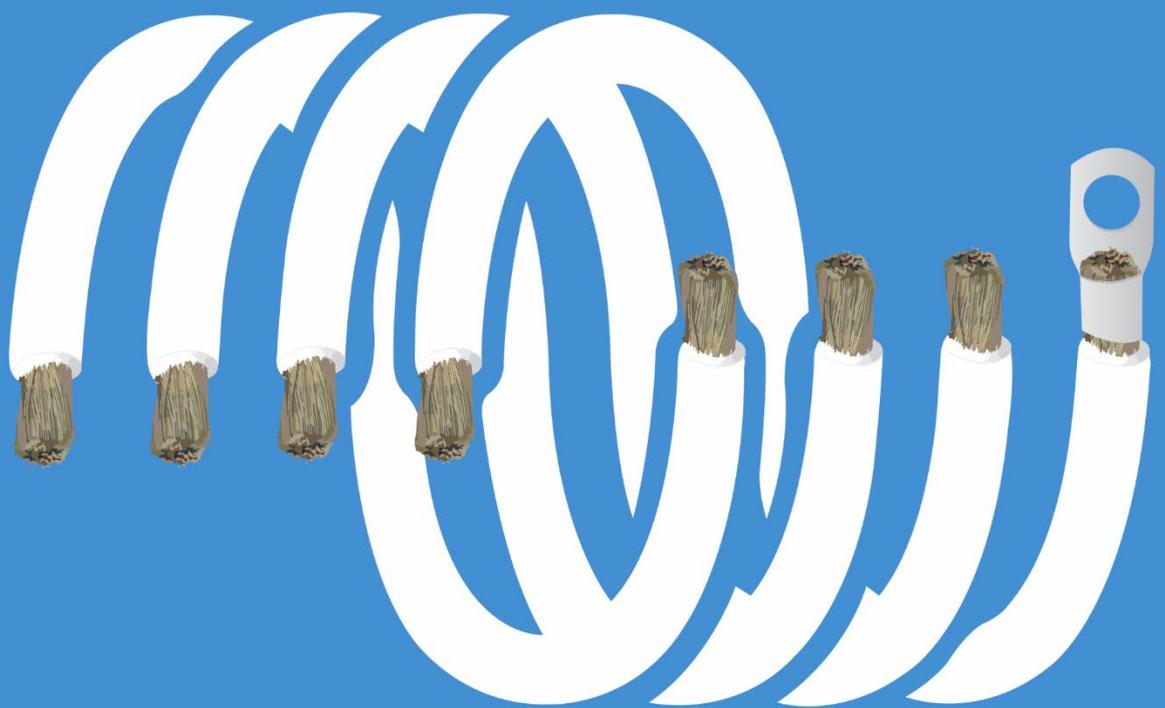


Wiring Unlimited



Wiring Unlimited

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1. Introduction

Welcome to 'Wiring unlimited', a book about electrical wiring of systems containing batteries, inverters, charger and inverter/chargers.

With this book we aim to explain wiring basics of electrical systems. We will explain the importance of 'getting it right' and the issues that might result if a system has inferior wiring. It also assists electrical installers or users to troubleshoot issues that have arisen from bad wiring. This so correct conclusions can be drawn for the electrical systems they are involved with.

Wiring issues are often a cause of system problems, or they can lead to underperformance of systems.

For a trouble-free operation of any electrical system and particularly those systems that contain an inverter/charger and batteries which are 'high-current' devices, it is essential that the wiring of the system is done correctly.

This book will help you with 'getting it right'.

1.1 Safety warnings

Electricity is dangerous. It can cause harm to persons or property.

It takes a remarkably small amount of current across the human heart to stop it. Due to the natural resistance of the human skin and tissue this means that a high voltage is required to generate this heart-stopping current. But humans have died at as low as 42 Volt. Both DC and AC can cause this fatal occurrence. Electrical work should therefore always be carried out by a qualified electrician or technician and the local safety guidelines and requirements need to be adhered to.

IMPORTANT:

- AC and DC voltages are dangerous and harmful.
- Always use insulated tools when working with electricity and batteries.
- Do not short circuit batteries this can cause fire or explosion.
- Battery charging can create explosive gasses.
- Undersized wiring or bad electrical contact can cause fire.

1.2 Disclaimer

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.

Electrical wiring regulations can be 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 from local authorities and/or licensed electricians prior to undertaking any electrical work.

2. Theory

You will get the most out of this document if you have knowledge of basic electrical theory. This will help you to understand the underlying factors that determine wiring thickness and fuse ratings. You might already have this basic understanding and can perhaps skip this chapter, but we highly recommend that you at least have a read.

2.1 Ohm's Law

Ohm's law is the most important law of an electric circuit. It is the basis of almost all electrical calculations. It allows you to calculate the current that runs through a cable (or a fuse) at different voltages. Knowing how much current runs through a cable is essential knowledge to be able to choose the correct cable for your system.

But first some electricity basics are needed.

Electricity is movement of electrons in a material, called a conductor. This movement creates an electric current. This current is measured in "ampere" (amps for short) and the symbol is A.

The force required to make the electrons flow is called voltage (or potential). It is measured in volt and the symbol is V (In Europe also referred to as U).

When an electrical current passes through a material, it meets a certain resistance. This resistance is measured in Ohm. The symbol is Ω .

Voltage, current and resistance are related to each other.

- When the resistance is low, many electrons move, and the current is high.
- When the resistance is higher, less electrons move, and the current is lower.
- When the resistance is very high, no electrons move at all, and the current has stopped.

You can say that the resistance of a conductor 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:

$$\text{Current (A)} = \text{Voltage (V)} / \text{Resistance } (\Omega)$$

$$I = V/R$$

2.2 Power

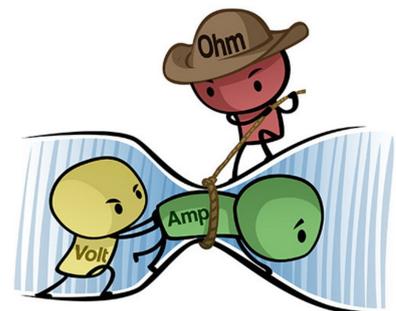
Ohm's law describes the relationship between resistance, current and voltage. But there is one more electrical unit that can be derived from Ohm's law and this is Power.

Power is an expression of how much work an electric current can do.

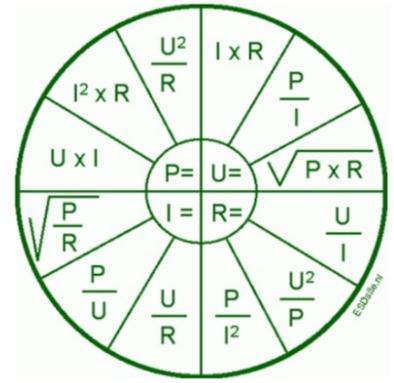
It is measured in Watts and the symbol is P.

It can be calculated using the following formula:

$$P = I \times V$$



From Ohm's law other formulas can be derived. 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 : $I = P/V$

This formula lets you calculate how much current runs through a cable when the voltage and the power is known.

An example of how this formula can be used:

Question:

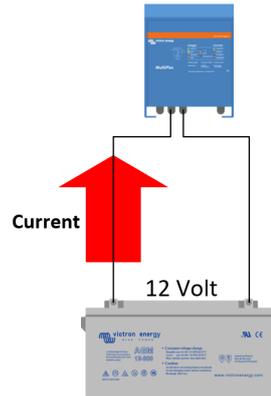
If we have a 12V battery that is connected to a 2400 W load. How much current is running through the cable?

Answer:

V = 12 V

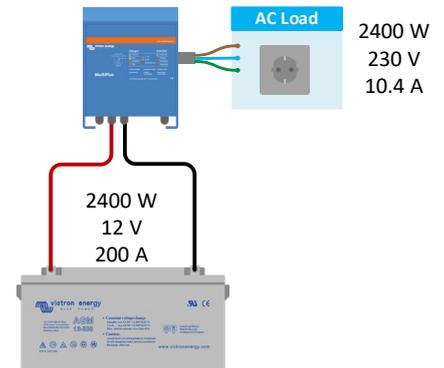
P = 2400 W

$I = P/V = 2400/12 = 200 \text{ A}$



A big advantage of using power in calculations or for measurements is that power is independent of voltage. This is useful in systems where multiple voltages exist. An example of this would be a system with a battery, mains power and perhaps a solar panel.

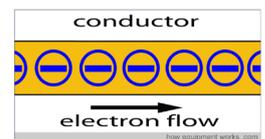
Power remains the same across the different voltages. For example, if you run an AC load of 2400 W via an inverter from a 12 V battery it will also take 2400 W from the battery (ignoring the inverter inefficiencies).



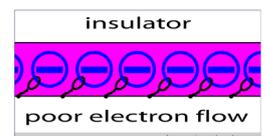
2.3 Conductivity and resistance

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 is why non-conductive materials, like plastic or rubber, are used on the outside of cables. You will not get an electrical shock when you touch the cable because electricity cannot travel through this material. Insulators are also used to prevent short circuit when two cables touch each other.



Each material has its own specific resistance. It is measured in $\Omega \cdot m$. and the symbol is ρ (rho).

The table on the right lists various conducting materials, their electrical conductivity and their specific resistance. As you can see in this table, 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 therefore has a higher specific resistance. Titanium is not very suitable as an electric conductor.

 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
Platinum	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 of the same length.
- A long cable has a higher resistance than a short cable of the same thickness.

The resistance of a length of cable can be calculated:

Resistance = Rho x *length*/Area

$R = \rho \times l/A$

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

- The electrical resistance of the material used.
- 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. When a current passes through a cable the cable resistance is responsible for these two effects:

- There will be a voltage drop (loss) over the cable length.
- The cables heat up.

If the current is increased these effects will be worse. An increased current will increase the voltage drop and the cable will heat up more.

This is how to calculate the resistance of a cable:

Question:

What is the resistance of a 1.5-meter-long, 16 mm² cable?

Given:

ρ copper = $1.7 \times 10^{-8} \Omega/m$

$l = 1.5 \text{ m}$

$A = 16 \text{ mm}^2 = 16 \times 10^{-6} \text{ m}^2$

Answer:

$R = \rho \times l/A$

$R = 1.7 \times 10^{-8} \times 1.5 / (16 \times 10^{-6})$

$R = 1.7 \times 10^{-2} \times 1.5 / 16$

$R = 0.16 \times 10^{-2} = 1.6 \times 10^{-3}$

$R = 1.6 \text{ m}\Omega$

The effect of cable length:

Let's use the previous example and now calculate for a 5 m 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 cable with a cross-section of 2.5 m². The result will be that the resistance is 10.2 mΩ. If you make the cable thinner the resistance increases.

Conclusion:

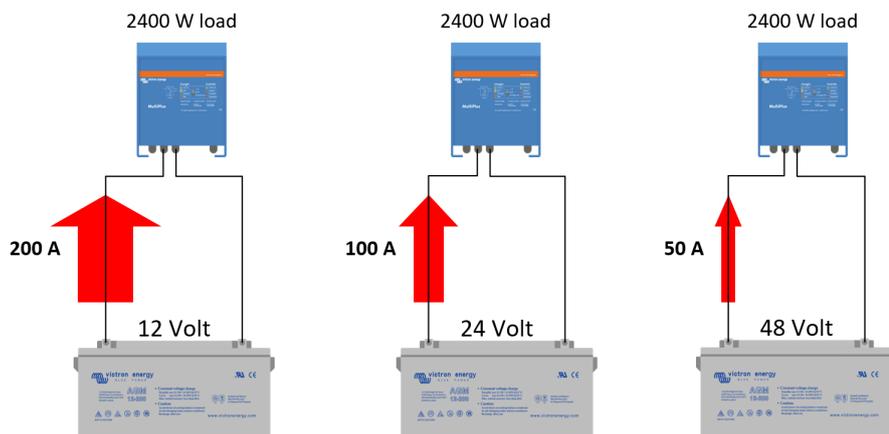
Both cable thickness and cable length have a big impact on cable resistance.

2.4 Current, cable resistance and voltage drop

As already explained, the current that flows through an electrical circuit for a fixed load, is different for a variety of circuit voltages. The higher the voltage, the lower the current will be.

$$I = P/V$$

Below is an overview of the amount of current that flows in 3 different circuits where the load is the same, but the battery voltage varies:



Also, as explained already, a cable has a certain amount of resistance. The cable is part of the electrical circuit and can be treated as a resistor.

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

$$\text{Power} = \text{Resistance} \times \text{Current}^2$$

$$P = R \times I^2$$

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

$$\text{Voltage} = \text{Resistance} \times \text{Current}$$

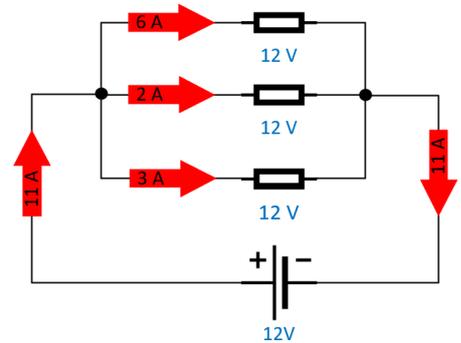
$$V = R \times I$$

To be able to calculate the effect of a cable voltage drop, you will need to know two more electric laws, the first and second law of Kirchhoff:

Kirchhoff's current law (1st Law)

The current flowing into a junction must be equal to current flowing out of it.

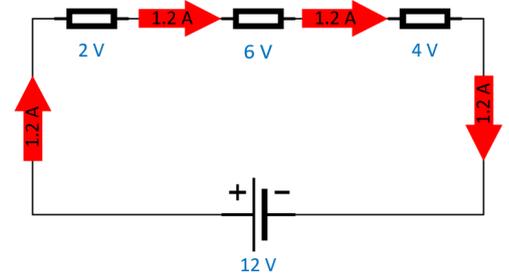
An example of this is a parallel circuit. The voltage over each resistor is the same while the sum of current flowing through each resistor equals the overall current.



Kirchhoff's voltage law (2nd Law)

The sum of all voltages around any closed loop in a circuit must equal zero.

Here the exact opposite is the case. In a series circuit, the current through each resistor is the same, while the sum of the voltages over each resistor equals the overall voltage.

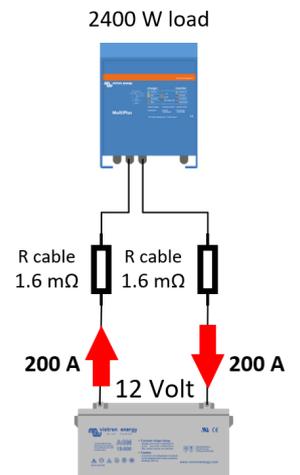


Now, let's use a real-world example of an inverter that is connected to a 12 V battery and calculate the cable losses. In the circuit diagram on the right you find a 2400 W inverter connected to a 12 V battery using two 1.5-meter-long, 16 mm² cables.

As we calculated earlier, each cable has a resistance of 1.6 mΩ.

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

- A 2400 W load at 12 V creates a current of 200 A.
- The voltage drop over one cable is: $V = I \times R = 200 \times 0.0016 = 0.32 \text{ V}$.
- Because we have two cables, the total voltage loss in this system is 0.64 V.

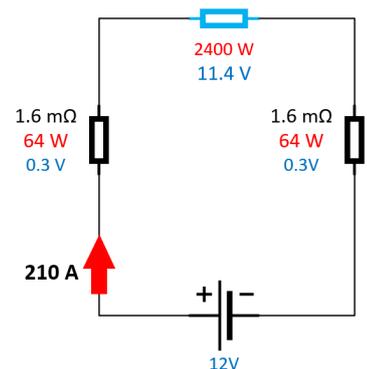


Because of the 0.6 V voltage drop, the inverter does not get 12 V anymore, but $12 - 0.6 = 11.4 \text{ V}$.

The power of the inverter is a constant in this circuit. So, when the voltage to the inverter drops, the current will increase. Remember $I = P/V$.

The battery will now deliver more current to compensate for the losses. In this example this means that the current will increase to 210 A.

This makes the system inefficient because we now have lost = 5 % ($0.64 / 12$) of the total energy. This lost energy has been turned into heat.



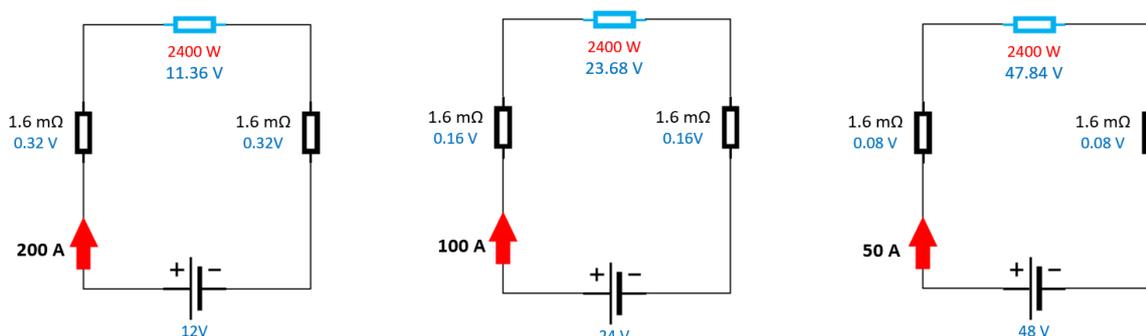
It is important to keep this voltage drop as low as possible. The obvious way to do that is to increase the thickness of the cable or to keep the cable length as short as possible. But there is something else you can do, and this is to increase the circuit's voltage. The cable voltage drop varies for different battery (system) voltages. Generally speaking, the higher the circuits voltage the lower the voltage drop will be.

Example:

If we look at the same 2400 W load, but now the circuit voltage is 24 V:

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

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



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 this table:

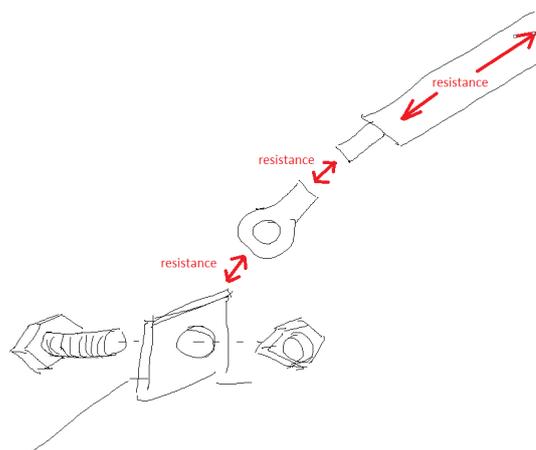
Battery voltage	Percentage	Voltage drop
12 V	2.5 %	0.3 V
24 V	2.5 %	0.6 V
48 V	2.5 %	1.2 V

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

- Cable length and thickness.
- Fuses.
- Shunts.
- Switches.
- Cable lug crimps.
- Connections.

And especially watch out for:

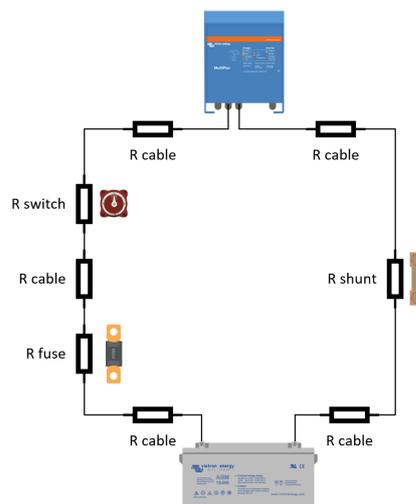
- Loose connections.
- Dirty or corroded contacts.
- Bad cable lug crimps.



Resistance will be added to the electrical circuit each time a connection is made, or something is placed in the path between the battery and the inverter.

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 know what we need to do to keep resistance in a circuit down to prevent a voltage drop. But what are the negative effects if there is a high voltage drop in a system?

This is a list of the negative effects of a high voltage drop:

- Energy is lost, and the system is less efficient. Batteries will be discharged quicker.
- The system current will increase. This can lead to DC fuses blowing.
- High system currents can lead to premature inverter overloads.
- Voltage drop during charging will cause batteries to be undercharged.
- The inverter receives a lower battery voltage. This can potentially trigger low voltage alarms.
- The battery cables heat up. This can cause melting wiring insulation or cause damage to cable conduits or contented equipment. In extreme cases cable heating can cause fire.
- All devices connected to the system have a shorter lifetime because of DC ripple.

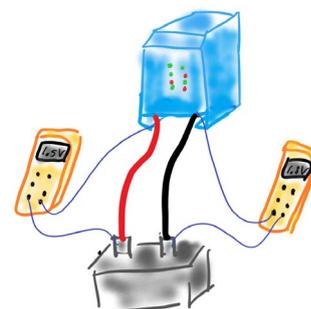
This is how to prevent voltage losses:

- Keep cables as short as possible.
- 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 cable lugs and crimp these with the appropriate tool.
- Use quality battery isolator switches.
- Reduce the amount of connections within a cable run.
- Use DC distribution point or busbars.
- Follow wiring legislation.

It is good practice to measure the system voltage drop once you have completed an electrical installation that contains batteries. Remember that a voltage drop typically occurs during a high current event. The voltage drop becomes larger when the current increases. This is the case when an inverter is loaded with maximum load or when a battery charger is charging at full current.

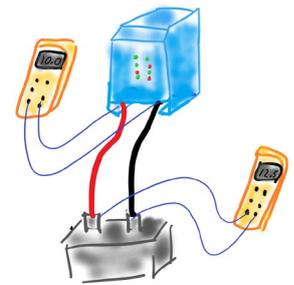
This is how to measure voltage drop, for example in a system with an inverter:

- Load the inverter with maximum power.
- Measure the voltage across the negative cable between inverter connection and the battery pole.
- Repeat this for the positive cable.



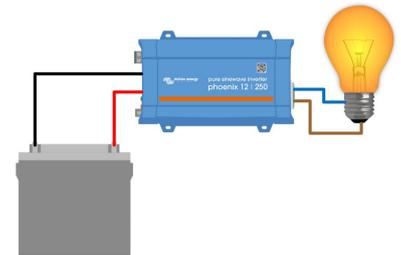
In case of the battery and the inverter being too far away, or the battery is located in a different room or enclosure:

- Load the inverter with maximum power.
- Measure with the voltage across the DC connections inside the inverter.
- Measure the voltage across the battery poles.
- Compare these readings. The difference between the two readings is the voltage drop.



2.6 Ripple

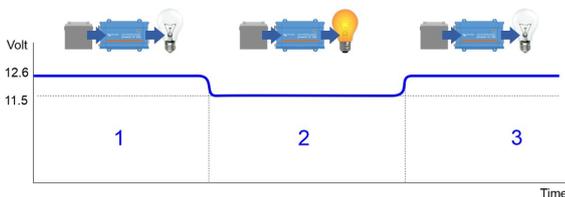
One of the negative effects of a high voltage drop in a system is ripple. Ripple appears in a system where the power source is a battery (DC) and the load is an AC device. This is always the case in a system with an inverter. The inverter connects to batteries, but it powers an AC load.



The mechanism that causes 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, this becomes particularly exaggerated when thin cables have been used.

The voltage drop in a system as a whole can be even bigger, especially if lead acid batteries are used that are too small, too old or damaged. The voltage drop will not only occur over the cables, but also within the battery itself.

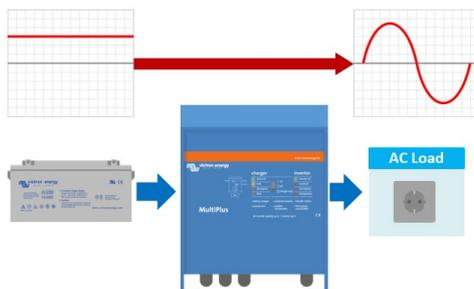
Ripple is related to the phenomenon that when an inverter is powering a large load, the system DC voltage drops. But the system voltage recovers once the load has been turned off. This process is depicted in the drawing below.



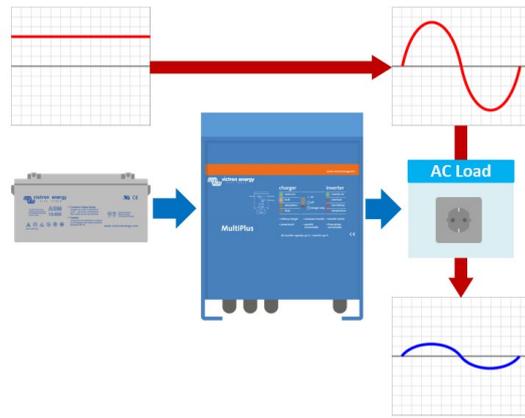
1. The voltage measured at the inverter is normal. In this example it is 12.6 V.
2. When a large load is turned on the battery voltage drops to 11.5 V.
3. When the load is turned off, the battery voltage usually recovers back to 12.6 V.

How is ripple created?

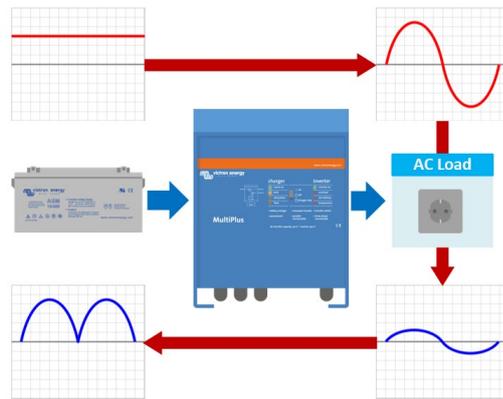
1. The inverter converts a DC voltage into an AC voltage.



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

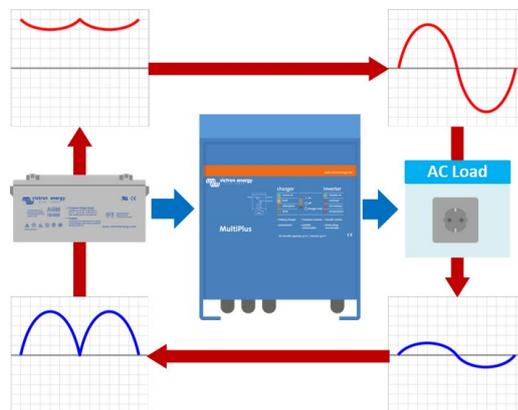


3. This AC current causes (via the inverter) a fluctuating DC current on the battery.



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 and so forth.

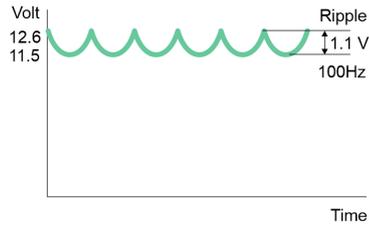


The DC voltage will keep going up and down and is not constant anymore. It now is fluctuating. It will go up and down 100 times per second (100 Hz). The amount the DC voltage fluctuation is called ripple voltage.

Normal DC looks like this:



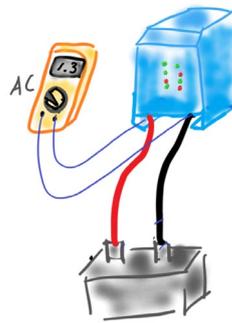
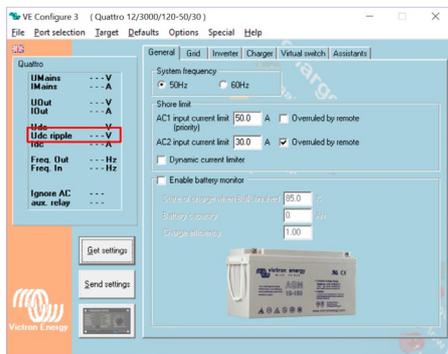
DC voltage with ripple looks like this:



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

- Use a multimeter. Select AC mode on the multimeter. Measure across the inverter's DC connections. You are now measuring the AC component of the DC voltage. This AC voltage is the ripple voltage.
- Use VEConfigure, it keeps track of ripple.

When measuring ripple, remember that this only occurs when the system is under full load. The same applies as for voltage drop. Ripple can only be detected when the inverter is powering a full load or when a charger is charging at a high current.



A small amount of ripple can exist with no measurable impact. However, 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 as 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 off after 20 minutes.
- Full ripple alarm: Both the overload and low battery LEDs are on and the unit powers down.

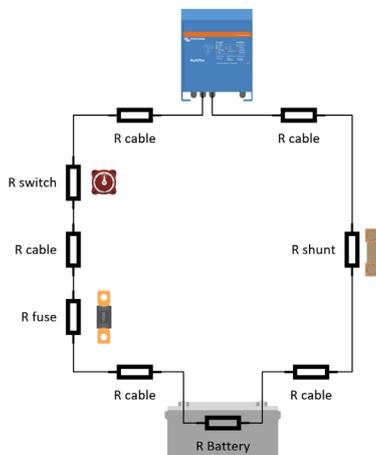
These are the ripple alarm levels for the different voltages:

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

Ripple will only occur when there is a voltage drop in a system. To fix ripple you will have to reduce the voltage drop. This means that you have to reduce the resistance in the path from battery to inverter and back to the battery. For more information see 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 for connectivity.
- Check the specifications of the 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.
- Always use good quality components.



3. Battery bank wiring

3.1 Battery bank

At the heart of any Victron system sits the battery. This is either a single battery or a number of interconnected batteries.

Batteries are interconnected to increase the battery voltage or to increase the battery capacity or both. Multiple interconnected batteries are called a battery bank.

The following applies to battery banks:

- When two batteries are connected in series the voltage increases.
- When 2 batteries are connected in parallel the capacity increases.
- When batteries are connected in series/parallel voltage and capacity increase.

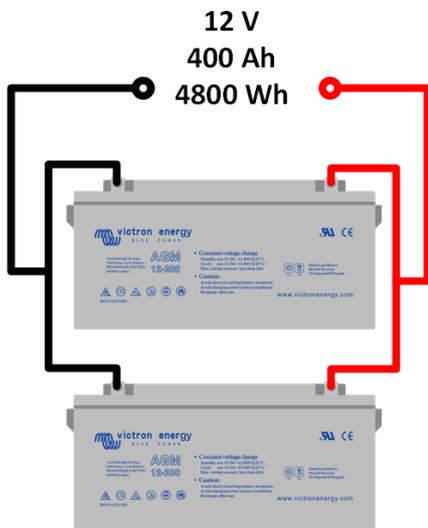
Some examples:



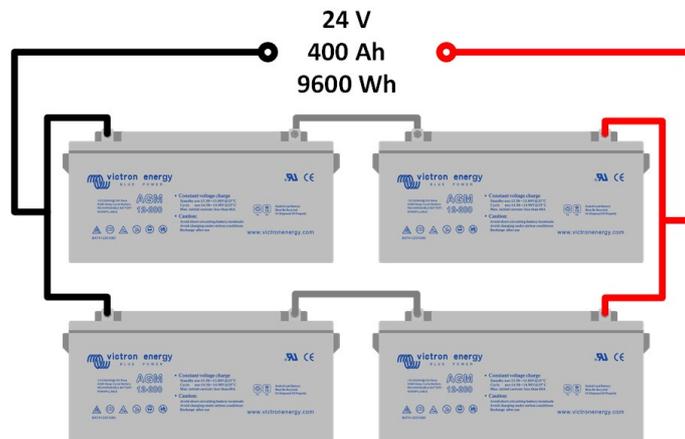
Single battery



Two batteries in series



Two batteries in parallel



Four batteries in series/parallel



Four batteries in series

3.2 Large battery banks

If a large battery bank is needed, we do not recommend that you construct the battery bank out of numerous series/parallel 12V lead acid batteries. The maximum is at around 3 (or 4) paralleled strings. The reason for this is that with a large battery bank like this, it becomes tricky to create a balanced battery bank. In a large series/parallel battery bank imbalance is created because of wiring and because of slight differences in battery internal resistance.

If a large battery bank is needed, consider using 2 V lead acid batteries or lithium batteries.

2V lead acid batteries

2 V 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 cell balancing and internal or external battery management system (BMS).



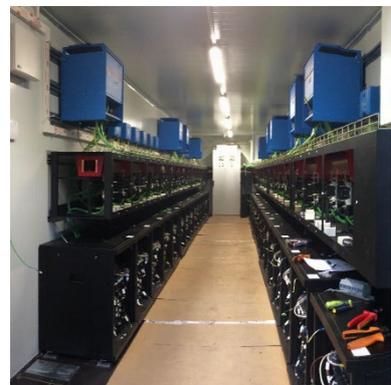
Smart Lithium batteries

With cell balancing and internal or external battery management system (BMS).

Each battery has the ability to communicate with each other, but they can also communicate with a monitoring device. In Victron's case this is a GX device.

The batteries will generate a total state of charge value for the whole battery bank and send this to the GX device.

More info on which brands can work with Victron and how to set them up see [here](#).



Other battery chemistries

Flow batteries and other chemistries. These are commonly available in 48 V. 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 GX monitoring device is needed in the system.

More info on which brands can work with Victron and how to set them up see [here](#).

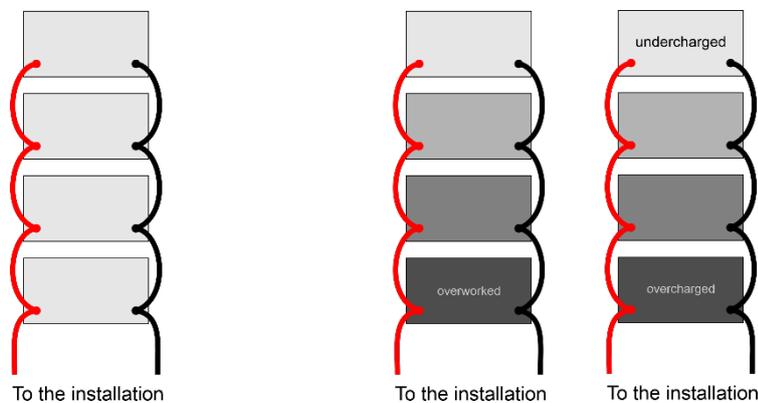


3.3 Parallel battery bank wiring

It matters how a battery bank is wired into the system. When wiring a battery bank, 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 electrical installation. As indicated in the image below.

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. Each set of leads has its own resistance and is additive. The top battery will provide much less current than the bottom battery.

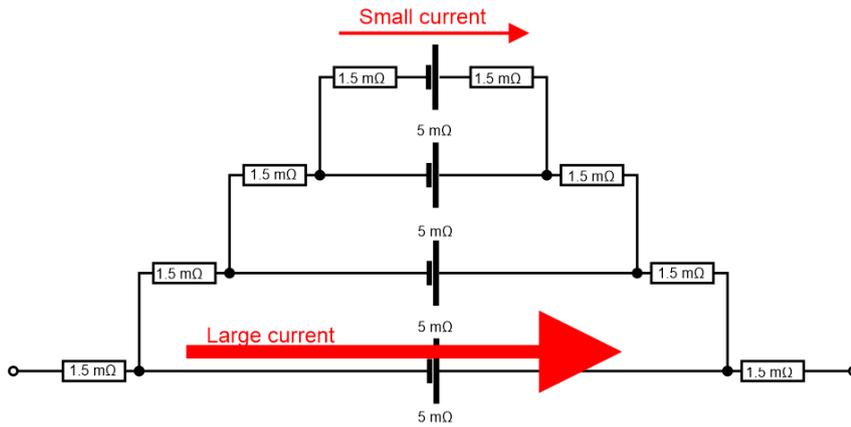
What happens if the battery bank is being charged? The bottom battery gets charged with a higher current than the top battery. The top battery gets charged with a lower voltage than the bottom battery. The result is that the bottom battery is worked harder, discharged harder, charged harder. The bottom 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. Also, the cable lugs and the battery connections will add to this resistance.

To give an indication of this, the total resistance for a 20 cm, 35 m² cable together with cable lugs attached is about 1.5 mΩ. You might say that 1.5 mΩ is not much but remember that the internal resistance of a 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:

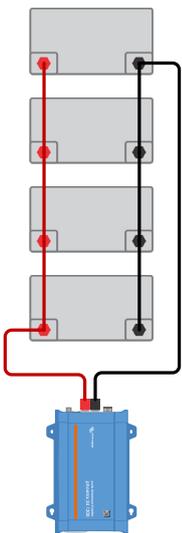


Current will always choose the path of least resistance. Most of the current will therefore travel through the bottom battery. And only a small amount of current will travel through the top battery.

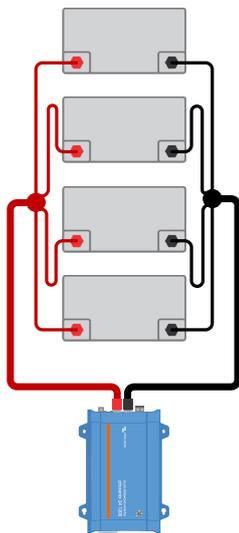
The correct way of connecting multiple batteries in parallel is to ensure that the total path of the current in and out of each battery is equal.

There are 4 ways to do this:

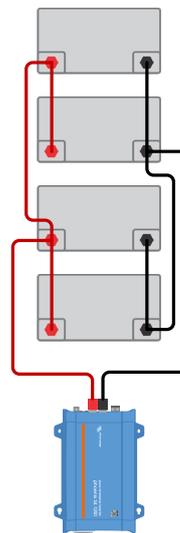
- Connect diagonally.
- Use a positive and negative post. The cable lengths from post to each battery need to be equal.
- Connect halfway. Make sure all cables have the same thickness.
- Use busbars.



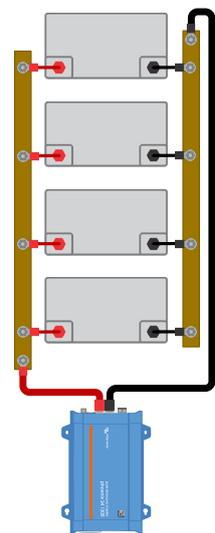
Diagonally



Posts



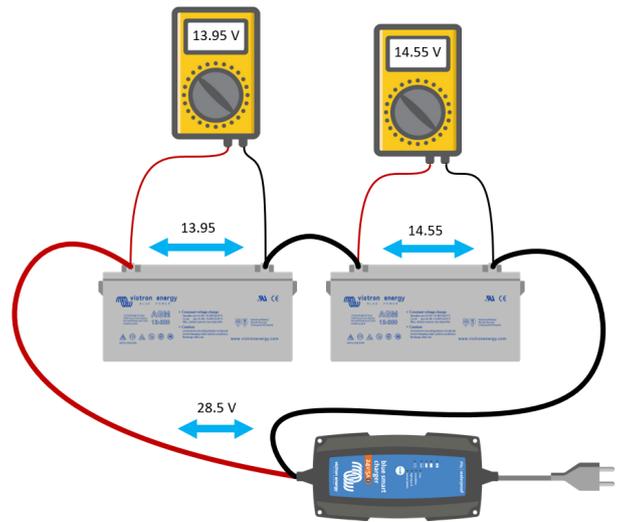
Halfway



Busbars

3.4 Battery bank balancing

When creating a battery bank with a higher voltage, like 24 V or 48 V you will need to connect multiple 12 V batteries series. But there is one problem with connecting batteries in series, and this is that batteries are not electrically identical. They have slight differences in internal resistance. So, when a series string of batteries is charged, this difference in resistance will cause a variance in terminal voltages on each battery. Their voltages become “unbalanced” This “unbalance” will increase over time and will lead to one of the batteries being constantly overcharged while the other battery is constantly under charged. This will result in a premature failure of one of the batteries in the series string.



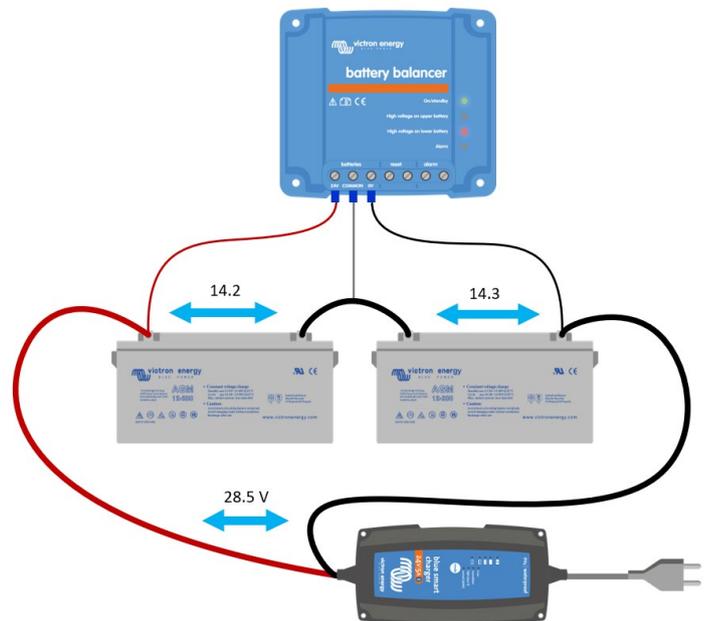
To check if battery unbalance is occurring in your system:

- Charge the battery bank.
- Measure towards the end of the bulk charge stage. This is when the charger is charging at full current.
- Measure the individual battery voltage of one of the batteries.
- Measure the individual battery voltage 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, make sure you 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 is wired into a system as indicated in the image on the right. It measures the battery bank voltage and also the individual battery voltages. The battery balancer activates as soon as the battery bank is being charged and the charge voltage has reached more than 27.3 V. At that moment, the battery balancer will start to measure and compare the voltages of both batteries. As soon as it detects a voltage difference of more than 0.1 V between the two batteries, it will illuminate a warning light and it will start to balance the two batteries. It does this by discharging the higher battery by drawing a current of up to 0.7 A from that battery until both battery voltages are equal.



If battery balancing does not have the required effect and the voltage difference becomes larger than 0.2 V, the battery unbalance is larger than the battery balance can correct. This is most likely an indication that one of the batteries has developed a fault and the Battery Balancer will sound an alarm and it will activate its alarm relay.

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

For more info see the datasheet of the [Battery Balancer](#).

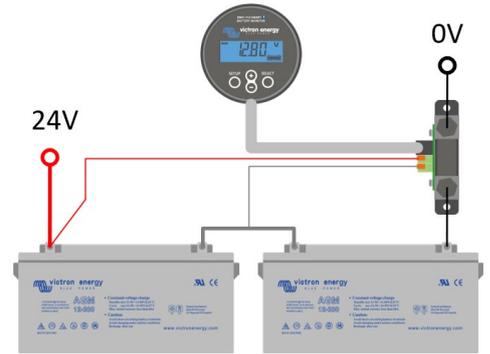
3.5 Battery bank midpoint

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)

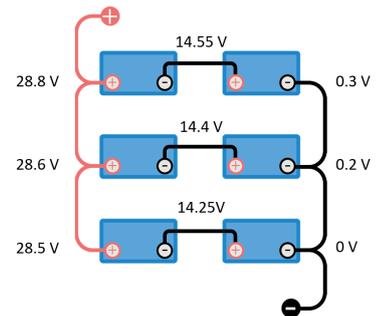
Both the battery balancer and the Battery Monitor BMV 702 and BMV 712 can generate a midpoint alarm.



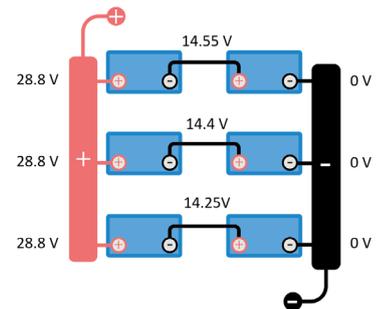
The BMV 702 and BMV 712 have a second voltage input that can be used for midpoint monitoring. It can be wired to the midpoint of the battery bank. The BMV will display the difference between the two voltages or as a percentage. For more info see the battery monitor [product page](#).

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

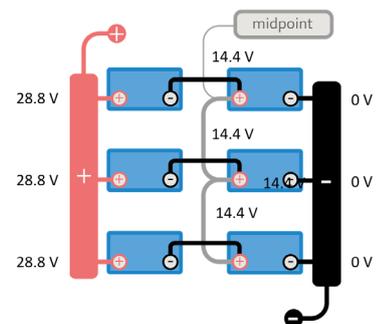
If you connect batteries in series/parallel, like the image on the right, you will see that the individual voltages will vary per series string and they will also vary within the string.



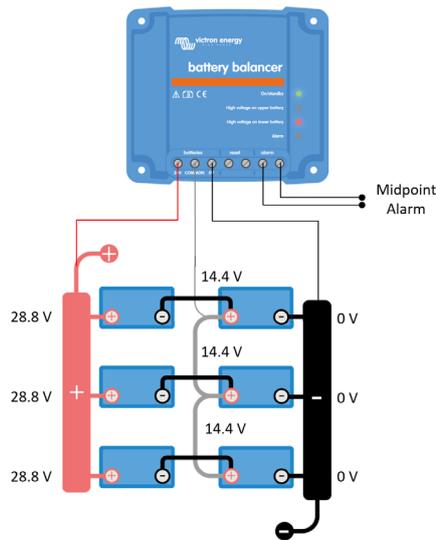
First make sure that each string has the same voltages by using a common negative and positive connection point or busbar.



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.

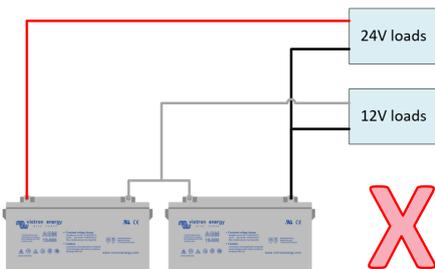


Once the midpoint of the battery bank is connected one battery balancer can be used, instead of using 3 battery balancers (one for each string). Also, a single BMV can be used for midpoint monitoring of the entire battery bank.

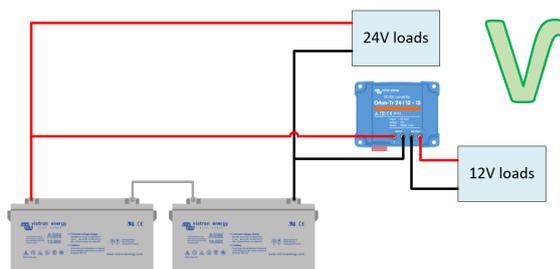


But please be aware, that the only reason to use the midpoints of a battery bank is for balancing and/or monitoring purposes. It is not allowed to connect loads to the midpoint of a battery bank in order to be able to run loads that require a lower voltage. Doing so will create a large imbalance in a battery bank. This imbalance is much bigger than a battery balancer can potentially rectify (larger than 0.7 A) and 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:

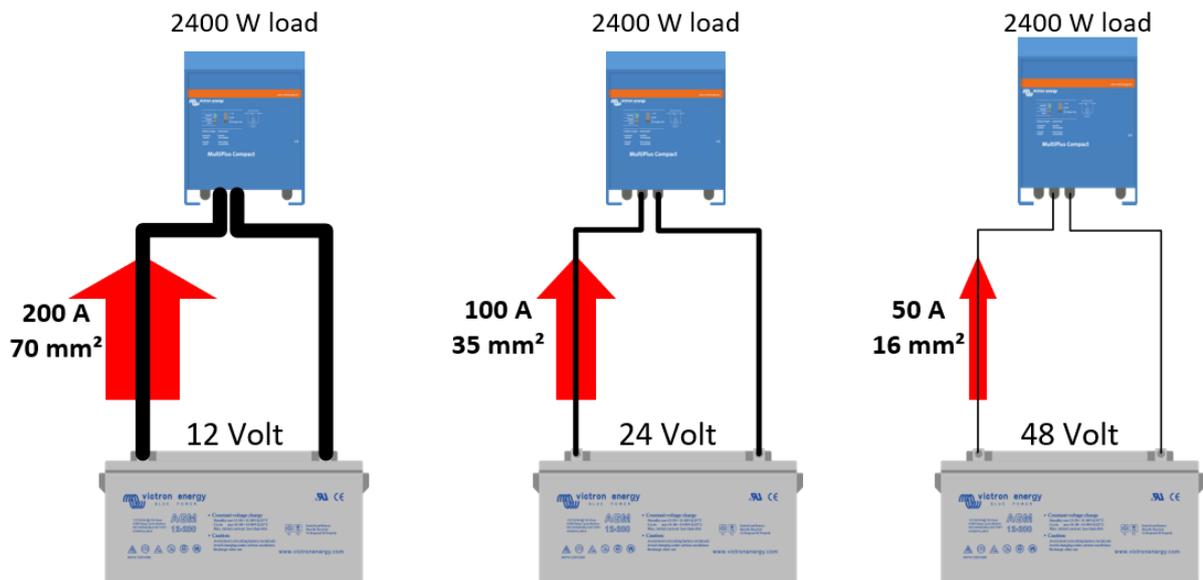


4. DC wiring

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.

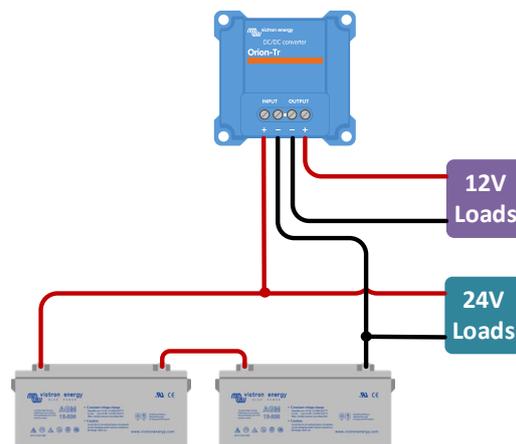
This is an example of what cable size belongs to these currents. Providing that the cable distance is less than 5 meters.



In order to avoid very thick cables, the first thing you should consider is to increase the system voltage. A system with a large inverter will cause large DC currents. If the DC system voltage is increased, the DC current will drop, and the cables can be thinner. The preferred upper inverter power limits per system voltage are:

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

If you want to increase the system voltage, but there are DC loads or DC charge sources that only can deal with 12V, you could consider using 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. You can find the correct cable thickness in the product manual. Using a too thin cable has a direct negative effect on system performance.

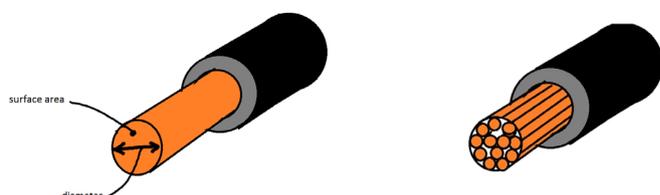
Generally, cable core thickness is indicated in mm². This indicates the surface area of the cable core. But other annotations are used as well. Like AWG (American Wire gauge) is used. In that case see [here](#) for a conversion table.

To find out the core diameter of a stranded core cable, look at 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. Find out the actual core diameter by looking at the cable marking or at its specifications, or alternatively do a physical check. Strip a bit of cable insulation away and look at the copper core of the cable and estimate the core diameter.

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 method is not that precise. (Please note that we do not recommend using solid core cables).



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

If you cannot find a thick enough cable, double up. Use two cables per connection, rather than one very thick one. But if you do, always make sure that the combined surface area of both cables is equal to the recommended surface area. For example, 2 x 35 mm² cables equal one 70 mm² cable. Larger Victron inverter/chargers are equipped with 2 positive and 2 negative battery connections especially for this purpose.



When selecting cables avoid these mistakes:

- Don't use cables with coarse strands.
- Don't use non-flexible cables.
- Don't use AC cables.
- For marine or moist situations use "marine cables". These are cables with tin coated copper strands.



Calculating cable thickness can be difficult. There are ways to help you with selecting the correct cable thickness:

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

Product manuals

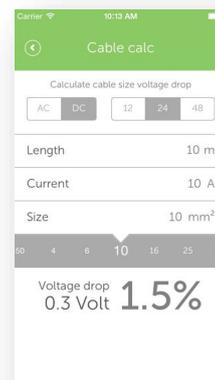
All our manuals recommend the battery cable size (and fuse size) that needs to be used for the product.

	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 [Toolkit App](#) will calculate the voltage drop over both cables.

Recommended battery cables document

This [document](#) contains a table that shows the maximum current for a number of standard cables where the voltage drop is 0.259 Volt.

cable diam mm	cable section mm ²	L(+) + L(-) tot 5 meters	L(+) + L(-) tot 10 meters	L(+) + L(-) tot 15 meters	L(+) + L(-) tot 20 meters
		I max A	I max A	I max A	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:

$$\text{Current} / 3 = \text{cable size in mm}^2$$

Example:

Current is 200 A

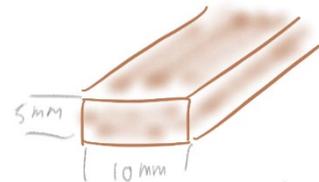
Then the cable needs to be: $200/3 = 66 \text{ mm}^2$

4.2 Busbars

Busbars are like cables, only they are rigid metal bars. They are made of copper or tinned copper. They are used in large systems where large currents flow. They provide a common positive and a common negative point between the batteries and multiple inverters. Busbars are also used in smaller systems, especially when there is 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 busbar cross-section area.

$$\text{surface area} = \text{width} \times \text{depth}$$



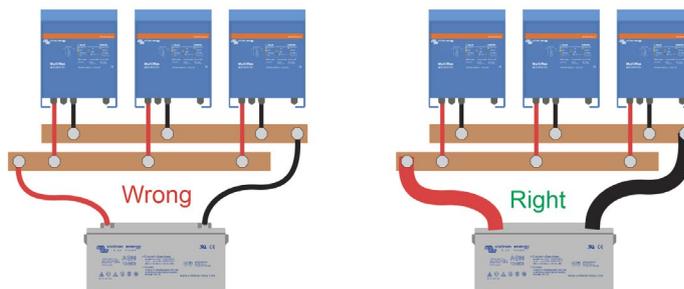
For example:

A busbar of 10 mm x 5 mm.

The surface area cross-section is $5 \times 10 = 50 \text{ mm}^2$.

This should be suitable for 150 A for distances up to 5 meters.

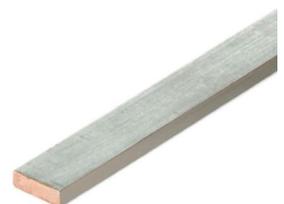
When wiring the system please make sure that the cross-section of the connection between the batteries and the DC distribution point equals the sum of the required cross-sections of the connections between the distribution point and the DC equipment.



When using busbars, it is in most cases necessary to shield the busbar, especially if the busbar is out in the open. This is to prevent people touching the busbar, or to prevent a short circuit if a metal object should accidentally fall across the positive and negative busbars and accidentally short circuit both busbars. An easy way to do this is to mount a Perspex sheet in front or over the busbar. See image on the right.



Busbars can be easily made by yourself, you simply need a copper bar where you drill holes in so electrical cables can be connected to the bar. For marine applications use tinned copper busbars. Busbars can be purchased from electrical wholesalers or metal suppliers.



Victron has two product ranges that contain busbars.

The first product is the [modular fuse and busbar](#) system. The busbar is rated up to 500 A.



The second product range is the [Lynx system](#). It consists of separate units that can be connected to each other to form a busbar. The busbar is rated up to 1000 A. The Lynx can be used in 12, 24 or 48 V systems

- Lynx Power in - to connect batteries (a Lynx distributor can also be used).
- Lynx shunt - This unit houses the main fuse, the shunt and battery monitor electronics (A GX device is needed to read out the battery monitor).
- Lynx distributor - to connect 4 DC loads and their fuses and indication light per fuse. (multiples can be connected).



4.3 Cable connections

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

Bolts, nuts and screws

These usually come in sizes like M5, M6, M8 or M10. Bolts for electrical purposes are usually made out of tinned brass. So, when tightening these always use the correct torque. Over tightening might break the nut or bolt. See product manual for the recommended torque.



Cable eye lugs are used to connect the cable to a bolt. 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 connecting the cable eye to the bolt, place a washer and spring ring and then the nut.

Ensure that the lug is flat against the surface below. Do not insert anything between the lug and the mounting surface, like washers or fuses. This will reduce the current carrying capacity of the connection.



Use insulated tools when tightening the nut. An accidental battery short circuit can be very dangerous, and the currents can melt your uninsulated spanner, or the spark can cause a battery explosion.

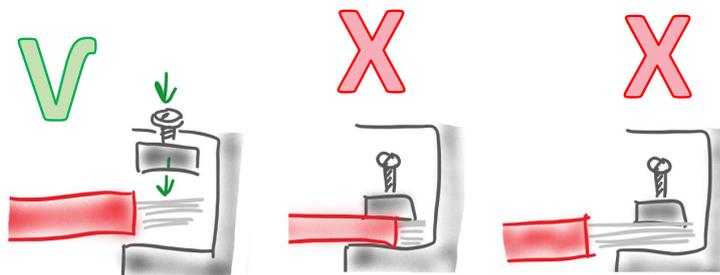


Screw connectors

Screw connectors come in a variety of shapes and sizes, suitable for thick or thin wires.



Strip a sufficient length of cable insulation before inserting the bare end into the connector cavity. Avoid cable insulation entering the connector. This can lead to too much resistance and the connector will heat up and potentially melt. Avoid uninsulated cable (bare cable) to be visible outside the connector. This is dangerous it can cause electrocution or a short circuit.

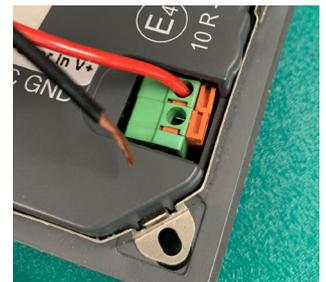


The screws inside electrical connectors are usually made out of tinned brass.

When tightening use always the correct torque. Over tightening might break the screw. See product manuals.

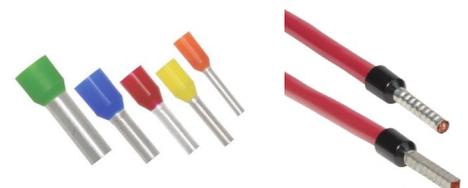
Push connectors

- Strip away a sufficient length of cable insulation.
- Push down the orange part with a flat screwdriver.
- Insert the stripped wire.
- Avoid cable insulation entering the connector. This can lead to too much resistance and the connector will heat up and potentially melt.
- Avoid uninsulated cable (bare cable) to be visible outside the connector. This is dangerous it can cause electrocution or a short circuit.
- 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.



Ferrules

- 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.
- The range of these connector include those with insulated ends and some with special features, like piggyback connectors.



MC connectors

These connectors are exclusively used to connect solar panels to MPPTs. The most common is the MC4, but MC , MC2 and MC3 also exists, but are not used anymore. The letters 'MC' stand for MultiContact, this is the name of one of the original manufacturers which caught on. The digits 1 to 4 stand for the contact pin cross-section in mm².

Some specifics:

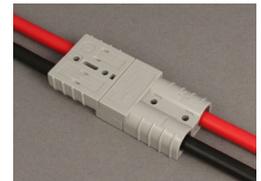
- They are waterproof (IP67) and can be used outdoors.
- Male or female connectors.
- Rated for 20 A, 600 V (newer versions 1500 V).
- A special crimping tool is needed.
- Can be bought as pre-assembled cables.
- MC4 Y-pieces (or Y cables) used to connect solar panels in parallel.



For more info see chapter 4.10 - solar panels.

Anderson plugs

- Often used in automotive or mobile applications where rapid connection and disconnections are common.
- Available in different current ratings and cable thicknesses.
- Make sure the current rating matches the currents when your system is under full load.
- They will add to the cable resistance if they are located between battery and inverter. In this case 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 permanently used in an electrical system.
- Limit or avoid their use.



4.4 Fuses and circuit breakers

A fuse is an electrical safety device. It protects an electrical circuit against high currents.

The fuse is placed in the supply cable to an electrical device. As soon as current flows through the fuse that is higher than its current rating, for a certain amount of time, the fuse will blow. Once the fuse has blown, no more current will flow into the circuit.

Higher than expected current situations can occur when an electrical device develops a fault or when there is short-circuit in the electrical circuit.

The fuse protects against:

- Severe overload - when more current runs in the system than it is rated for.
- Short circuit - when one conductor accidentally comes in contact with another conductor.

How does a fuse work?

There are 3 types of fuse mechanisms. being:

- Wire fuse.
- Thermal fuse.
- Magnetic fuse.

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

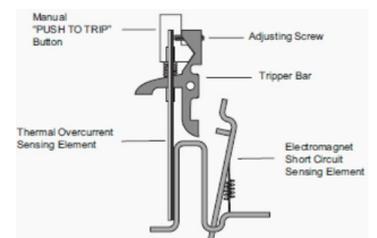
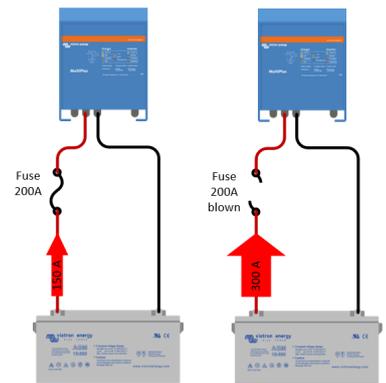
Once the fuse has blown it will need to be replaced by a new fuse to make the circuit operational again. These fuses are one-time use fuses. Once they have blown, they can't be reset. They need to be replaced by a new one.

Another type of fuse is the automatic fuse, often called circuit breaker or miniature circuit breaker (CB or MCB). These devices interrupt the current flow when high current is detected. Sometimes they will reconnect after the high current event has passed, or they need to be manually reset. They do not need to be replaced like the traditional fuses.

There are 2 ways how these fuses operate, either thermal or magnetic or a combination of these.

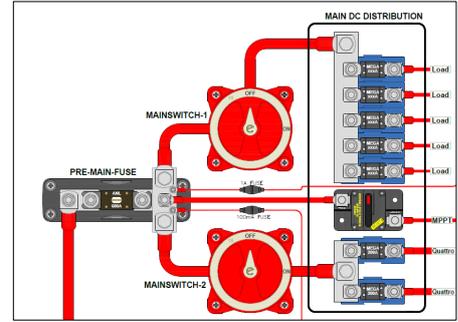
The thermal circuit breaker contains a bi-metal strip that heats up when over current flows. It bends when heated up and by doing so it will break the path of current.

The magnetic breaker contains an electromagnet that is sensitive to a large current. When a large current flow the electromagnet creates a magnetic force that breaks the path of the current.



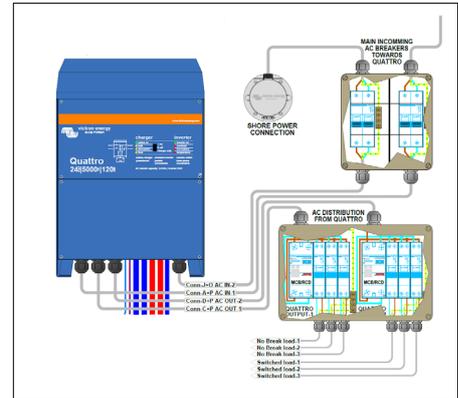
Location of the DC fuses:

Each consumer that connects to a battery needs to be fused. The fuse is placed in the positive cable. Each individual consumer needs to have an individual fuse. No matter how big or small the power rating of the equipment is. Batteries can potentially produce very high currents that can cause a fire. If the consumer develops a fault and internally short circuits, a very large current will flow, potentially causing a fire hazard. A DC circuit usually contains a main battery fuse, after which it branches off to the individual consumers. Each consumer has an individual fuse.



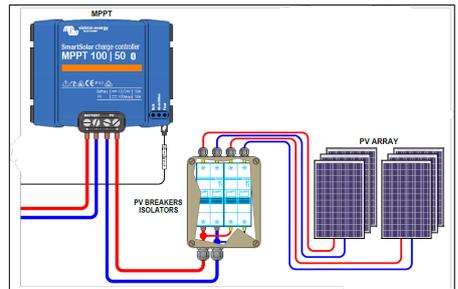
Location of the AC circuit breakers:

The circuit breakers are located near the entry point of the public grid and/or the generator into the switchboard. The AC breaker is placed in the live conductor or in both the live and the neutral conductor. Single or double pole circuit breakers are used. There usually is one main circuit breaker per AC supply, after which the supply branches off into a variety of groups. Each group contains a circuit breaker, protecting a group of AC consumers.



Location of the PV array circuit breakers:

A fuse needs to be located between a PV array and the solar charger. Please check with the local authorities, regulations per application and country will vary.



Fuse holders

Fuses need to be placed in fuse holders. The fuse holder securely holds the fuse in place. And in some cases, they also provide electric insulation. Circuit breakers are usually mounted on DIN rail. Fuses and circuit breakers are usually located in a switch board, preferably inside an enclosure.

Fuse ratings and how to select the correct fuse:

When selecting a fuse there are 4 selection criteria:

- Current rating
- Voltage rating
- Speed
- Type

It is important to choose the correct fuse that will match the circuit and match the power consumption of the equipment in that circuit.

The rating of the fuse is displayed on the fuse or can be found in the fuse's datasheet or its specifications.

Current rating

If there is only one consumer in a circuit, the fuse will need to match the current rating of that consumer or the current rating of the cable, whichever is the lowest of the two.

If there are multiple consumers in a circuit, then the fuse will need to match the current rating of the cabling in the circuit.

Voltage rating

The fuse voltage rating needs to be equal or bigger than the expected maximum voltage in the system.

The fuse needs to be specifically rated for the required type, DC and/or AC.

Most DC fuses are suitable for 12 and 24 V, but they are not necessarily suitable for 48 V and higher.

Please note that not all fuses or circuit breakers can be used in both AC, and DC circuits. If the fuse is able to be used for both AC and DC, the voltage for AC is often rated higher than the DC voltage rating.

Also take care that circuit breakers might not be unidirectional, so for DC it matters which way they are wired into the circuit.

Speed

The speed of a fuse is the time it takes for the fuse to open when a fault current occurs. This is dictated by the fuse material, it's mechanism, the current and the temperature.

There are slow and fast blow fuses:

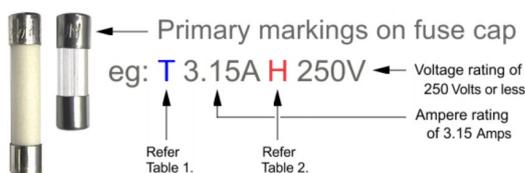
- Slow blow fuses are commonly used in DC applications that can be found in automotive and marine circuits. These circuits contain consumers with a high start-up current, like motors, or devices with capacitors, like an inverter. The slow blow fuse will withstand a high, short duration, initial current, enabling a motor to start.
- Fast blow fuses are used in AC applications. AC consumers are often sensitive to changes in flow of electricity, so they need a fuse that can react fast, to protect the consumer. But in some cases, an AC consumer can have a high start-up current, this is equipment with electromotors, such as refrigerators, air-conditioners and compressors. In these scenarios a slower fuse will be needed.

Fuse element speed range:

- FF Very Fast Acting (Flink Flink).
- F Fast Acting (Flink).
- M Medium Acting (Mitteltrage).
- T Slow Acting (Trage).
- TT Very Slow Acting (Trage Trage).

Fuse markings

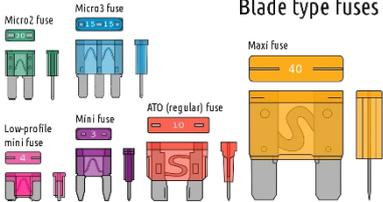
The fuse contains marking as to what its ratings are. But information might be missing. Then a good source to find out more are the fuse specifications. These can be easily found online or from your fuse supplier.

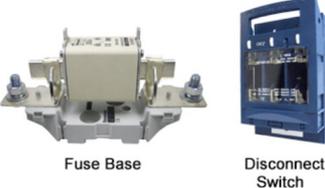


Catalog Number	Marine Rated Battery Fuses
Application	Full range circuit protection for automotive and marine applications. Break in capacity meets the requirements of conventional vehicle batteries and 42V electrical networks
Voltage Rating	58Vdc Maximum
Amperage Rating	30A - 300A
Ingress Protection	IP66
Ignition Protected	Per SAEJ1117
Interrupt Rating	10000 AMP @ 14Vdc 5000 AMP @ 32Vdc 2000 AMP @ 58Vdc
Torque Rating	Maximum 12 N•m (106 in-lbs)
Material	Body - Ceramic Housing & Cover; UL-rated 94V0 Thermoplastic Ring Terminals - Tin Plated



Overview of fuse types:

Glass or ceramic fuses	Fuse	Holders
<p>Wire fuse Up to approximately 60A Up to 250V AC or DC Fast or slow</p>		
Blade type (automotive)	Fuse	Holder
<p>Wire fuse Up to 120A 32 V DC Slow</p>		
Midi	Fuse	Holder
<p>Wire fuse 23 – 200A 32 Vdc Slow</p>		
Cooper Bussmann MRBF	Fuse	Holder
<p>Wire fuse 30 – 300A 58 Vdc Marine rated Can mount straight on positive busbar</p>		
CNN fuse	Fuse	Holder
<p>Wire fuse 10 – 800 A 48 Vdc, 125 Vac Fast</p>		
Mega fuse	Fuse	Holder
<p>Wire fuse 40 - 500A 32 Vdc Slow</p>		

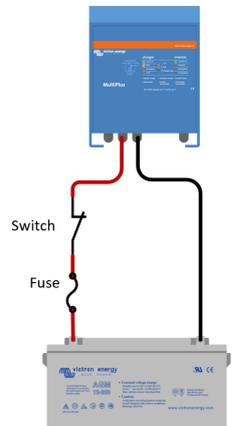
ANL fuse	Fuse	Holder
Wire fuse 35 – 750 A 32V dc Fast		
NH fuse	Fuse	Holder
Wire fuse Up to 1000A 500 - 690 Vac 440 - 550 Vdc Multiple speeds available		
Circuit breaker (CB or MCB)	Fuse	Holder
AC or DC A variety of current ratings A variety of voltages A variety of speeds Mounts on DIN rail		

4.5 DC isolation switches

A battery isolation switch can be used to isolate the battery (or battery bank) from the rest of the electrical circuit. Or it can be used to isolate a DC source or DC consumer from an electrical circuit. Being able to isolate a battery or DC consumers from the electric circuit is useful in case the system is not going to be used for a certain amount of time, or for system maintenance.

When selecting an isolator switch always make sure that the isolator switch is rated to the currents that can be expected in the system under full load.

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.



It might not even be necessary to add an isolator switch. A DC system always contains a main fuse. Removing the fuse will also break the circuit. So, when the system needs to be maintained, or if the battery needs to be replaced, removing the main fuse will be sufficient to isolate the battery from the rest of the system.

Always use quality isolator switches. The isolator switch will add to the circuit resistance. A low-quality switch will have more resistance, this can potentially increase the voltage drop and will cause system issues.

Types of isolator switches

- Battery isolator switch for mobile systems (usually 12 and 24 V).
- DIN mounted circuit breakers, for land-based systems for battery and PV (usually 48 V and up).
- NH fuse holder switch for high current land-based systems for battery and PV (usually 48 V and up).



Battery Isolator switch



High current DC MCB



NH fuse holders can be used as circuit breaker

Switching the negative in multiple unit systems

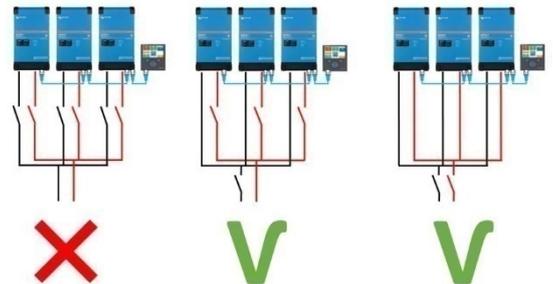
In inverter/charger system the battery isolator switch is only located in the positive battery cable. But in some installations, it might be required that both the positive and the negative are switched. This can be requirement of local regulations.

When both the positive and the negative battery cables need to be switched, this is not a problem in a single Victron inverter/charger system. However, it can cause a problem in systems with multiple inverter/charger units that are connected into a parallel and/or a 3-phase system.

In a parallel and/or 3-phase system the individual units in the system need to communicate with each other via a communication cable that interconnects the VE.Bus connectors. Some of our inverter/charger models do not have galvanic isolation between the battery and the VE.Bus. The lack of insulation means that if, in certain scenarios, the negative battery connection is broken it will cause a current in the negative signal of the data cable. This current can damage the inverter/charger's communication chip.

In a system with more than one inverter/charger, and if the negative needs to be switched, follow this advice:

- 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.



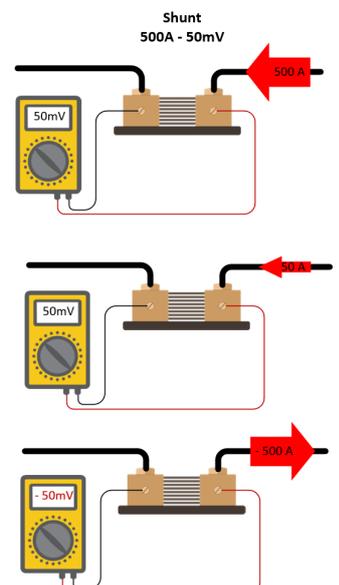
4.6 Shunt

A shunt is added to a system to measure current flow. This is needed for system monitoring or to calculate battery state of charge.

A shunt is a resistive element. When current passes through it a small voltage drop will occur over the shunt. If the current is small the voltage will be low, and if the current is large the voltage will be higher. If the current flow reverses, the voltage drop will change polarity. The voltage of the shunt is an indication of the amount of current and the direction of the current. This information can be used to find out how much current runs into a system or for battery state of charger calculation.

A shunt has a current and a voltage rating, for example 500 A, 50 mV. This means that if 500 A current passes through the shunt, there will be a 50 mV (= 0.05 V) voltage drop over the shunt.

The shunt needs to be rated to the maximum DC current that will flow into the combined consumers in the system.



Example:

An inverter is connected to a battery. The maximum current will be the peak rating of the inverter. A 3000 VA inverter has a peak current of 6000 W, this is, at 12 V a 500 A current.

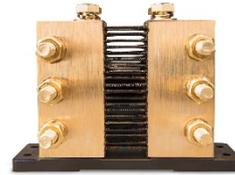
A BMV battery monitor comes with a 500 A, 50 mV shunt. In case this shunt is not big enough you will need to add a bigger shunt. Victron shunts are available in the following sizes: 500, 1000, 2000 and 6000 A. And they are 50 mV. When using a bigger shunt make sure that you change the shunt parameters in the battery monitor.



BMV shunt 500A



1000 A Shunt



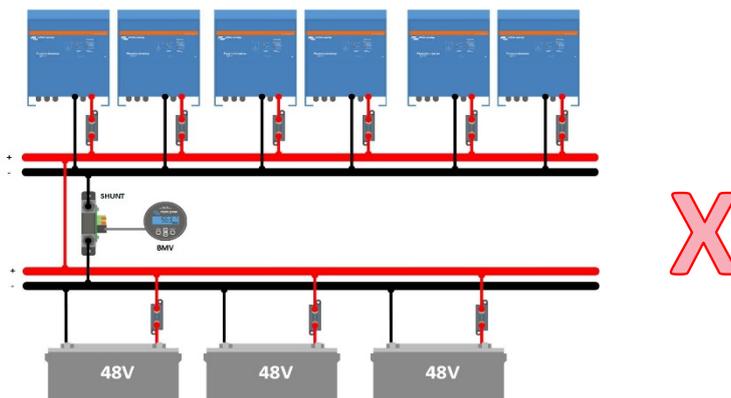
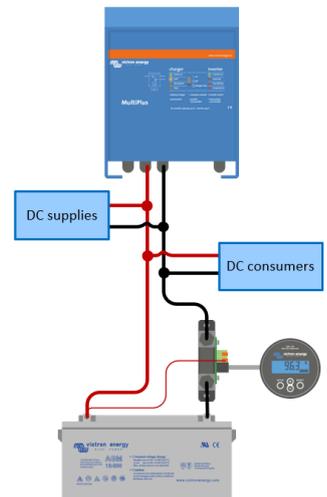
6000 A shunt

The shunt is typically located in the negative cable. The negative is chosen because that is safer.

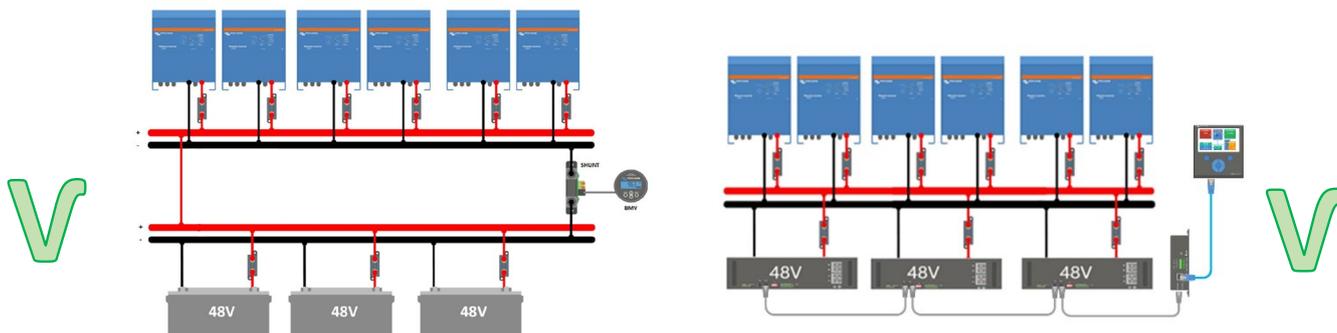
The shunt needs to be the last item before the battery bank or battery bank bus-bar. All DC consumers and DC supplies need to be connected after the shunt. See on the right how to wire the shunt into a system.

Shunts can also be placed elsewhere in a system, for example: to measure a DC consumer or a DC supply. These shunts usually connect to a current meter.

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 very large systems where there is 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 state of charge.



4.7 Parallel and/or 3 phase system DC wiring

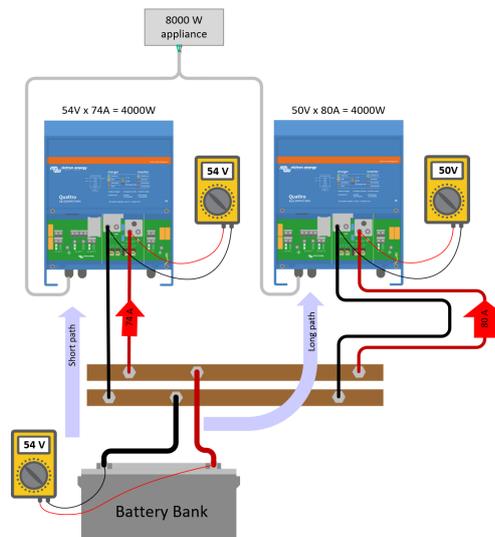
A large inverter/charger or a 3-phase inverter/charger can be created by connecting multiple inverter/chargers together. These units communicate with each other and, together, they become one large inverter/charger. They all need to be connected to the same battery bank.

When wiring an installation like this, there are some important considerations regarding the battery cables.

For correct operation it is essential that each unit receives exactly the same voltages. To ensure this the DC path from battery bank to each individual unit, or from the busbar to each individual unit needs to be exactly the same.

If there is a difference between the cable thickness or the cable length between the individual units, there will be a difference between the voltages of these units.

Different voltages mean different currents. The unit with a lower voltage will have a higher current running through its power electronics. Inverter/charger overload is triggered by the amount of this current. So, although the power that each inverter delivers will be the same, the unit with the lower voltage will have a larger current running through it and will go into overload before the other units do. The total inverter power of the system will now be less because when one unit goes into overload, the whole system will stop 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. Also ensure that all cable lugs are identical, and all connections are tightened with the same torque values. Consider using busbars or power-posts between the battery bank and the inverter/chargers.

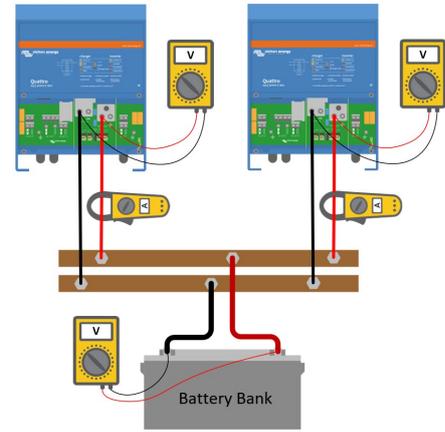
When placing fuses into the installation consider using only one DC fuse per phase. If a big single fuse is not available, then use one fuse per unit, but make sure that all these fuses are exactly the same.

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. All these voltages readings should be identical.

For more info on parallel and 3 phase system see this [manual](#).

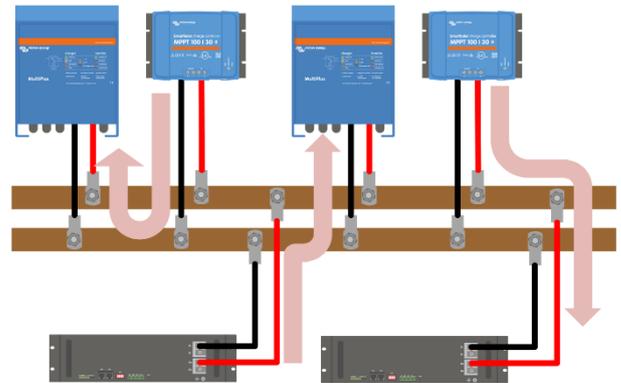


4.8 Large system busbars

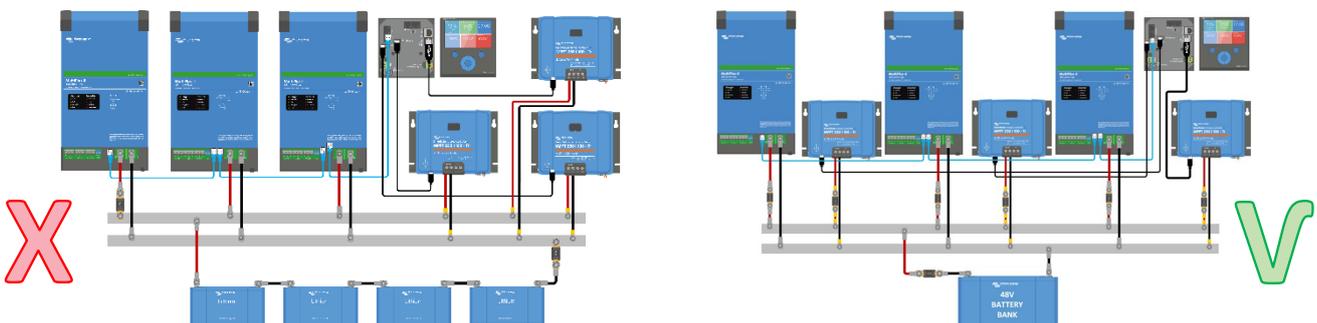
Large installations typically consist out of multiple DC consumers and DC sources. Like multiple batteries, multiple inverter/chargers and multiple MPPTs. They all connect to a central busbar. When wiring these installations, special considerations need to be made.

In these systems you will need to use bus-bars, but even still, it matters how all equipment is connected to the busbar and in what order. It is important to alternately connect the inverter/chargers and the MPPTs to the busbars.

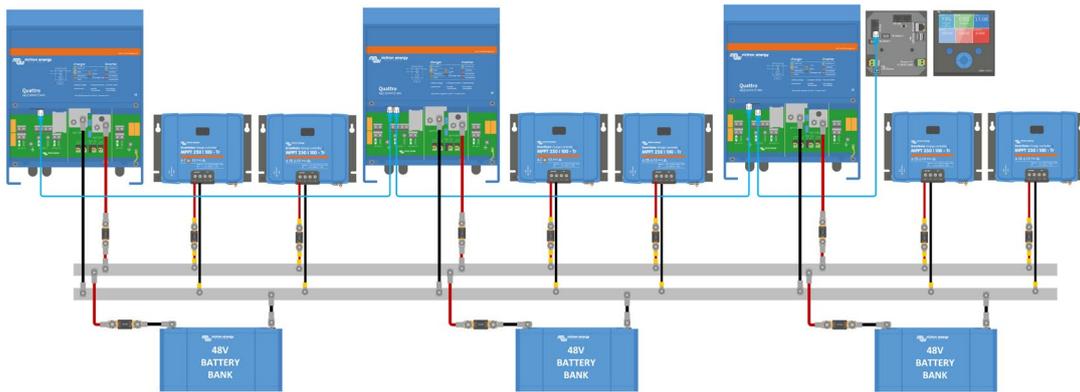
The reason for this, is that this will reduce the current flowing through the busbars. To simply put it, the current entering the bus-bar from a MPPT can travel via a short path straight into the inverter or into a battery. This current does not need to travel through the entire busbar. It keeps the local "traffic" low.



When wiring, make sure all inverter/chargers have the same cable length. Also, the MPPTs need to have approximately the same cable length. And the same for the batteries.



If the system 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 or smart batteries, they should also be distributed evenly along the busbars.



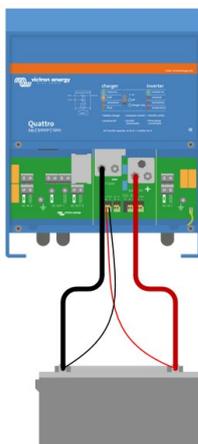
4.9 Voltage sensing and compensation

Voltage sensing is a battery charger feature. It works by measuring the difference between the voltage in the unit the voltage at the battery terminals. As soon as a difference is detected, the charge voltage will be increased to compensate for cable losses during charging. This will ensure that the batteries are always charged with the correct voltage. This feature generally will only compensate for voltage losses up to 1 V. If the losses in the system are bigger than 1 V (i.e. 1 V over the positive connection and 1 V over the negative connection), the battery charger, MPPT solar charge controller 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.

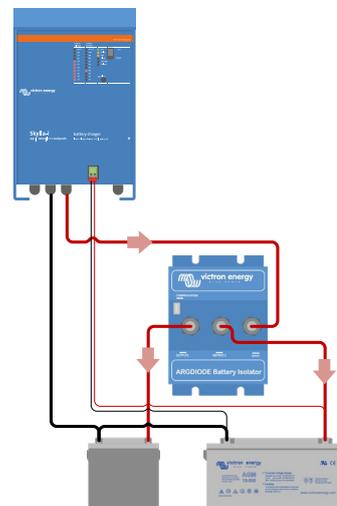
Voltage sense can also be used to compensate for voltage losses when diode splitters are used. A diode splitter has a 0.3 V voltage drop over the diode.

Some Victron products, like inverter/chargers or large chargers, have voltage sense build in. For other products, such as MPPTs and large smart battery chargers you will need to add a smart battery sense.

If the product has a voltage sense (V-sense) terminal two sense wires can be connected from the V-sense terminal directly on the battery positive and negative terminal or distribution. Use a cable with a cross-section of 0,75 mm².



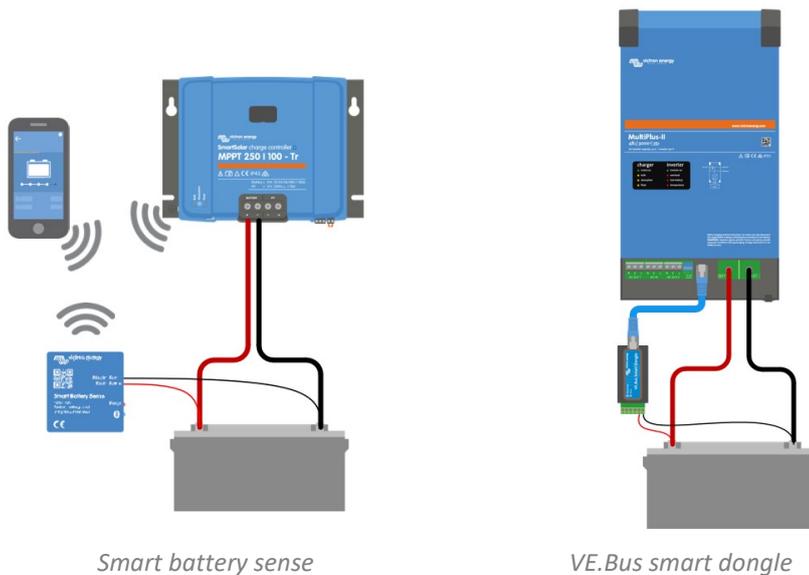
Voltage sensing inverter/charger



Large charger with voltage sensing and diode splitter

If an inverter/charger is equipped with the VE.Bus smart dongle no voltage sense wires are needed. The Smart dongle takes care of voltage sensing.

In case of a MPPT smart charger, connect a Smart Battery Sense to the battery and match it to a MPPT via the VictronConnect App.



Smart battery sense

VE.Bus smart dongle

Voltage sensing in an Energy Storage System (ESS) with DC Solar

In an ESS system with an MPPT the charger of the inverter/charger is disabled.

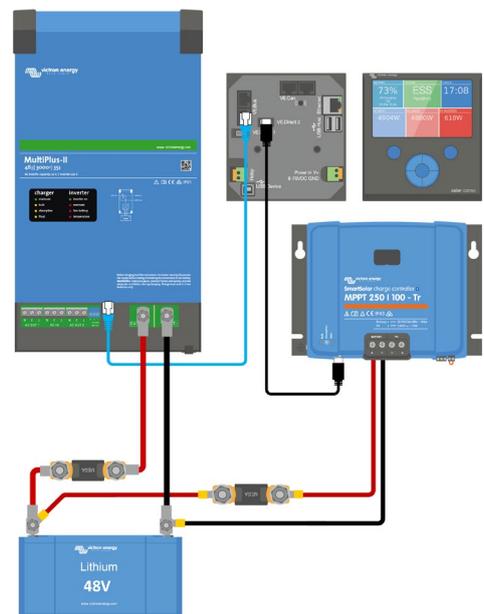
This is because the MPPT charges the battery and excess solar power is being fed back into the grid. This process is controlled by the CCGX. To make this work, the CCGX will set the MPPT at a higher DC voltage than the inverter/charger's DC voltage.

When the battery is almost full the battery voltage will be slightly higher than the inverter/charger's DC voltage. This is the "cue" for the inverter/charger to reduce this "overvoltage". It does this by feeding power into the grid.

In a 48 V system this overvoltage is set at 0.4 V and in a 24 V system it is 0.2 V.

For this process to work properly it is essential that the battery receives the correct voltage from the MPPT. Special care is needed as to the design and placement of the DC cabling, fuses and connections, as they can potentially cause a voltage drop in the system.

A voltage drop can reduce the "overvoltage" the inverter/charger needs before it can feed power into the grid.



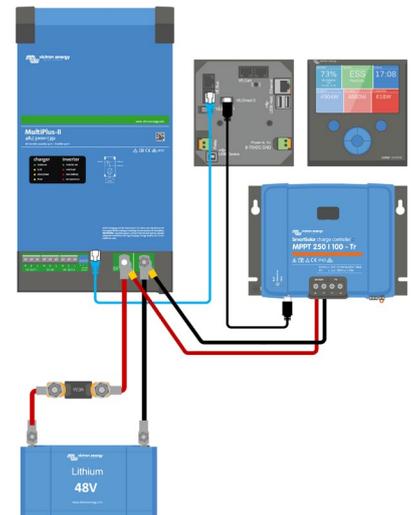
Example:

In an ESS system with 100 A MPPT with 2 x 1 m cable 35 mm² and a 150 A 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 100 A is 178 mV

The solution is to use an MPPT with automatic voltage drop compensation. The result will be 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 panels

Solar panels are not allowed to be directly connected to a battery. A solar charger needs to be placed between the solar panels and the batteries. The solar charger converts the higher solar panel voltage into a voltage suitable for battery charging. If a solar panel is connected directly to a battery the battery will get damaged.

To connect solar panels to a solar charger the solar panel is in most cases fitted out with special waterproof connectors, commonly these are MC4 connectors. These connectors come in 2 varieties, a male connector and a female connector.

The male connector connects to the positive cable coming from the solar panel and the female connector connects to the negative cable.

In case the solar cables are not long enough, an extension cable will need to be used. The extension cable is often pre-assembled with MC4 connectors. A solar cable is fitted out with a male connector on one end and a female connector on the other end. Like this:



MC4 connectors can be connected to 4 mm² or 6 mm² solar cable.

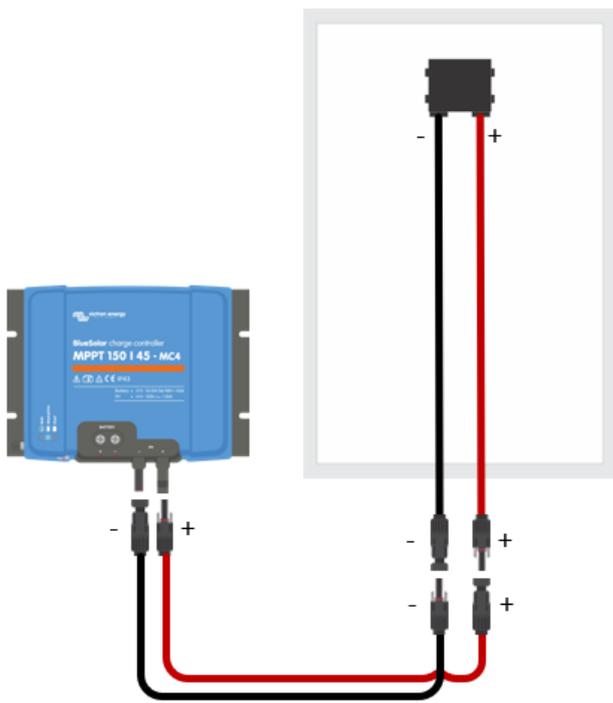
A solar cable is a special cable. It is a very tough cable and has been designed for outdoor use in solar panel installations. It is dust, age and UV resistant and has tinned copper wire strands.

A solar cable for small PV arrays, like for Automotive or marine application is often a dual core cable. Again, the same applies for these installations, the cable must be UV rated and will need to have tinned copper wire strands.

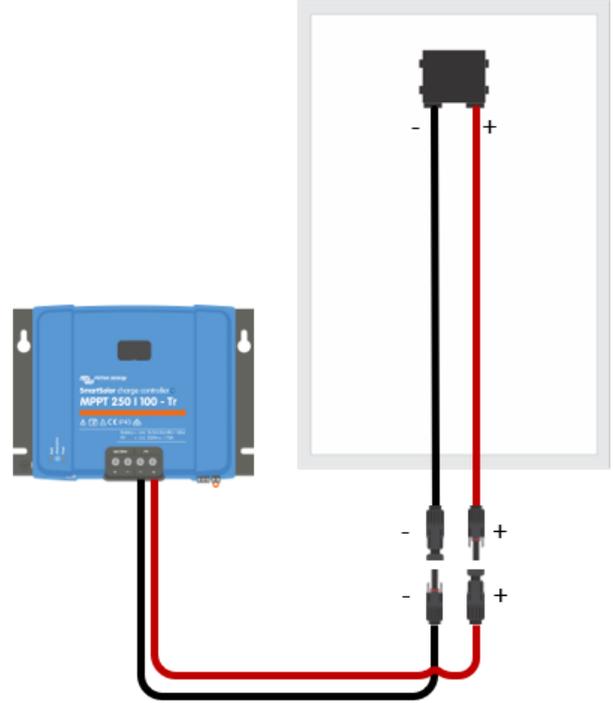


The cable thickness you will need depends on the size of the solar array and what voltage it has. This will determine the current and this will determine cable thickness. Please see chapter 4.1 for more information on this.

MPPT solar chargers are sold in two models, with either MC4 connectors or with screw connectors on the PV side. This is how to connect them to a solar panel as seen from the rear of the solar panel.

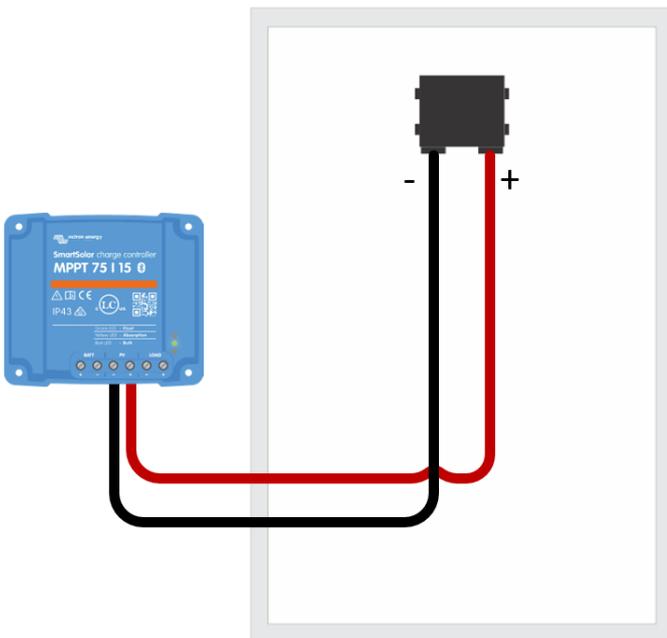


MPPT MC4



MPPT TR

In some occasions the solar panel does not have cables attached. You will then need to attach these yourself. To do this, open the junction box at the rear of the panel and connect the cables there. You can either use solar cables with or without MC 4 connectors. If you are wiring the solar panel directly to the MPPT, then this is what the installation will look like:

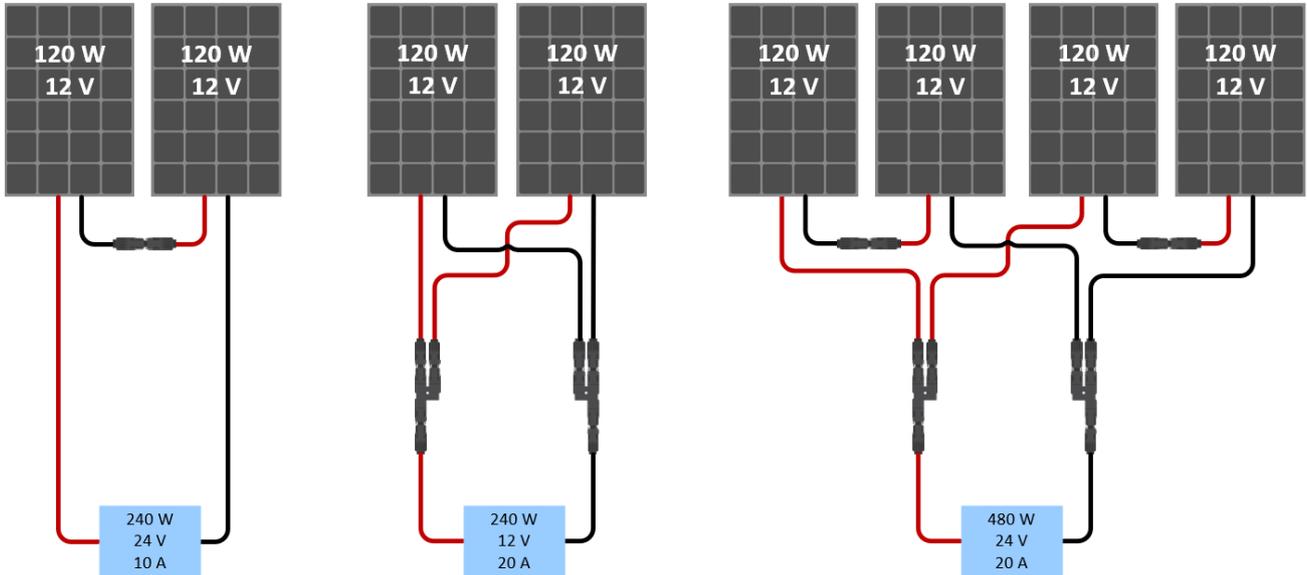


In many solar installations one solar panel is not enough. In this case a solar array, or photovoltaic (PV) array needs to be created. A Solar array consist of multiple solar panels that are connected together.

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

To make parallel connections easy, use MC 4 Y connectors. There are two types:

Example of series and parallel solar arrays:

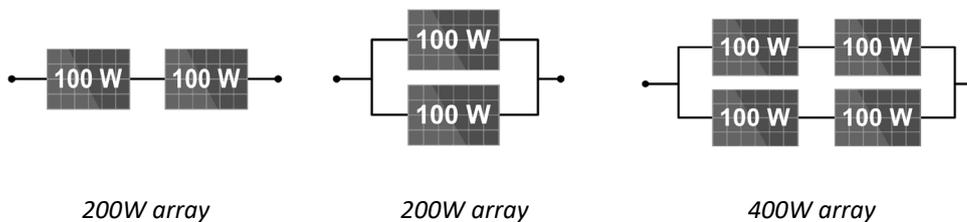


Series solar array

Parallel solar array

Series/parallel solar array

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



200W array

200W array

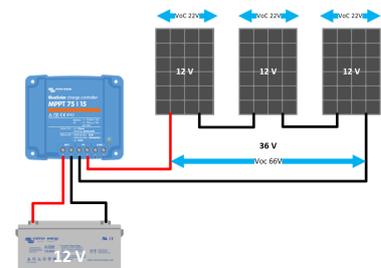
400W array

When designing a solar array, you will need to make sure that the array open circuit voltage (Voc) does not exceed the voltage rating of the MPPT.

An example of panel in series:

If you look at the specs of a 12 V solar panel, you will find that the Voc is around 22 V.

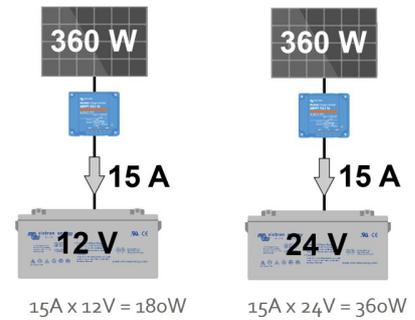
For a 75/15 MPPT the solar voltage can be as high as 75 V. This will allow you to connect up to 3 x 12 V panels in series.



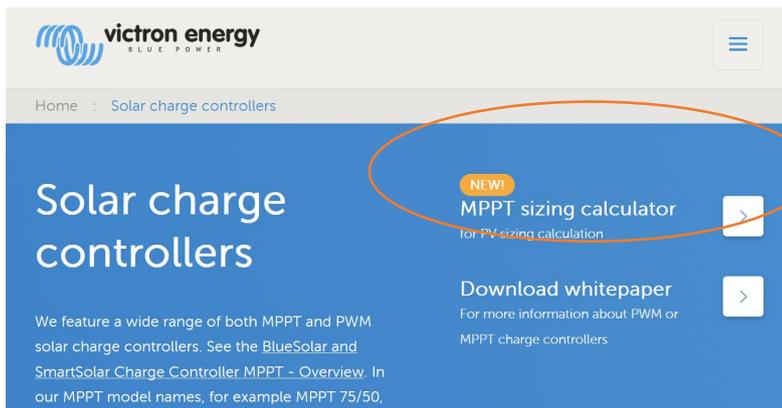
Note on charge current at different battery voltages:

For a 75/15 MPPT the current rating is 15 A. This is the current going into the battery.

This means that with a 12 V battery you will get less power into the battery than with a 24 V battery.



To help you design a solar array and to match it to the correct solar charger see the MPPT sizing calculator [here](#).



5. Communication wiring

Equipment in modern systems need to be able to communicate, either with each other or with a control or monitoring device. To make communication happen, communication cables are needed. They send information from one piece of equipment to another piece of equipment. Quite often these are mission-essential communications. If the cable fails, the communication stops, and the system might stop operating.

Some examples communication cables in inverter/charger systems:

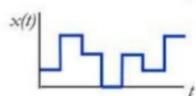
- Communication cables between inverter/charger units to create a parallel and/or 3 phase system.
- Communication cables to control equipment, for example between a solar charger and the Color Control GX or another GX device.
- The cables from a measuring device to a monitoring device, like between the BMV shunt and the BMV head unit, or between a temperature sensor and an inverter/charger.
- Internet or network cables.
- 2 wire signal or control cables, for example between an alarm relay and a generator auto start, or a car ignition switch and a DC/DC converter, or between a battery BMS and a BatteryProtect.

5.1 Data signals

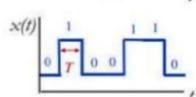
A data signal is a signal that constantly changes in line with the information it sends. It can be analogue or digital. The signals in communication cables can be any of these types. These signals have a low voltage and current. Often no more than 5 V.



Analogue signal - the voltage can have any value and there is a direct correlation between voltage and value.



Digital signal - the voltage of the signal is limited to a finite set of voltages.



Binary signal - has only 2 values representing on or off (one or zero). It can represent an on/off condition or it transmits data, by sending strings of ones and zeros.

5.2 Interference

Like with all cabling, it is important that the communication cables are of good quality. Also, their connectors need to be of good quality and that they have been crimped on the cable correctly. It also matters how good the connection to the receiving socket is.

Communication cables carry low voltage signals of low current. If these signals travel over a distance, of course, a voltage drop can occur, but that is not so common, because these signals only carry a very low current. Voltage drop will not normally be an issue unless the cables are very long.

However, another aspect is critical for communication cables when low voltage signals are sent over a long distance and that is interference.

The different interference types and what they are caused by:

- Electromagnetic interference - from generators, transformers, electromotors and knife switches.
- Radio frequency interference - from radio transmitting sources, radar and badly shielded equipment.
- Electrostatic interference - from static electricity.
- Cross talk interference – interference from nearby cables.
- Common interference – caused by current flowing between different potential grounds in a system.

In the first 4 cases the cable acts as an antenna and it receives this interference. The interference induces additional electricity into the communication cables. This will change the voltage of the signal and this will alter the data that is being send. This will cause confusing or disrupted communication.

In really bad cases, where there is a lot of interference or a grounding issue, the voltages in the cable can become so high that it causes damage to the communication circuitry in the equipment that connects to the communication cable.

There are ways to limit or prevent interference, these are:

- Keep cables short.
- Use twisted pair cables.
- Use shielded cables.

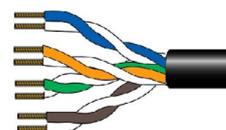
Unshielded and untwisted cables

These cables are very susceptible to interference. And because of this they have a length limit. This is approximately 10 meters. This is why we do not sell VE.Direct cables longer than 10 meters. The VE.Direct cable is unshielded and untwisted cable.



Twisted pair cables

Two conductors of a single circuit are twisted together. This will improve rejection of electromagnetic interference and it also will make the cable less susceptible to crosstalk from neighbouring cables.



Cable shielding

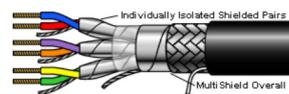
A metal foil or braid covers a group of cables or might even cover twisted pairs.



Foil shield



Braid shield



Multi shield

5.3 Communication cables and connector types

This paragraph contains a short selection off commonly used communication cable types as used in inverter/charger systems.

RJ45 straight UTP cable

This cable is used for computer networks, internet, ethernet, but also used for inverter/chargers to communicate to each other and to a control product, like the Multi Control panel or the Color Control. This is a cable with 8 conductors.



In a straight cable pin 1 on one side connect to pin 1 on the other side, pin2 connects to pin 2 and so on. To test if the cable is wired correctly us a cable tester.

Victron uses this cable for VE.Bus and VE.Can applications. It was also used for the deprecated VE.Net applications.

In the past these cables usually had a blue colour, but more different colour cables have recently appeared.

Victron manufactures different length cables as do other manufacturers. It is not recommended to make these cables yourself. A badly crimped connector can be the cause of hard to diagnose system faults.

To test a RJ45 cable replace the cable and see if the problem has gone away.

Another source of faults are when the male RJ45 connector is not properly inserted into the female RJ45 socket or when the RJ45 sockets contacts have lost their springiness and do not make good contact anymore.



RJ45 terminator

Used to terminate a daisy chain CANbus network. One terminator is placed at the first item in the chain and one at the last item in the chain.



RJ45 cable with special pinouts.

They look like regular "straight" RJ45 UTP cables, but they have been rewired to serve a specific purpose. These type of cables are for special applications. They often only have a unique application. In case of Victron they are used between a smart battery and a Color Control GX or other GX device. Cable labeling is very important. The label needs to indicate how the cable is internally wired. This means that at a later stage these cables do not end up in a regular system, where they can potentially cause a communication fault.



RJ45 cross over cable

They look like a regular "straight" RJ45 UTP cable. These were used in old computer networks or used by other inverter manufacturers. It can be very off putting in case one of these cables are used where a straight cable should have been used. These cables cannot be used for Victron equipment.

RJ12 UTP cable

These are used between the BMV shunt and the BMV head unit. This is a cable with 6 conductors. These cables are normally used to send digital data but the BMV uses it to send analogue data.

The BMV is supplied with one of these cables. Victron manufactures cables of various lengths, choose one of these if a bespoke cable is needed. As with the RJ45 cable, only use pre-manufactured cables. We do not recommend that you make this cable yourself. Too often a badly crimped connector is the cause of a hard to diagnose strange system behaviour.

Cables with RJ12 connectors are also commonly used for telephones. But in case of a telephone cable not all 6 wires are present. Also, the phone cable is not twisted pair. They cannot be used for a BMV.



VE.Direct cable

This is 4 core data cable. This is a special cable for monitoring or control of certain Victron products like a BMV or MPPT.



Signal wire

This is "normal" wire. It is mostly a thin wire, usually no thicker than 1.5 mm². They come as cable with single, double or multiple conductors. These cables typically carry analogue signals or an on/off signal.



NMEA2000 cables and connectors

Used in marine CAN-bus data networks. The cabling consists of special marinized data cable and waterproof connectors, T pieces and terminators. For more information see [Wikipedia](https://en.wikipedia.org/wiki/NMEA2000).



RS485

Used for serial communications. In case of Victron it is used for communication between energy meters and a GX device. For more information on RS485 see [Wikipedia](https://en.wikipedia.org/wiki/RS485).

USB cables

Available in a variety of types. Victron mainly uses the type A connector. For more info on USB see [Wikipedia](https://en.wikipedia.org/wiki/USB).

5.4 Interfaces

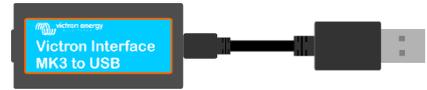
These are little devices that translate one data protocol to another data protocol. They are often wired into a cable or are located at one end of a cable.

These are the main Victron interfaces:

MK3 to USB interface

Used to connect a computer to a VE.Bus product.

The MK3 replaced the MK2 interface. The MK2 can still be used.



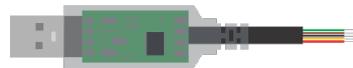
VE.Direct to USB interface

Used to connect a computer to a VE.Direct product or used to connect a VE.Direct product to a GX device USB port.



RS485 to USB interface

Used to connect an energy meter to a GX device.



VE.Bus to NMEA2000 interface

Used to connect a VE.Bus product to a NMEA2000 network.



VE.Direct to NMEA interface

Used to connect a Victron VE.Direct product to a NMEA2000 network.

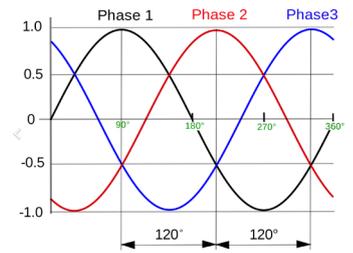


For the full range of Victron interfaces see the Victron [accessories](#) product page.

6. AC wiring

6.1 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° phase shift between each phase.



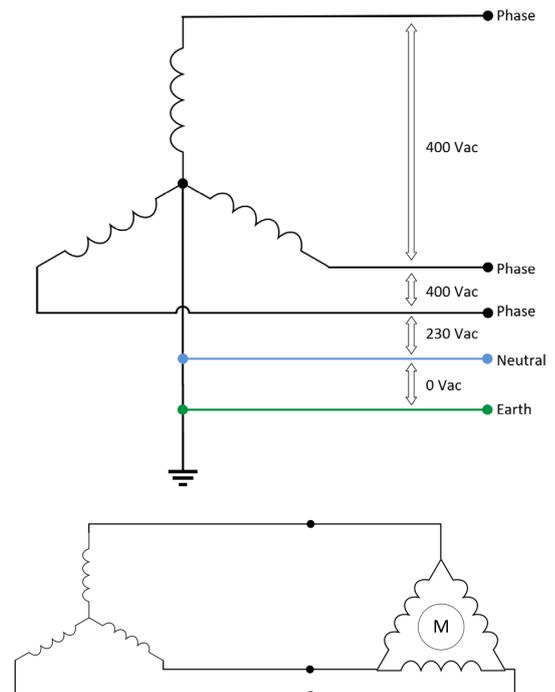
The 3 coils are connected to each other and create a triple circuit, a so-called star configuration. A single coil (phase) has a potential of 230 Vac. And a second potential level is created between two coils. Due to the 120° phase shift the potential is 400 Vac.

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 Vac 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 an electrical house installation. The function of the neutral conductor is to enable separate use of each phase and each phase can be used as an individual 230 Vac 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. But the 3-phase inverter/charger system can power a “delta” configured load.

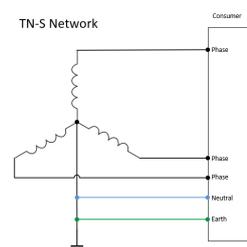
Unequal loading is not an issue when the inverter/chargers are operating in inverting mode, but it might be an issue if they are operating in pass-through mode and are connected to a generator that is unable to deal with an unbalanced load.

6.2 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 per network type.

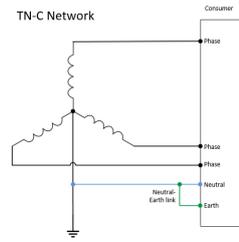
TN-S network

- 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.



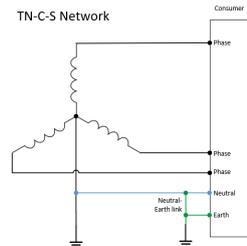
TN-C Network

- 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.



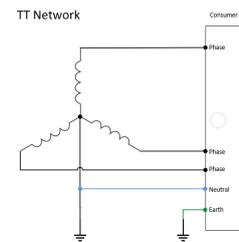
TN-C-S Network

- 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 the earth to an earth stake.
- The consumer uses the supplied phases and the newly created neutral and earth.



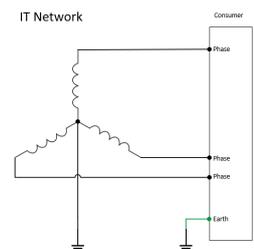
TT network

- 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 via an earth stake.



IT network

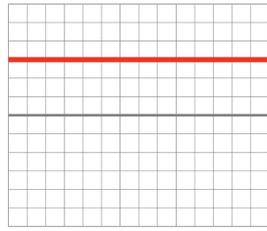
- The generator star point is not connected to neutral and earth.
- The phases are distributed.
- The consumer uses the supplied phases.
- The consumer creates a local earth connection.



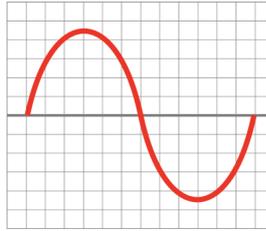
6.3 System current VA and Watt

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

Like explained before, AC power is alternating power. Both the voltage and the current do not have a constant value like DC, but they alternate from positive, to negative, to positive and so on. They do these 50 times a second in a 50 Hz system and 60 times per second in a 60 Hz system. The wave form is a sine wave.



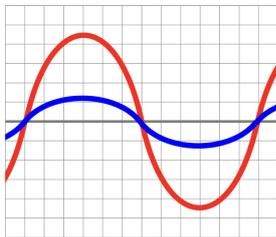
DC voltage



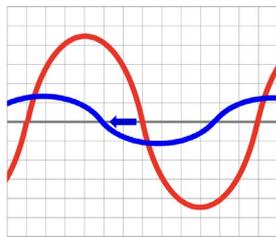
AC voltage

Not only the voltage alternates in an AC circuit, the current also alternates. In a resistive system they alternate at the same time. However, if the circuit contains non-resistive loads, the current sine wave can lag behind the voltage sine wave or be in front of the voltage sine wave.

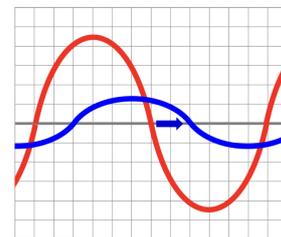
Below images depict the behaviour of the voltage (red) and current (blue) in an AC circuit with different type of loads.



Resistive load



Inductive load - passive



Capacitive load - reactive

Resistive loads are loads with resistive elements, such as: heaters, incandescent light globes, toasters, hair dryers and so on.

Inductive loads are loads with coils, like electromotors or transformers. Examples are: refrigerators, compressors, air conditioners, fluorescent lights.

Capacitive loads are loads that contain capacitors, examples are capacitor banks, start motors, battery chargers, UPS devices.

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

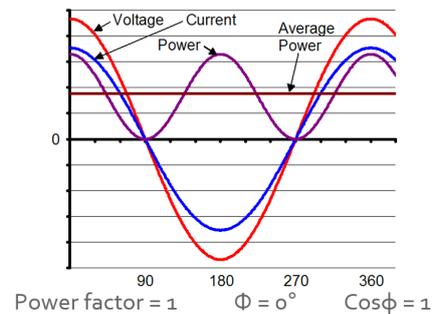
VA is the “apparent power” and is the product of the voltage times the current drawn by the equipment. The VA rating is used for sizing wiring, circuit breakers, inverters or generators.

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

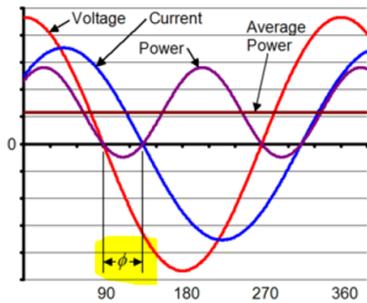
$I = P/V$

The power factor is 1 in a purely resistive system.

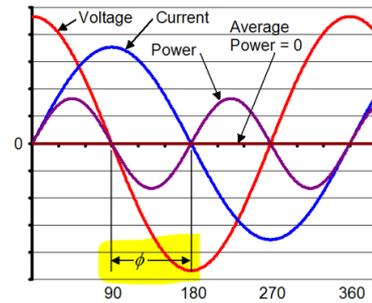


When an AC circuit contains loads such as inductors or capacitors, a phase shift will occur between the current and voltage waves. Both these waves are not in step (in phase) anymore.

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 $\Phi = 45^\circ$ $\text{Cos}\phi = 0.71$



Power factor = 0 $\phi = 90^\circ$ $\text{Cos}\phi = 1$

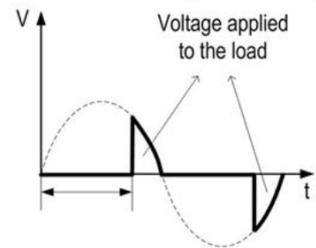
When the power factor is known the apparent power can be calculated.

$W = V \times A \times \text{Power factor}$

True power = Apparent power x Power factor

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.

Then there is one more type of load and this is the non-linear load. To put it simply, these are loads that do not load up the whole sine wave equally or they might only use a part of the wave. The current drawn by the non-linear load will not have a sine wave shape, although the load is connected to a sine wave voltage.



These often are loads that contain semiconductors, like diodes or LEDs. Examples of these are AC LED lighting, light dimmers, heat guns and certain soft start devices. When an inverter powers a non-linear load, it will go earlier into overload than the power rating of the load.

6.4 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 can cause heating up of cables and in extreme cases 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 earlier.

For wiring calculations, you can use the same calculations as are used for DC wiring as already explained. But be aware that the earlier mentioned rule of thumb cannot be used. For wiring for voltages from 100 to 400 Vac use this rule of thumb:

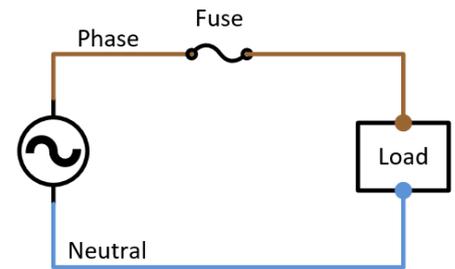
Nominal current / 8 = core diameter in mm
 Add 1 mm² for each 5 meters of cable length

6.5 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 and to the cabling thickness.

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.

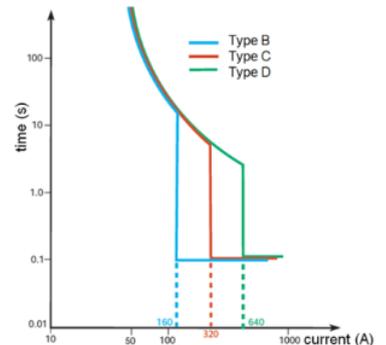


Traditionally, a fuse contains a wire that melts when unacceptable current passes through. As soon as the wire in the fuse has melted the electrical circuit has been broken and no additional current will flow.

More commonly automatic circuit breakers are used to protect against overcurrent. These are called: "Miniature Circuit Breaker (MCB)". This device has two triggers for activating its switch-off mechanism. 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.



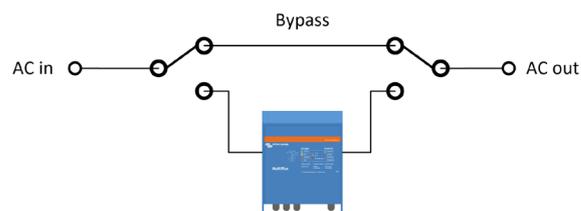
When a short circuit current occurs, with sufficient current, the MCB (B,C or D) is switched off within 100 ms.

6.6 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 you to bypass the inverter/charger and will connect 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 needs to be rated to the full AC load of the system.



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

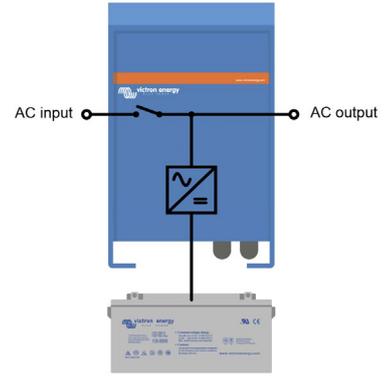
AC cabling

Multiple inverter/chargers can be connected in parallel to create a larger inverter/charger. When connecting a parallel system to an AC supply it matters what length and thickness the AC wires have. Unlike DC cabling, for AC cabling it is important to not make the cables too short or too thick. Do not over-dimension the AC cabling. Using extra thick cabling has negative side effects.

In a parallel system each inverter/charger should be identical. Only this is not always the case. Each inverter/charger contains an internal AC input contactor. These contactors are not always completely identical, they can have a small difference in its internal resistance, compared to the other contactors. This small resistance difference might result in AC current being diverted from one unit to another.

In a parallel system the AC current should be evenly distributed through all paralleled inverter/charger units.

When the resistance in the cabling is very low, the small difference in contactor resistance will result in a large relative difference. And this will cause unequal current distribution.

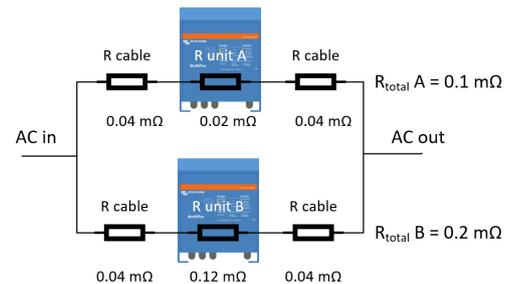


An exaggerated example:

Unit A and unit B are connected in parallel. Extremely thick and short cabling is used so that a very low wiring resistance was created. But, the two units have a slight internal (AC contactor) resistance. See image on the right.

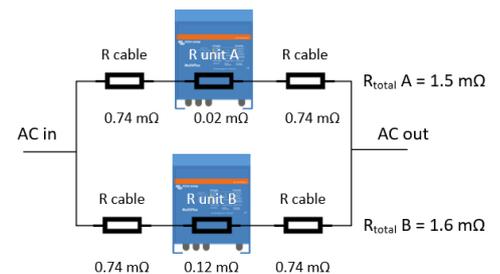
In this scenario a total resistance for unit A is 0.1 mΩ and a total resistance for unit B is 0.2mΩ.

This will result in Unit A carrying twice as much current as Unit B



Now, we use the same 2 units in parallel, but we use thinner and longer cables. See image on the right.

The total resistance for unit A is 1.5 Ω and a total resistance for unit B is 1.6 Ω. This will result in a much better current distribution. Unit A will carry 1.066 times more current than unit B.

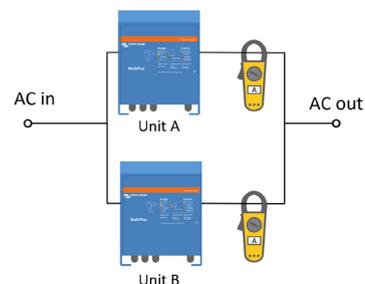


To safeguard against this issue, it is recommended to use long AC, cables of similar length. Always follow the recommended cable lengths and thicknesses as listed in the product manual. Do not increase the cross-section of the AC cabling more than is recommended in the manual!

For example: the voltage drop tolerance of a 100 A back feed contactor is about 20 mV at 100 A. The total cable resistance (input + output) should therefore be larger than $R = 60 \text{ mV}/100 \text{ A} = 6 \text{ m}\Omega$.

The best way to check if this type of wiring issue is affecting a parallel system is the following:

- Fully load the system.
- Measure (current clamp) each units individual AC currents.
- Compare the currents.



The current readings should be very similar. If there are big differences, then there is an issue with wiring (or with a connection).

AC fusing parallel strings

For units in parallel it is advised to 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

The 3 phases L1, L2 and L3 of a 3-phase supply need to be connected in numerical order. Pay special attention to the phase rotation of the AC supply from grid or generator. When wired in the wrong rotation, the system will not accept the mains input and will only operate 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.

For more info on parallel and 3 phase systems please read the [Parallel and 3-phase manual](#).

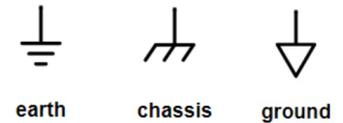
7. Ground, earth and electrical safety

Ground or earth provides a common return path for electric current in an electric circuit. It is created by connecting the neutral point of an installation to the general mass of the earth or a chassis.

Grounding is needed for electric safety and it also creates a reference point in a circuit to which voltages are measured.

Generally speaking, there are 3 types of grounding, namely: earth, chassis earth and ground.

- Earth is a direct physical connection to the Earth. This is usually done by driving a copper rod (earth stake) into the ground. But, depending on age and location of the system this can also be a copper plate or copper strip buried in the ground, or the water mains or water pipes in a house.
- Chassis earth is a connection to a metal frame such as that of a vehicle or the metal hull of a boat. It can also be the metal case of electrical equipment.
- Ground is a common reference point in a circuit to which voltages are measured. As a result, a voltage may be above ground (positive) or below ground (negative).



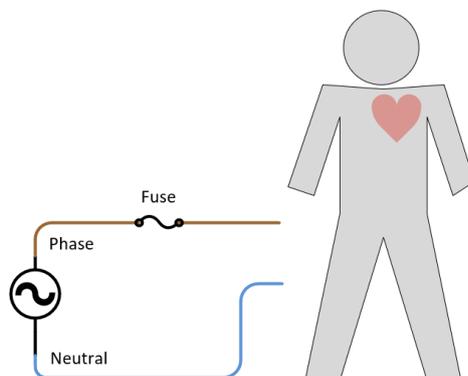
7.1 Electrical safety

Electricity is dangerous, it can kill, injure or burn a person. It is current that is the most dangerous part of electricity. A small current running through a person can already be very dangerous. See table on the right.

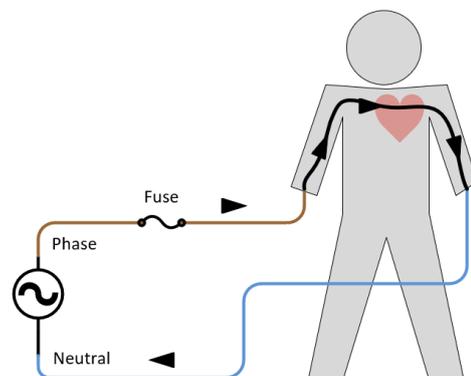
Current will flow as soon as an electric circuit is closed.

For example, imagine two loose AC wires, a live and a neutral wire. When the wires are just there no current will flow because the circuit is not closed. But as soon as you touch a live wire with one hand and the neutral wire with another hand you have closed the circuit and electricity will flow from the live wire, via your body and via your heart, back to the Neutral wire. Current will keep flowing until the fuse blows, but by then you are probably dead already.

Electric Current (1 second contact)	Physiological Effect
1 mA	Threshold of feeling, tingling sensation.
5 mA	Accepted as maximum harmless current
10-20 mA	Beginning of sustained muscular contraction ("Can't let go" current.)
100-300 mA	Ventricular fibrillation, fatal if continued. Respiratory function continues.
6 A	Sustained ventricular contraction followed by normal heart rhythm. (defibrillation). Temporary respiratory paralysis and possibly burns.



*Electric circuit not closed
Electricity cannot flow*



*Electric circuit is closed
Electricity will flow*

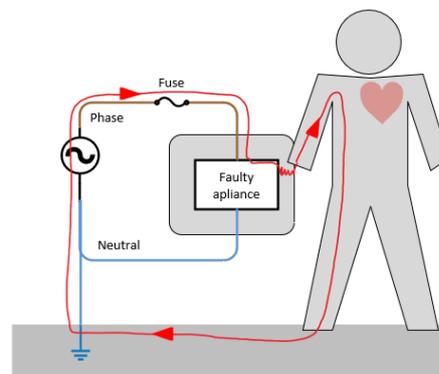
Apart from touching a neutral and a live wire at the same time, there is another way in which an unsafe situation can occur and that is when the electricity flows via earth. This is a more common situation to occur than someone touching a phase and neutral conductor at the same time.

The neutral conductor is connected to earth at some point. This can be in the house installation, in the distribution network or at the power generator (the star point).

If there is a fault in electric equipment the metal parts of the outside of that equipment can become live. This can be because there is an internal shortcut between live electricity and the equipment's metal housing. Think for example of a faulty washing machine. A fault can have been caused because there is an electrical fault, mechanical damage, or damaged electrical wires that are touching the metal housing of electrical equipment.

The moment you touch the faulty washing machine, electricity will flow from phase, to the metal housing, via you to earth. From the earth the electricity will then flow into the Neutral of the mains supply. The circuit is complete.

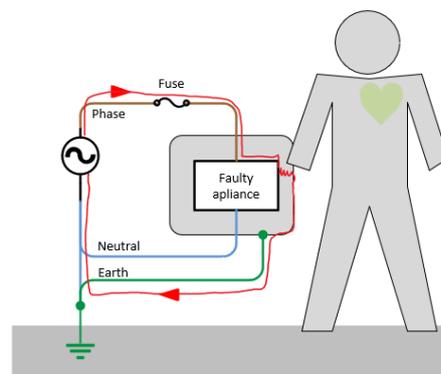
Electricity will keep flowing until the fuse in the mains supply has blown. But like in the previous situation, you are probably dead already.



To make electrical installations safer the earth conductor was introduced. The earth wire connects the metal housing to earth.

If you now touch the faulty equipment, electricity will flow into the earth wire rather than into you. The reason for this is because electricity will travel through the path of least resistance. The path via you and the earth is more resistive path via the earth wire. But be aware that a very small amount of current can still flow via a person. A current greater than 30 mA can already be dangerous.

Just an earth wire is not enough. A residual current device (RCD) is also needed in an installation. See chapter 7.3 for more information on RCDs.

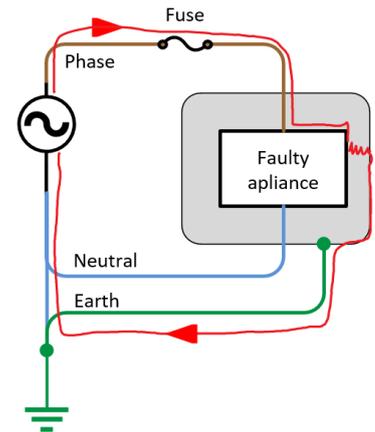


7.2 Earth wiring

Earth or ground wires are yellow/green. In older installation or in different countries you might also see green wire.

Good earth wiring is essential to electrical safety. The wire and the earth connections must be of low electrical resistance. Remember that electricity will travel through the path of least resistance. So, you have to make sure that the earth cable is thick enough and all connections are tight.

The earth wire can have potential large currents flowing through it when there is an equipment fault. The earth wire needs to be able to carry this current until the system fuse blows. So it is important that the earth wire is thick enough.



7.3 RCD

Electricity can be very dangerous. Adding an earth conductor into a system improves safety, but an installation can be made even safer by incorporating an RCD (residual current device).

The use of an RCD is compulsory in all AC installations.

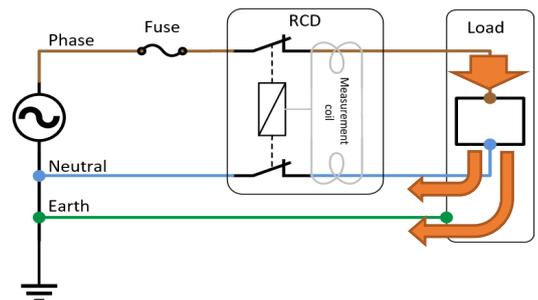
The RCD detects and disconnects as soon as it detects that electricity is flowing into earth. Electricity will flow into earth if there is a fault in the system, or more importantly when current is flowing through a person. RCDs are designed to disconnect as soon as a current flow to earth is detected.

A residual current devices (RCD) can be known under different names:

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

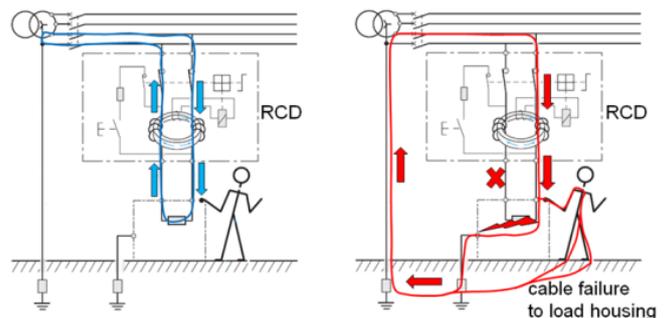
An RCD measures the current balance between the phase and the neutral conductor. The device will open its contact when it detects a difference in current between phase and neutral.

In a safe system the supply and return currents must sum to zero. If this is not the case there is a fault in the system, current is leaking to somewhere 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 milliamperes) than the currents that needed to trip conventional circuit breakers or fuses (several Amperes). RCDs are intended to operate within 25 - 40 milliseconds. This time is faster than the time needed for the electric shock to drive the heart into ventricular fibrillation, the most common cause of death through electric shock.

A safe system is a system that protects against short-circuit, overload and 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 an RCD

An 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 into different 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 (neutral to earth) link, this will cause the RCD to trip due to a potential difference in earth.
- The system contains equipment that introduces a small 'below threshold' amount of neutral earth leakage, and the cumulative effect of that 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).

7.4 Neutral to earth link in inverters and in inverter/chargers

An AC power source needs to have a Neutral to Earth (MEN link) so that an RCD can operate. This is the case for the grid, but also if the AC source is a generator or an inverter.

- If the AC power source is the grid, the MEN link will have been hard wired in the switchboard where the grid enters the installation.
- If the AC power source is a generator, the MEN link will have been hard wired in AC connection terminals of the generator.
- If the AC power source is an inverter, the MEN link will have been hard wired either at the inverter's AC connection or in the installation switchboard.

But when combination inverter/charger units are used, the MEN link is less straight forward.

The inverter/charger unit has two different modes of operation:

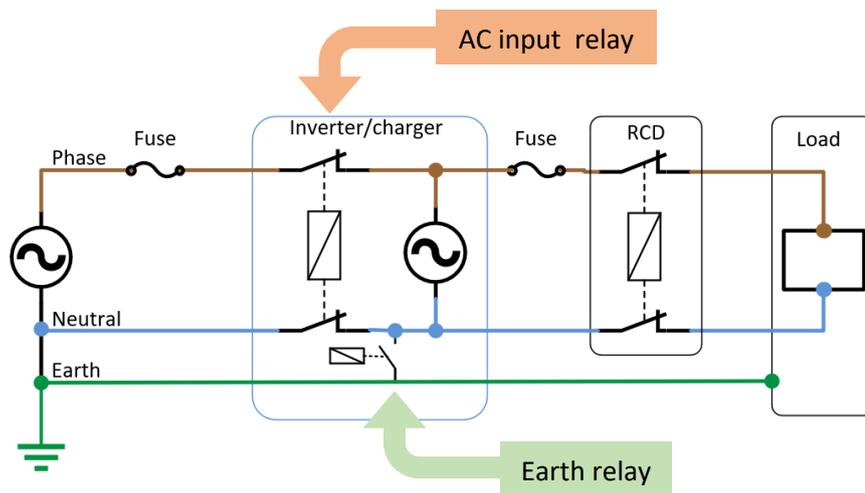
- In inverter mode it is operating as a standalone inverter and is the main power supply in the system.
- In charger mode it will feed through grid or generator power into the system.

When the inverter/charger is inverting and acting as a power supply, it will have to make an independent MEN link. But when it is feeding through a generator or grid supply, the incoming supply has to have the MEN link instead of the inverter/charger.

Victron inverter/chargers contain an internal ground relay. This relay automatically makes or breaks the connection between earth and neutral.

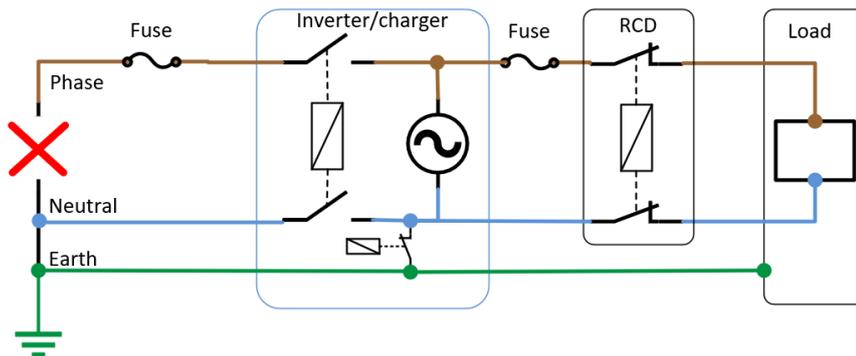
Inverter/charger is charger and feed through mode

When the inverter is connected to AC power the AC input relay is closed and at the same time the earth relay is open. The AC output system relies on the AC power supply to provide the neutral to earth link. This link is needed so the RCD in the AC output circuit is operational.



Inverter/charger is in inverter mode

When the AC power supply is disconnected, has been turned off, or has failed, the AC input relay opens. When the AC input relay is open the installation does not have a neutral to earth link anymore. This is why at the same time the earth relay is closed. As soon as the earth relay closes the inverter/charger has made an internal neutral to earth link. This link is needed so the RCD in the AC output circuit is operational.



7.5 Mobile installations

A mobile installation is an installation that operates independently from the grid. When it connects to AC power it usually connects to the grid at different locations and/or generators. For example, like boats, vehicles or mobile back-up power systems. In this chapter a boat installation is used, however, this information can be used for any mobile installation.

A mobile system does not have an earth stake. So, something else in its place is needed to create a central earth potential. All touchable metal parts of the boat or vehicle must be connected to each other to create a local earth. Examples of metal parts in a boat or vehicle are: chassis, hull, metal fluid pipes, railing, engine, power point earth contacts, lightning conductors and the earth plate (if present).

A mobile system typically connects to a variety of power sources it is sometimes not clear which of the leads in the shore power supply is connected to earth or if earth is connected at all. Also phase and neutral may have not been wired correctly. Connecting a supply like this to a mobile system can potentially create a short circuit to earth. Or earth is missing completely.

It also matters if the mobile system connects to power or if it is disconnected from power and running autonomously.

Some examples of different situations a mobile system can be in:

A boat is connected to shore power

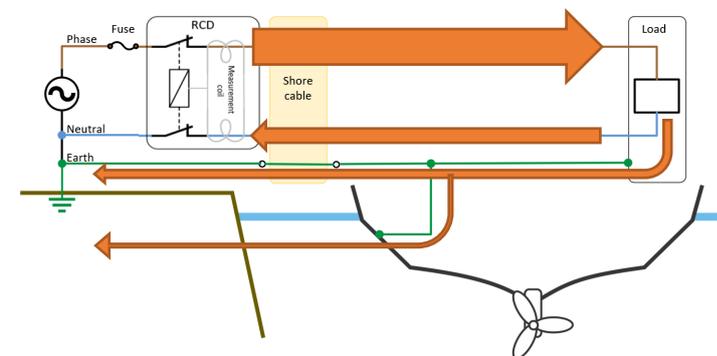
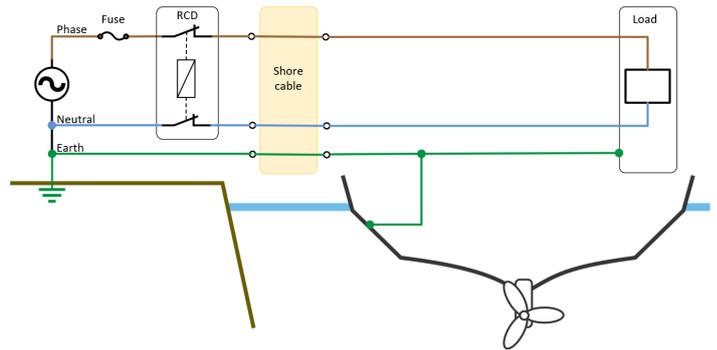
When a boat is moored and connected to shore power installation is similar to a residential installation. There is only one difference; the boat does not have its own earth connection; like the earth spike you will find in a house.

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 might 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 neutral.

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

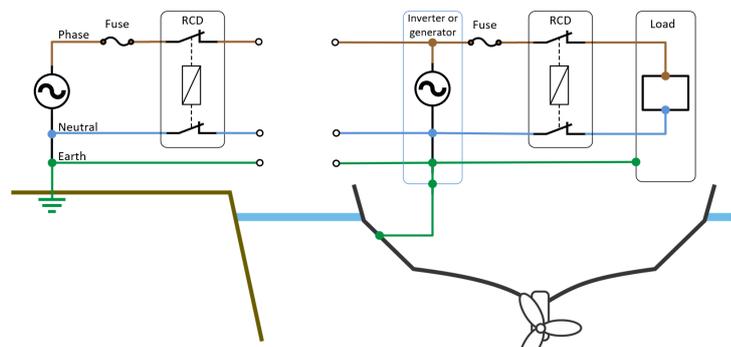
The RCD will still trigger an earth fault, because it will compare phase current in versus current out via neutral.



A boat is disconnected from shore power

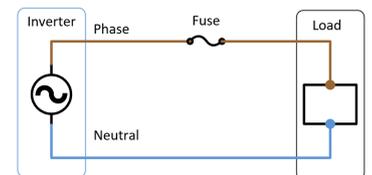
As soon as the boat disconnects from shore power the entire installation changes because the installation is now not part of the grid anymore and the connection with neutral and earth are lost.

The installation is now the main power supply and together with the load forms its own autonomous electric circuit. No current will flow into the hull and into the water.



Floating network in boat or vehicle (IT Network)

In mobile system where an inverter (or generator) is the only 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. A system like this is very safe and simple to install.



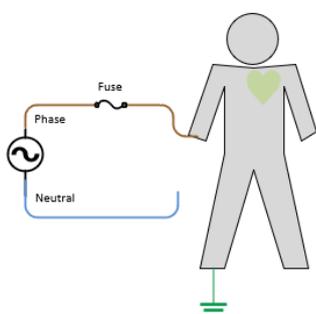
If a conductor or housing in this system is touched by a person, no current can flow to earth. Remember, for current to flow a complete circuit is needed.

In this system 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.

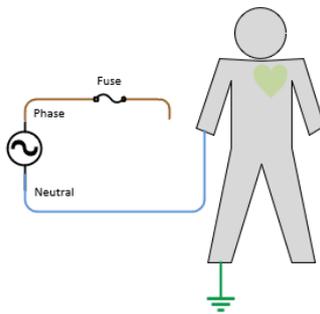
Inverters and generators are in principle nothing more than the source of two potential differences with a difference of 230 Volt. Touching will not lead to a current flow because the path is incomplete. It is the same as a bird sitting on an electricity wire.



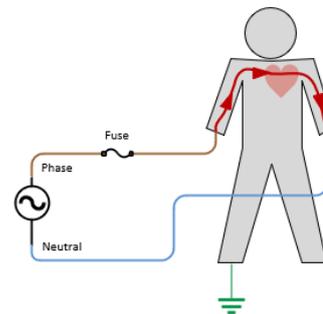
Be aware that touching both the phase and neutral wire at the same time is always dangerous because then the path is complete.



Safe, no electricity will flow



Safe, no electricity will flow



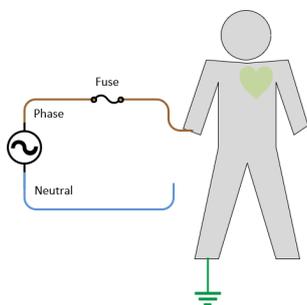
Unsafe, electricity will flow

Mobile network with earth and neutral to earth link (TT network)

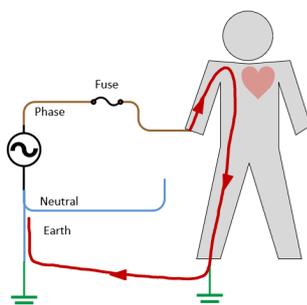
If the mobile system connects to the grid via a transfer switch or via an inverter/charger, earth and a neutral to earth link is introduced into the system. It becomes a TT network.

This is also the case if local regulation requires that earth, and neutral to earth link and an RCD has been hardwired in a mobile system that contains an inverter or generator.

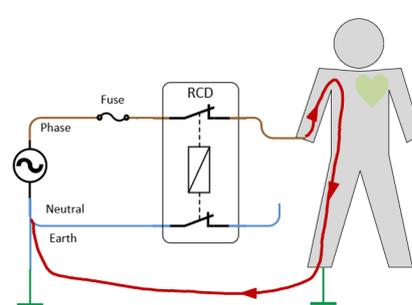
The moment this happens the system will become more dangerous, so as soon as earth and a neutral to earth link have been added to a system an RCD will need to be installed. as to satisfy the requirements of the TT or TN network where the mobile network is now connected to.



No earth, no electricity will flow



Earth added, electricity will flow



Safe, the RCD will protect in case electricity flows

From IT network to TT network

With mobile systems it is possible to create a network that is a TT network when connected to mains and at the same time become a floating IT network when the grid is disconnected, and a generator or inverter is in use. This is something that is not desired and should be avoided.

When an installation disconnects from the grid, it also disconnects from the grid earth. If the mobile installation does not have earth and also no earth and neutral link it will become a floating system, the moment the grid is disconnected.

Although the system might have an RCD, but the RCD cannot detect an earth leakage current anymore because the Neutral is not connected to earth.

Pressing the test button on the RCD is useless if the neutral to earth link is missing. When you press the test button you will get a false impression that the RCD is operational, while in reality the RCD will not operate in case of an earth fault as the neutral to earth link is missing. When the test button on an RCD is pressed, an internal bypass is activated, simulating an earth leak, so the RCD can be electrically and mechanically tested. The test button, by no means, is a test for the whole installation. It only tests the RCD itself.

This will lead to confusion and/or dangerous situations. It is for these reasons recommended to always follow the principles of the TT network, also for situations when the installation is not connected to mains power.

The switch from IT to TT network has to accommodate for a connection being made between neutral and mobile system earth as soon as grid is disconnected. This can be done automatic by an inverter/charger with an earth relay or must to be hard wired into a transfer switch.

Not all inverters and generators have a neutral that is connected to earth. This will always need to be checked prior to installation. And if needed a neutral to earth link needs to be hard wired.

7.6 Isolation and grounding of Victron Equipment

This chapter explains the isolation of a variety of Victron products between AC and DC, or between DC and DC. This information is needed so a system containing a Victron product can be grounded correctly.

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 48 V 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 1600 VA and above and the Phoenix Inverter Compact 1200 VA is connected to the chassis. Grounding the chassis will therefore also ground the AC neutral. A grounded neutral is required for proper operation of an RCD (or RCCB, RCBO or GFCI).

If no reliable ground is available and/or if an RCD (or RCCB, RCBO or 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 to 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).

7.7 System grounding

Thus far we discussed AC earth or ground in AC installations, but grounding is also needed for the DC components in an installation. This chapter describes some common installations that contain not only an inverter/charger but also a battery bank, solar charger and a PV array.

Off-grid system grounding

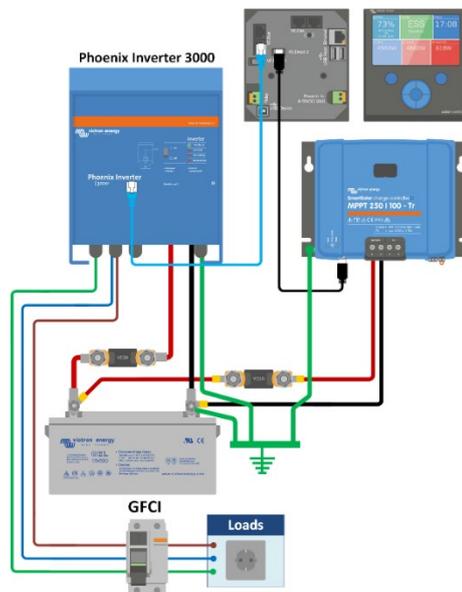
Do not ground the positive or negative of the PV array. The PV negative input of the MPPT is not isolated from the negative output. Grounding the PV will therefore result in ground currents.
The PV frames however may be grounded, either close to the PV array or (preferably) to the central ground. This 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.

The DC ground cabling should have a sufficient thickness to 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. There is basic insulation between AC and chassis.

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



Please note that the AC distribution with fuses or MCB's and PV array and PV frame grounding are not shown.

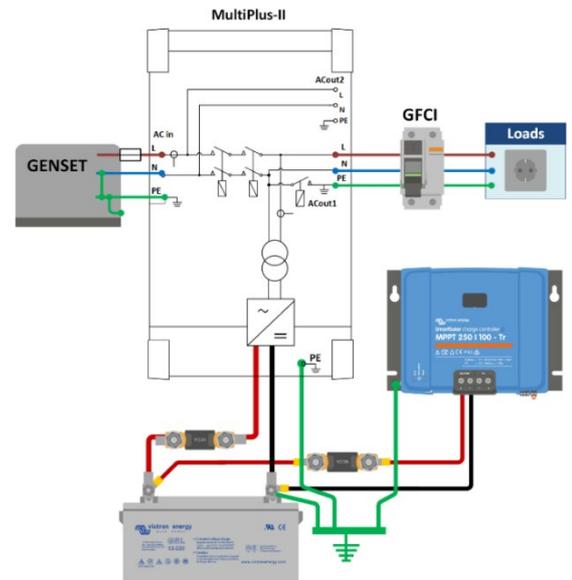
Off-grid with generator

Use one ground only, 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.

The DC ground cabling should have a sufficient thickness to be able to carry a fault current at least equal to the DC fuse rating.

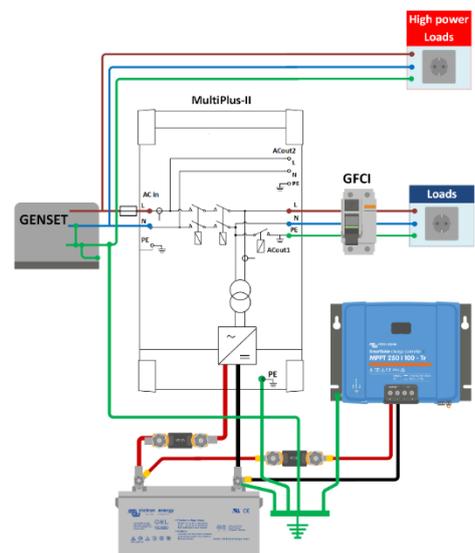
Similarly, AC ground cabling should be able to carry a fault current at least equal to the AC fuse rating.

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



Off-grid with high power generator

Ground the generator directly at the central ground.

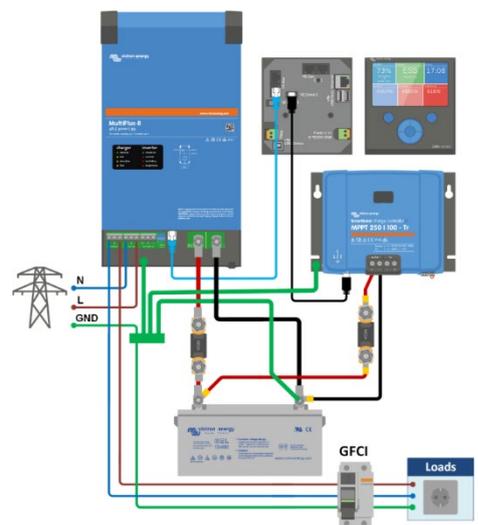


Grid connected Energy Storage System (ESS)

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.



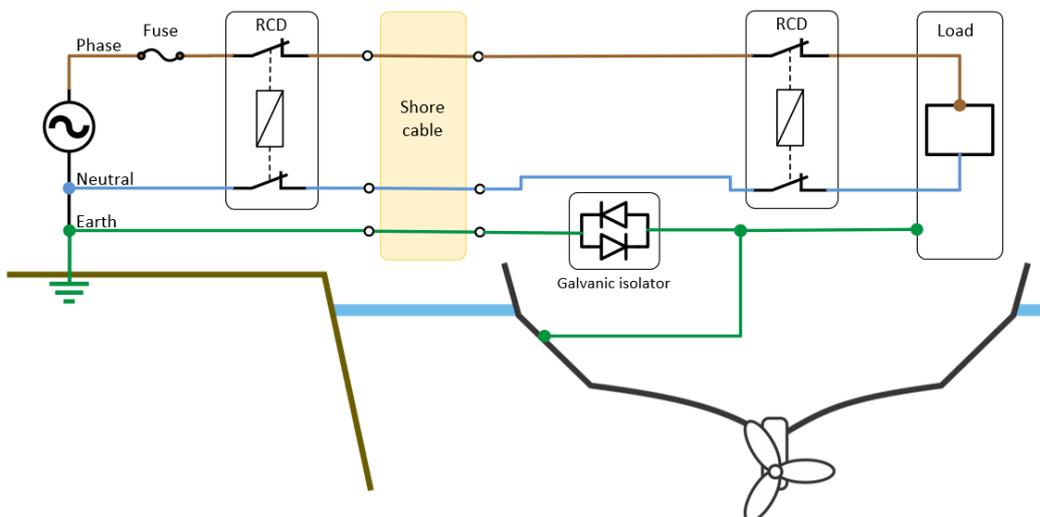
8.2 The galvanic isolator

The galvanic isolator prevents galvanic corrosion. It blocks the low voltage DC currents that enter your boat via the shore power earth wire. These currents can cause corrosion to the boat's underwater metals, like the hull, propeller, shaft and so on.

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 through one of the electrical appliances on board, like a suppression filter or other appliances.



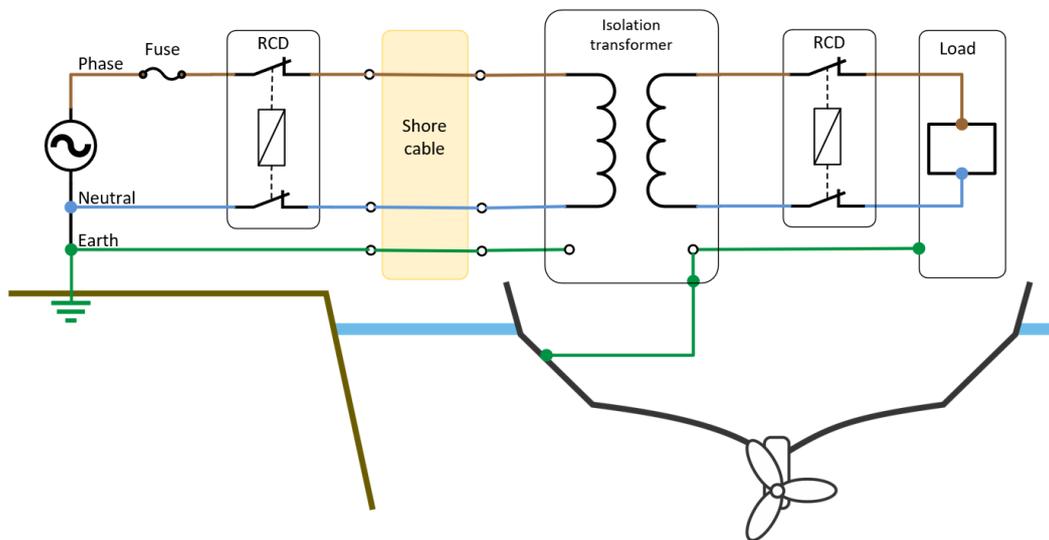
8.3 The isolation transformer

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 again 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 an 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 230 Vac boat has to connect to a 120 Vac supply, or vice versa.



9. Credits

Author:

Margreet Leeftink

With thanks to:

Reinout Vader for suppling grounding and isolation content

The Victron community and especially Mike Riley

The World wide web

Content credits:

Fuse speed info:

https://www.swe-check.com.au/pages/learn_fuse_markings.php

Bussmann:

http://www.cooperindustries.com/content/public/en/bussmann/transportation/products/circuit_protection/fuses/marine_rated_batteryfuses.html

Dangers of electricity:

https://www.hsa.ie/eng/Topics/Electricity/Dangers_of_Electricity/

Cable interference and shielding:

<https://www.multicable.com/resources/reference-data/signal-interference-and-cable-shielding/>

Image Ohm's law cartoon:

<https://www.clipart.email/download/4165420.html>

Image ohm's law formula wheel:

<https://www.esdsite.nl/elektronica/formules/wetvanohm.html>

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Blade fuses:

https://commons.wikimedia.org/wiki/File:Electrical_fuses,_blade_type.svg

NMEA2000 cable image:

<https://www.powerandmotoryacht.com/electronics/down-wire>