 120° phase shift the potential is 400 Vac.



To be able to use the phases separately the common point (star point) is connected to a conductor called "Neutral". Between the neutral and one of the phases a voltage of 230 Volt exists. The Neutral conductor is a conductor that can be used by all 3 phases and can be used in 3 separate electrical circuits.

The star point acts as a neutral in electrical house installations. The function of the neutral conductor is to enable separate use of each phase and each phase can be used as an individual 230 Volt AC supply.
The neutral is also connected to a metal spike driven into the ground, the so-called earth spike. In this way the potential of the earth equals 0 Volt. This connection is called earth.
A 3-phase load, like a 3-phase electric motor, uses electricity from all 3 phases. The neutral does not have a function because the 3 electrical circuits will keep each other balanced. Only if one of the phases consumes more load than the others, the neutral will start to conduct current. This current is called the "compensating or equalizing current".



When setting up 3 phase inverter/chargers they will need to be set up in a star configuration. They need to have a common Neutral. Delta is not allowed. The load they run can be a load in Delta configuration.

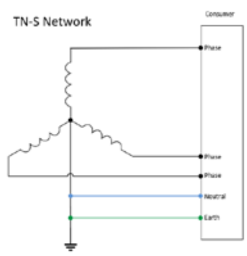
Unequal loading is not an issue if the inverter/chargers run in inverting mode, but it might be an issue if they un in pass-through mode and they are connected to a generator that is unable to deal with an unbalanced load.

5.2 Distribution networks

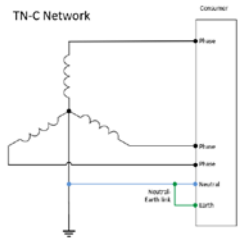
There are different ways in which power is distributed to the consumer. And different ways in how the consumer system is connected. All networks supply the 3 phases, but the way Neutral and Earth are bonded varies.

TN-S network

- The generator star point is connected to Neutral and to Earth.
- The phases, Neutral and Earth are distributed.
- The consumer uses the supplied phases Neutral and Earth.
- Neutral and Earth are not connected to each other.

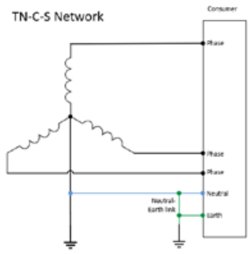


TN-C Network

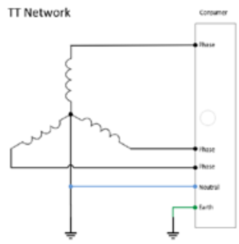


- The generator star point is connected to Neutral and to Earth.
- The phases and a combined Neutral-Earth are distributed.
- The consumer splits up the incoming Neutral and Earth (MEN link).
- The consumer uses the supplied phases and the newly created Neutral and Earth.

TN-C-S Network

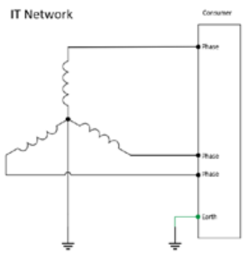


- The generator star point is connected to Neutral and to Earth.
- The phases and a combined Neutral-Earth are distributed.
- The consumer splits up the incoming Neutral and Earth (MEN link).
- The consumer connects to Earth to earth stake.
- The consumer uses the supplied phases and the newly created Neutral and Earth.



TT network

- The generator star point is connected to Neutral and Earth.
- The phases and Neutral are distributed.
- The consumer uses the supplied phases and Neutral.
- The consumer creates a local Earth connection.



IT network

- The generator star point is not connected to Neutral and Earth.
- The phases are distributed.
- The consumer uses the supplied phases.
- The consumer creates a local Earth connection.

5.3 System current VA and Watt

To be able to correctly calculate fuses, wiring size or inverter size you will need to know the currents that can run through an AC circuit. To be able to correctly calculate current there is one aspect of AC power that will need to be explained, namely Watt and VA.

AC power is alternating power. Both the voltage and the current are a sine wave. Certain loads can cause the current sine wave to lag behind the voltage sinewave.

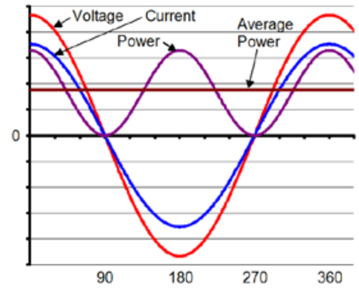
Watt is the real power drawn by the equipment. The Watt rating determines the actual power purchased from the utility company, the diesel consumed by a generator or the heat loading generated by the equipment.

VA is the “apparent power” and is the product of the voltage times the current drawn by the equipment. The VA rating is used for sizing wiring, circuit breakers, inverters or generators.

In a purely resistive AC circuit, voltage and current waves are in step (or in phase) with each other. To calculate current this formula can be used:

Current = Power/Voltage

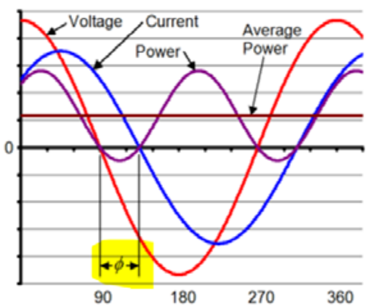
I = P/V



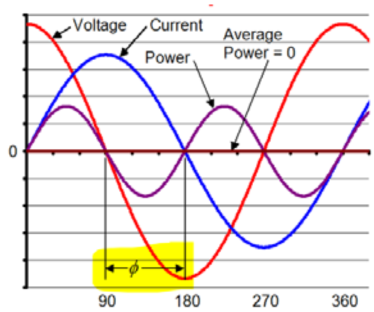
Power factor = 1 Φ = 0° Cosϕ = 1

In a purely resistive system the Power factor is 1

When an AC circuit contains loads such as inductors or capacitors, a phase shift will occur between the current and voltage waves. Both these waves are not in step (in phase) anymore.
Looking at the waves, if you calculate the power you will see that the True power (W) is less than the apparent power (VA).



Power factor = 0.7 Φ = 45° Cosϕ = 0.71



Power factor = 0 ϕ = 90° Cosϕ = 1

When the power factor is known the apparent power can be calculated.

W x Power factor = V x A

True power x Power factor = Apparent power

On average a residential AC circuit has an average power factor of 0.8. So, for general calculations it is okay to use 0.8 as power factor.

5.4 AC wiring

In a house installation the incoming electricity is divided into groups, usually on a distribution board.
The diameter of the electrical wiring for each AC circuit (group) needs to be matched to the size of the expected maximum current in that circuit. This is to protect the connected loads and the electrical wiring.

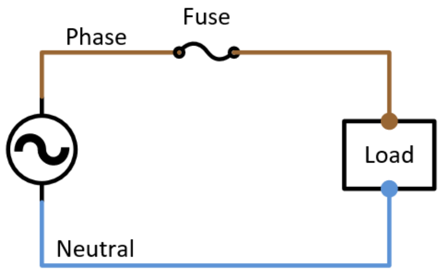
Voltage drop and heating of cables can also occur in AC circuits. Voltage drops can lead to damage of the connected appliance and heating up of cables can lead to house fires.

It is also important to make good cable connections. Bad cable connections can also lead to voltage drop and heating. Use the guidelines as already described in the chapter 5: “cable connections”.

For wiring calculation use the same calculations as we used for DC wiring as mentioned in chapter 5: “select the right cable”. But be aware that the previous mentioned rule of thumb cannot be used. For wiring for voltages from 100 to 400 Vac use this rule of thumb:
Nominal current / 8 = core diameter in mm
Add 1 mm2 for each 5 meters of cable length

5.5 Fuses and circuit breakers

Fuses are generally located in the distribution board. Each AC circuit (group) is fused separately. The fuse is matched to the size of the expected load.



The fuse protects against:

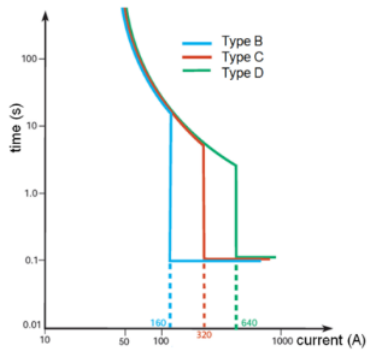
- Overload - when more current runs in the system that can be normally expected.
- Short circuit - when the phase conductor accidentally comes in contact with Neutral or Earth.

Traditionally a fuse contains a wire that melts when unacceptable current passes through. As soon as the wire in the fuse has melted the electrical circuit has been broken and no additional current will flow.

But, more common are overcurrent protection devices called: “Miniature Circuit Breaker (MCB)”. This device has two triggers for activating its switch-off mechanism. Being a thermal trigger for long term small overload currents and a magnetic trigger for large short duration currents like short circuit currents.

MCBs come in three types: B, C and D. They all have the same thermal characteristics. But they have different short circuit current levels.

- Type B disconnects at 5 In (5 rated currents) and is commonly used as a household MCB.
- Type C disconnects at 10 In and is used for transformers and fluorescent lamps.
- Type D disconnects at 20 In and is used for large motors, transformers and mercury lamps.

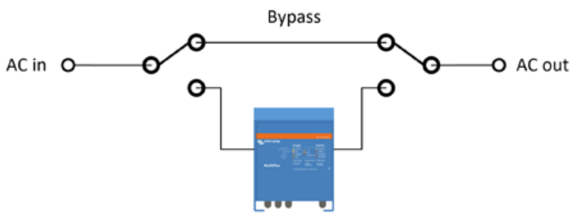


When a short circuit current occurs, with sufficient current, the MCB (B,C or D) is switched off within 100 ms.

5.6 AC bypass switch

It is recommended to add a manual bypass switch to an inverter/charger system. This is especially useful in mission critical systems.
This switch allows to bypass the inverter/charger and connects the AC input (grid or generator) directly to the loads.

A switch like this will prove invaluable in case the inverter/charger needs a configuration change or should anything go wrong with the inverter/charger and it needs to be removed for service.



The bypass switch will need to break the AC in and AC out path to and from the inverter/charger and it then needs to make the bypass circuit. The switch need to be rated to the full AC load of the system.

5.7 Special considerations for AC wiring of parallel and/or 3 phase inverter/chargers

AC fusing parallel strings

For units in parallel use one AC fuse for all units on that phase. Both on the input, and on the output. Multiple fuses which are mechanically connected are okay to be used, this is counted as one fuse.

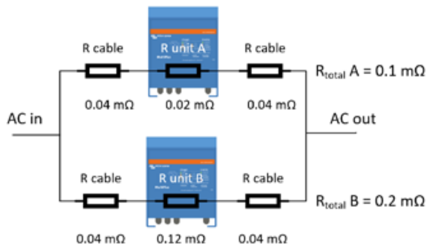
Phase rotation
Beware of phase rotation between the inverter and AC in. When wired in the wrong rotation, the system will not accept the mains input and only operates in inverter mode. In that case swap two phases to correct it. A quick way to fix phase rotation is to swap 2 random phases and see if now the inverter system will accept AC in. In case the system is mobile it is likely that, at some point, there will be a generator or grid connection with incorrectly wired phase rotation and the inverter/charger system will reject the input and stay in inverter mode, consequently draining the batteries.
Mounting a simple changeover switch that can swap two of the phases is a nice solution which instantly fixes the phase-rotation issue, without stalling the event. Besides manual switching there are also automatic devices available to do this.

AC input and AC output cabling
Do not over-dimension the AC cabling. Using extra thick cabling has negative side effects.

Technical background:
In a parallel system the AC current should be evenly distributed through all paralleled units. But small differences in the internal resistance of the back-feed contactors in each inverter/charger may result in AC current being diverted from one unit to another.

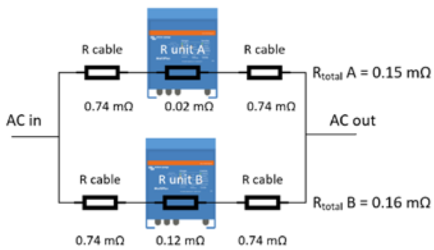
When the resistance in the cabling is very low, a small difference in resistance results in a large relative difference. And this results in bad current distribution.

An exaggerated example:
To units are connected in parallel, Unit A and unit B. If extremely thick and short cabling is used, one might achieve a very low wiring resistance. But a slight internal resistance difference might exist between the two units back feed contactors. In this scenario a total resistance for Unit A is 0.1 mΩ and a total resistance for Unit B is 0.2mΩ.

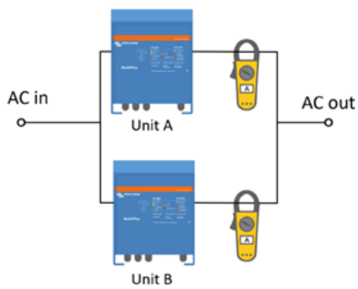


This will result in Unit A carrying twice as much current as Unit B although the resistance difference is very small.

Now if we use the same 2 units in parallel and we use thinner and longer cables one might end up with a total resistance for Unit A of 15Ω and a total resistance for Unit B of 16Ω. This will result in a much better current distribution (Unit A will carry 1.066 times more current than Unit A) even if the absolute difference in resistance is much bigger than in the previous example (1Ω vs 0.1 mΩ).



Recommendation*:*
Use AC long cables of similar length.
Look in the manual for recommended AC output cable lengths
Do not increase the cross section of the AC cabling more than is recommended in the manual!
For example: the voltage drop tolerance of a 100A back feed contactor is about 20mV at 100A. The total cable resistance (input + output) should therefore be larger than R = 60mV/100A = 6mΩ.



System check:
The best way to check for these type of wiring issues is to fully load the system and then measure (current clamp) each units individual AC currents. They should very similar. If there are big differences, then there is an issue with wiring (or with a connection).

6. Grounding, earth leakage and RCD

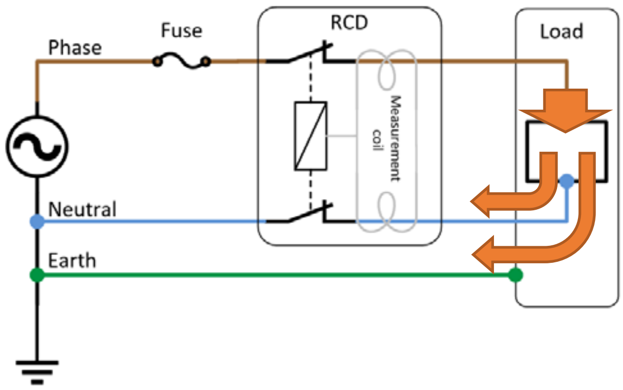
6.1 RCD

Electricity above 50V is dangerous therefore personal protection against electricity is needed in an AC circuit. This protection needs to prevent that metal housing around a device can become live. A dangerous situation can occur when a person touches the live housing. As soon as a person touches a “live” device, the person will complete the electrical circuit between the faulty device and earth. Current will flow through the person into earth and this can be lethal. Even a low current trough a human body can result in death.

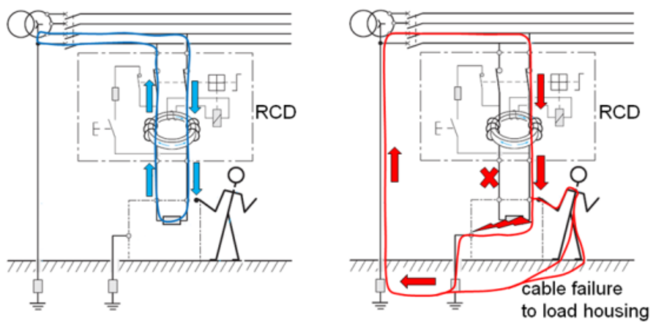
It is important to detect and disconnect when electricity is flowing into earth or potential via a person. Earth leakage detectors are incorporated into an electrical system. These are designed to disconnect quickly when a current flow to earth is detected in order to mitigate the harm caused by electric shocks.

Earth leakage detectors can be known under different names:

- Residual current device (RCD)
- Residual current circuit breaker (RCCB)
- Ground fault circuit interrupter (GFCI)
- Ground fault interrupter (GFI)
- Appliance leakage current interrupter (ALCI)
- Safety switch



RCDs operate by measuring the current balance between two conductors. The device will open its contacts when it detects a difference in current between the phase conductor and the neutral conductor. The supply and return currents must sum to zero, otherwise there is a leakage of current to somewhere else, to earth or to another circuit.
RCDs are designed to prevent electrocution by detecting this leakage current, which can be far smaller (typically 5–30 mill amperes) than the currents needed to operate conventional circuit breakers or fuses (several Amperes). RCDs are intended to operate within 25–40 milliseconds, before electric shock can drive the heart into ventricular fibrillation, the most common cause of death through electric shock.
A safe system is a system where short-circuit and overload is prevented as well as preventing of earth leakage currents. Earth leakage detection can only take place in systems where the neutral conductor is connected to the earth conductor; like in a TN or TT system. Earth leakage detection is not possible in an IT network.



Where to mount a RCD

A RCD must be mounted before the loads in an electrical installation. In reality this means that the RCDs have to be mounted before the installation is split up in groups. If an inverter or inverter/charger is used, the RCD should come after this, otherwise there will be no earth protection while the inverter is operational. Consumers that are only operational when connected to shore power will need their own RCD.

Nuisance Tripping of RCDs

In some installation RCD’s will trip prematurely. This can be caused by the following:

- The system has a double MEN link, this will cause the RCD to trip due to a potential difference in earth

- The system contains equipment that introducing a small 'below threshold' amount of neutral earth leakage, and the cumulative effect of the relay check can cause unpredictable nuisance tripping of RCD's. Some common troublesome appliances to check and disconnect first when troubleshooting are surge Protected Power-boards, old refrigerator compressors and electric hot water units (due to their own earth differential from the main earth stake).

6.2 Mobile or independent installations

A mobile or independent installation is an installation that is operating independently from the grid or regular mains power. For example, like in:

- Boat
- Automobile
- Campervan
- Off-grid installation.

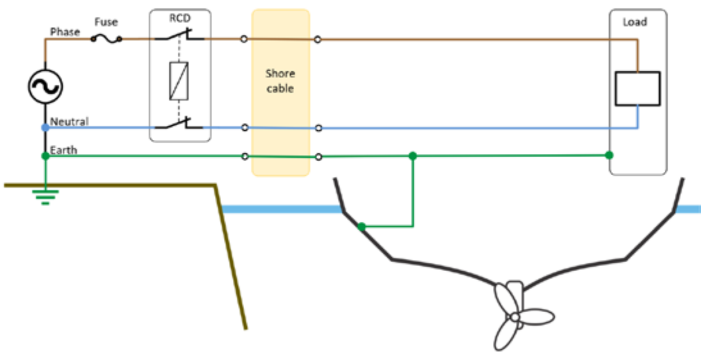
Please note that in this chapter we speak about a boat installation, however this text can also be used for any mobile or independent installations, including automobiles.

In a mobile application situations can exist that do not occur in a common, grid connected, house installation. In this chapter we recognize 2 different situations:

- A mobile installation is connected to mains or shore power (Situation 1)
- A mobile installation is disconnected from mains or shore power and is using a generator and/or an inverter (situation 2)

Situation 1

When a boat is moored and connected to shore power, the situation on board is almost the same as if this installation was a residential installation. There is only one difference; the boat does not have its own earth connection like the earth spike you will find in a house.



The boat installation relies on the earth provided by the shore connection. Unfortunately, this earth is not always reliable due to the fact that the marina cables are often long and have an insufficient cable core thickness.

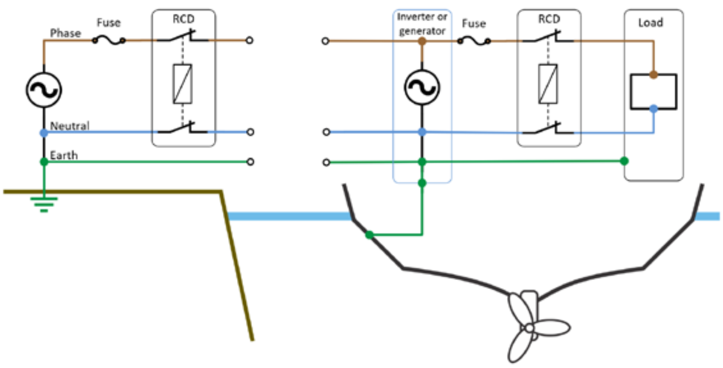
To create a safe situation, the metal parts of the boat, like the hull, will have to be connected to the incoming earth from the shore power cable. The shore power earth is connected to the star point of the mains distribution and is part of mains power.

In this situation 2 separate electric circuits are possible thus allowing for the proper operation of a RCD.

If an earth leakage occurs, current can flow though the earth conductor in the mains cable, but also via the hull trough the water and back to shore earth. Both earth leakage circuits have got the same potential and are in a way connected in parallel, but in the event of an earth leakage fault, more current will flow through the earth conductor in the shore cable, because the path through the hull and the water has got a bigger resistance.

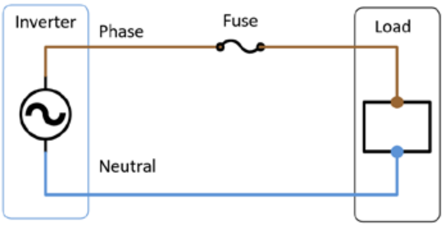
Situation 2

As soon as the boat disconnects from shore power the entire installation changes because the installation is not part of the mains anymore and the connection with the star point of the mains is lost.



The installation has got its own energy supply and together with the loads forms its own electric circuit. No current will flow into the hull and into the water.

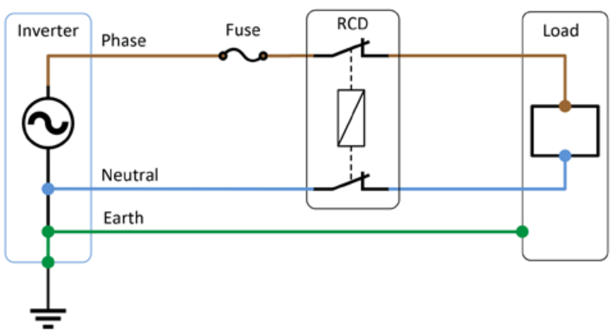
Floating network



In mobile systems with its own power source one can specifically choose not to use a TT network but to use an IT network.
In an IT network the phase and neutral are not coupled to another potential like earth. The voltages created by the independent power source are floating; this is very safe and simple.
If a conductor or housing, powered by the independent power source, is touched no electricity will flow. No current can flow to earth because the earthing conductor is absent and the electric circuit to earth is not complete. This is a similar situation as the safety transformer in a bathroom. If only 1 conductor is touched no current can flow.
Inverters and generators are in principle nothing more than the source of two potential differences with a difference of 230 Volt. Touching will not lead to a current flow because this voltage is unable to create power.

Independent power systems are more and more often connected to mains. As soon as a mains connection is made a RCD needs to be installed, as to satisfy the requirements of the TT or TN network where the mobile network is now connected to.
Theoretically, a network can be a TT network when connected to mains and at the same time be a floating IT network while the generator or inverter is in use. The external earth potential is only operational if the energy from this supply is used as well. If the used energy is not taken from the mains supply but from the inverter or generator supply, no earth leakage current can flow to the physical earth, trough the water back to shore. If a person comes into contact with a conductor, the circuit: phase – person – earth – star point – phase has not been completed and no current will flow through that person. The external earth is not part of this electrical circuit.
Fuses that protect for high currents in an overload or short circuit situation naturally remain operational. However, the RCD will never detect an earth leakage current because there is a bypass around the RCD in the network. Pressing the test button on the RCD is also useless. A false impression that the RCD is operational can be given, while in reality the RCD is not operational. When the test button on a RCD is pressed, an internal bypass is activated, simulating an earth leak, so the RCD can be electrically and mechanical tested. This by no means tests the whole installation, only the RCD itself. This will lead to confusion and/or dangerous situations. It is for these reasons recommended to follow the principles of the TT network, also for situations when the installation is not connected to mains power.

From IT network to TT network
The switch from IT to TT network has to accommodate for a connection being made between a phase, coming from the floating network, and earth. Like earlier explained; the difference between these is only a potential difference. When earth is connected to one of the phases, the network will automatically become a TT network. It is important to realize that this earth is by no means similar to the earth in a house installation. This is a different kind of electric circuit, i.e. power plant versus inverter or generator.
The earth is sometimes physical equal, but it belongs to 2 separate electrical circuits that are independent of each other. Of course, it is allowed and possible to connect the 2 earths together. I other words; the generator or inverter can supply power and be connected to the hull of the boat while that hull s also connected to earth (star point) of the shore supply. Current can never flow from one energy source to the other.



Almost all modern-day inverters and generators have one of their phases connected to ground. In that way they conform to a TT network. Never the less, this will always need to be checked prior to installation.
All Victron Energy inverters and have the neutral connected to the casing and to the earth connection.

Measurements should be:
Earth to Neutral = 0V
Neutral to Phase = 230V

6.3 Inverter/charger combinations

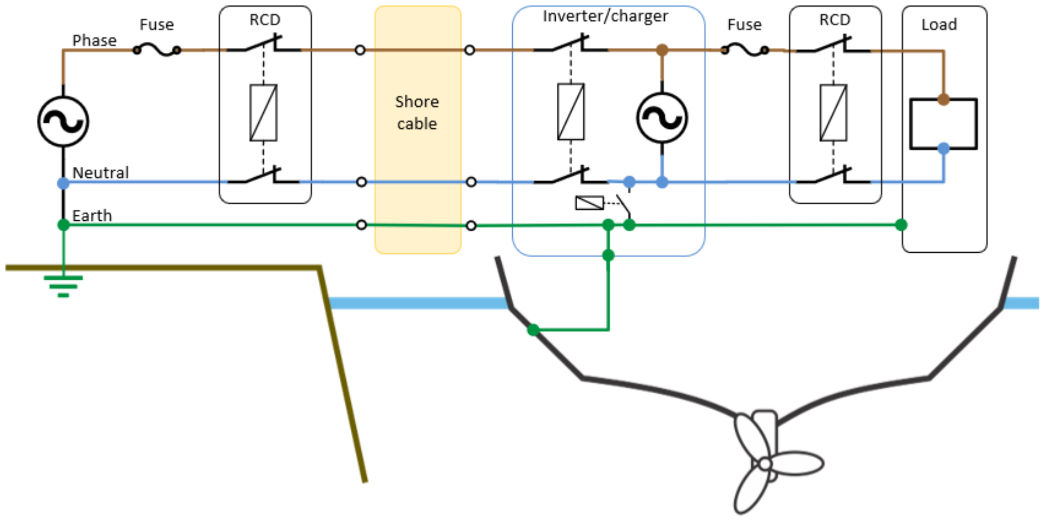
When combination inverter/charger units are used, the neutral to earth connection are different. Depending on the operation mode of the inverter/charger, shore power is being used or independent power is being generated. While connected to shore power a connection between ship earth and shore earth will need to be made. While the inverter/charger is inverting and acting as a power supply, it will have to make an independent earth connection.

As it is sometimes not clear which of the leads in the shore power cable is connected to earth, a short circuit to earth can be created. Depending on the country, a mains connection can sometimes be made in two different ways. It is also possible that phase and neutral have not been wired correctly in the plug or in the shore installation.

Inverter/chargers contain an internal ground relay; this relay automatically makes or breaks the connection between the earth and one of its outgoing phases. In case of an incoming voltage firstly the connection between the earth and the outgoing phase will be broken. Secondly the incoming voltage will be coupled to the boat network, after having been synchronized to accommodate a seamless transfer. Please see below for both situations.

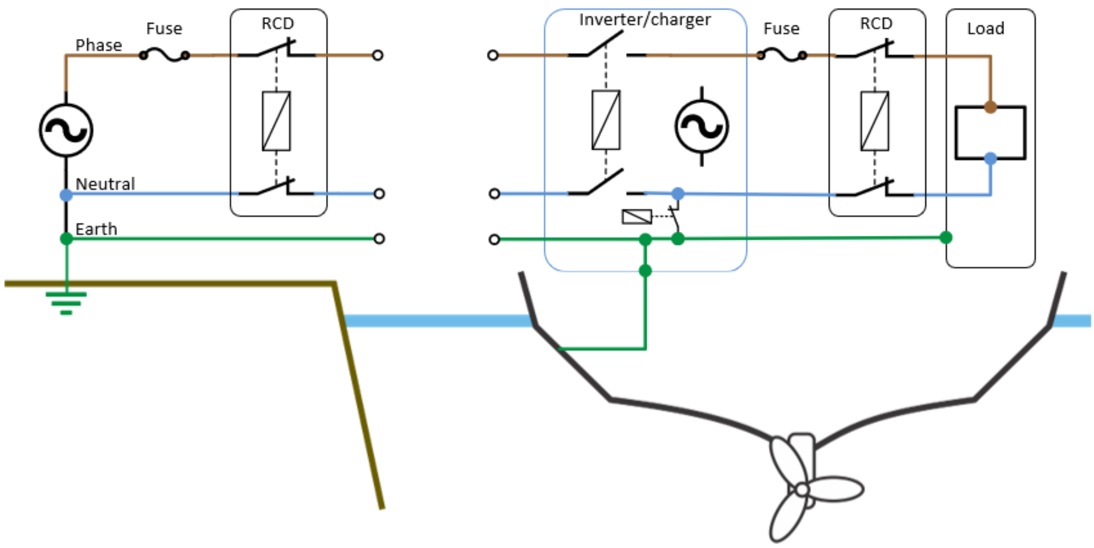
Situation 1

The boat is connected to shore power, the AC input relay is closed, and the neutral-earth relay is open. The AC output system relies on the shore connection to provide the neutral to earth link, so the RCD is functional



Situation 2

The boat is now disconnected from shore power, the AC input relay is open, and the neutral-earth relay is closed. The inverter/charger has made the Neutral to earth link itself, this so the RCD in the AC output circuit is operational.



6.4 Grounding boat parts

In shore or in inverter operation a central earth potential must be present. All metal parts must be connected to each other. Theoretically all touchable metal parts and pipes that carry fluids must be connected to earth. Examples of these are: hull, railing, engine, power point earth contacts, lightning conductors and the earth plate (if present).
It is important that the connecting earth wires are of sufficient thickness, as the currents that run through these wires can be momentarily quite high.

6.5 Isolation and grounding of Victron Equipment

Isolation of all Victron inverters and inverter/chargers:

- Between the AC circuitry and chassis: basic isolation. The chassis therefore must be grounded.
- Between AC and DC: reinforced isolation. Once the chassis has been grounded the DC is therefore considered safe to touch if the nominal voltage is 48V or lower.
- Between the DC circuitry and chassis: basic isolation. Therefore, DC negative or positive grounding is allowed.

In case of positive grounding, non-isolated interface connections will refer to the DC negative and not to ground. Grounding such a connection will damage the product.
The AC ground terminal of all inverters and inverter/chargers is connected to the chassis.

AC neutral grounding of Victron inverters
The neutral of all inverters rated at 1600VA or more and of the Phoenix Inverter Compact 1200VA is connected to the chassis. Grounding the chassis will therefore also ground the AC neutral. A grounded neutral is required for proper operation of a RCD (or RCCB, RCBO or GFCI).
If no reliable ground is available and/or if a GFCI is not installed, the AC neutral to chassis connection should be removed to improve safety. Warning: such an installation does probably not comply with local regulations.
The AC neutral of lower power inverters is generally not connected to the chassis. A neutral to ground connection can be established however: please see the product manual.

AC neutral grounding of Victron inverter/chargers
The output AC neutral of all inverter/chargers is connected the input AC neutral when the back-feed relays are closed (AC available on input). When the back-feed relays are open, a ground relay connects the outgoing neutral to the chassis. A grounded neutral is required for proper operation of an RCD.
Disabling the ground relay is possible on most models. Please see the product manual.

Isolation of MPPT solar chargers
No isolation between PV input and DC output
Basic isolation between input/output and chassis.

Isolation of other products
Battery chargers: reinforced isolation between AC and DC. Basic Isolation between AC and chassis, except for the Smart IP65 chargers which have reinforced isolation between AC and the plastic casing.
DC-DC converters, diode and FET splitters and other DC products: the casing is always isolated from the DC (basic isolation).

6.6 Land based systems

off-grid system grounding

Do not ground the positive or negative of the PV array: the PV negative input of the MPPT is not isolated from the negative output. Grounding the PV will therefore result in ground currents.

The PV frames however may be grounded, either close to the PV array or (preferably) to the central ground. This will provide some protection against lightning.

Ground close to the battery. The battery poles are supposed to be safe to touch. The battery ground should therefore be the most reliable and visible ground connection.

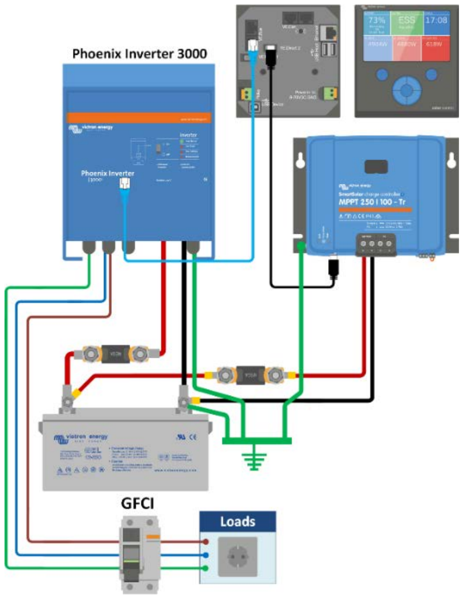
Required cross-section: DC ground cabling should be able to carry a fault current at least equal to the DC fuse rating.

The chassis of the inverter or Multi/Quattro must be grounded (basic insulation between AC and chassis).

The chassis of the MPPT solar charger must be grounded (basic insulation between AC and chassis).

AC distribution with fuses or MCB's: not shown.

PV array and PV frame grounding: not shown.



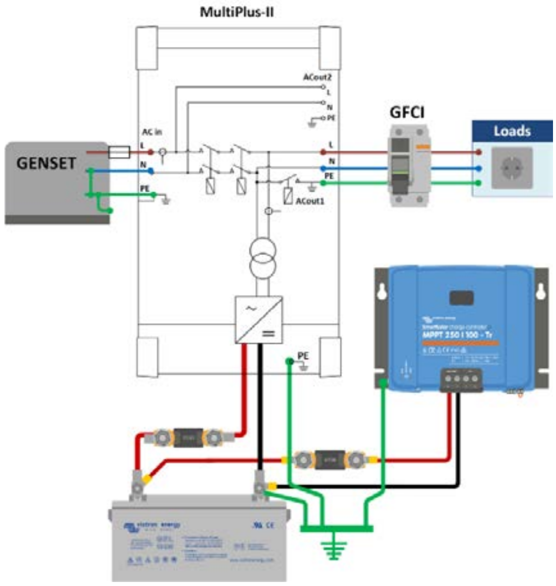
off-grid with generator

One ground only, close to the battery.

Required cross-section: DC ground cabling should be able to carry a fault current at least equal to the DC fuse rating.

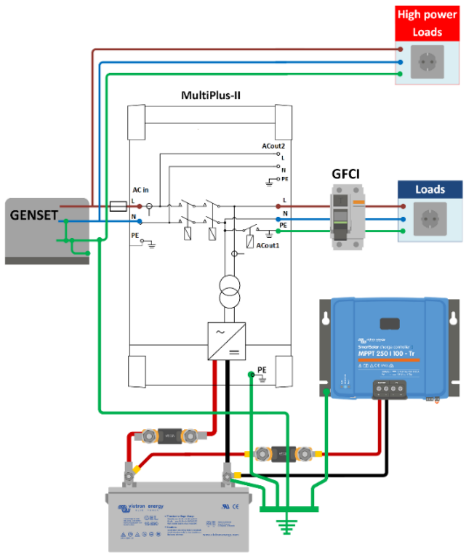
Similarly, AC ground cabling should be able to carry a fault current at least equal to the AC fuse rating.

A GFCI will be functional only if the chassis of the Multi/Quattro is grounded.

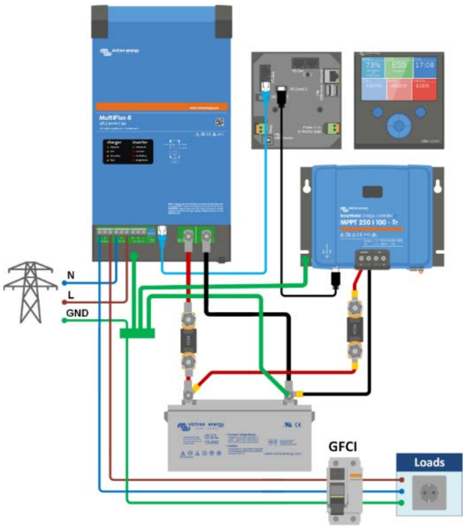


off-grid with high power generator

Ground the genset directly at the central ground.



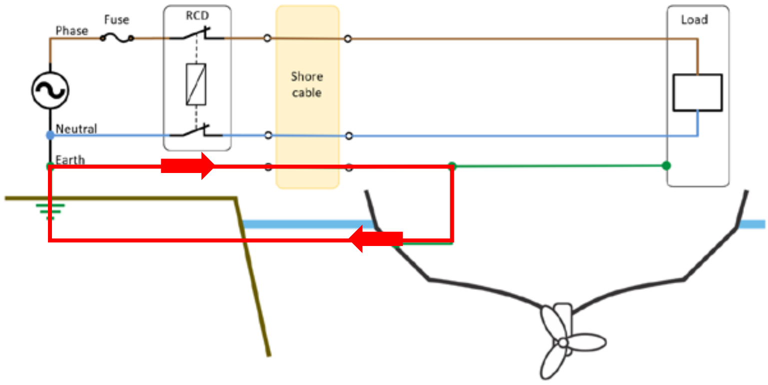
Grid connected Energy Storage System (ESS)
The DC ground cabling should be able to carry a fault current at least equal to the DC fuse rating.
Connect the chassis of the inverter/charger to the ground busbar
The AC-out ground may be taken from the central busbar or from the AC-out terminal.



7. Galvanic corrosion

Galvanic corrosion is a DC current. It is caused by the natural voltage difference between metals. A galvanic current can only exist when there is a closed electric circuit. A conductor belonging to another electric circuit can be part of the galvanic corrosion circuit. If a boat with a metal hull is near the shore a natural voltage difference of 0.1 – 1 Vdc exists between the hull and the water.

This potential difference leads no nothing as long there is no completion of the electric circuit. As soon as shore power is connected to the boat, the shore earth is automatically connected to the boats hull and the electric circuit is complete. Now the following circuit is made: hull – water – shore – earth spike – earth wire – hull. A current will flow through this circuit, called galvanic current. The galvanic current partly runs through the AC circuit but is not related to that circuit. Current will continue to flow until the potential difference is eliminated. The height of the current depends on the resistance of the electric circuit. The resistance is determined by factors like the length of the shore power cable and local earth spreading resistance.



Chemically speaking, the "weakest" metal in the galvanic circuit will be the quickest to submit its molecules to the keep the current going. If the hull of the ship is part of the galvanic circuit and the hull contains the weakest metal, the hull will start to corrode over time. This can develop into a nasty situation, if leaved unchecked; it can become quite expensive and unsafe.
There are known cases of ships having sunk due to galvanic corrosion. Aluminium hulls are notoriously susceptible to this kind of corrosion.

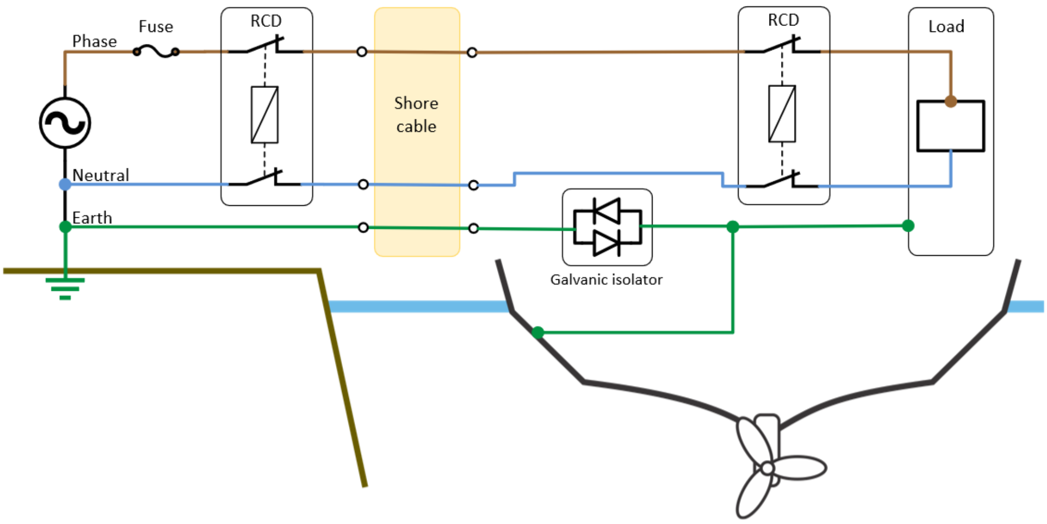
Galvanic corrosion can also exist between the different metals attached to a boat, like screw, motor, hull and so on. All these parts are connected to earth and therefore additional small currents will run between these parts. This is the reason sacrificial anodes are mounted.
A sacrificial anode is a piece of metal that is weaker than the metal around it. Therefore, they are sacrificed in order to protect the other metals. They can only prevent corrosion by postponing it. What type of sacrificial anode to use, depends on the type of metal it protects and what type of water the boat is in. It is recommended to regularly check these anodes.

7.1 Preventing galvanic corrosion

The answer to prevention is quite simple. To prevent corrosion the electric circuit must be broken. Although this is nearly impossible to achieve with the small circuits between the different metals attached to the boat, it is achievable with the shore power connection.
The easiest way to break this circuit is to not connect the shore earth to the hull. However, this is unsafe and not recommended, because this results in the hull being not sufficiently earthed and therefore a satisfactory working of the RCD cannot be guaranteed anymore, leading to unsafe situations on board.
There are safe ways to prevent galvanic corrosion without compromising safety. This can be achieved by using a galvanic isolator or by using an isolation transformer.

7.2 The galvanic isolator

The galvanic isolator consists of two diodes connected in anti-parallel. The galvanic isolator is connected between the shore earth connection and the central earth point in the boat.
The diodes in this configuration conduct electricity in both directions only when a certain threshold voltage is reached. The threshold voltage is approximately 1.4 VDC. The threshold voltage is higher than the galvanic potential difference between the various metals. In this way no galvanic current can run. On the other hand, a higher earth fault voltage in the AC circuit will be allowed to pass through enabling the full functioning of a connected RCD.
The advantage of the galvanic isolator is its low weight and size, the disadvantage is that this unit relies on a good earth conductor. Another consideration is that galvanic corrosion can also take place through the neutral conductor, this in cases where the neutral conductor has been connected to earth trough one of the electrical appliances on board, like a suppression filter or other appliances.



7.3 The isolation transformer

A better solution to stop galvanic corrosion is the use of an isolation transformer. In an isolation transformer the incoming electricity is changed into electromagnetism and then changed back into electricity.

The input and output are completely isolated and will break the electric circuit between star point – earth conductor – hull – water – star point, thus effectively blocking a galvanic current.
Another feature of the isolation transformer is that electrically speaking it is an electricity source, fed by another electricity source. On the output side of the transformer one of the outgoing phases is connected to the hull, whereby creating a phase, neutral and earth, thus guaranteeing a correct functioning of a RCD.

An isolation transformer will give the same safety as in a house installation and more. The installation is also completely isolated of electrical problems of surrounding boats. An added benefit is that an isolation transformer is quite often able to raise or lower the incoming shore voltage. This can be useful when 230Vac boat has to connect to a 120VAC supply, or vice versa.