DURAKOOL®

A Solid State Group Brand

HVDC Relays & contactors overview

Providing Switching Solutions

A quick word about definitions

IEC 60947 Low Voltage Directive <= 1000VAC or 1500VDC

But, in the automotive industry anything above 24VDC is called HVDC,

so

HVDC (for this presentation) = >30VDC & =<1500VDC

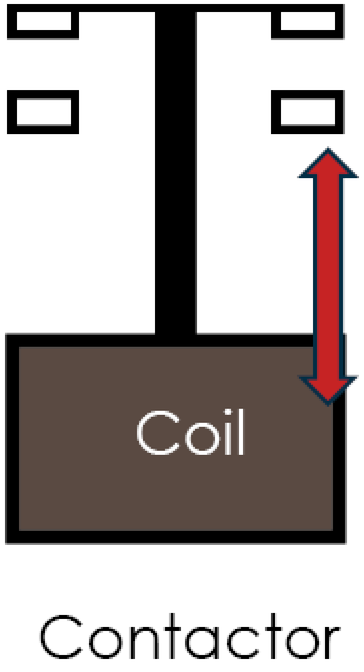
Special techniques needed above 1500VDC but principles are the same!

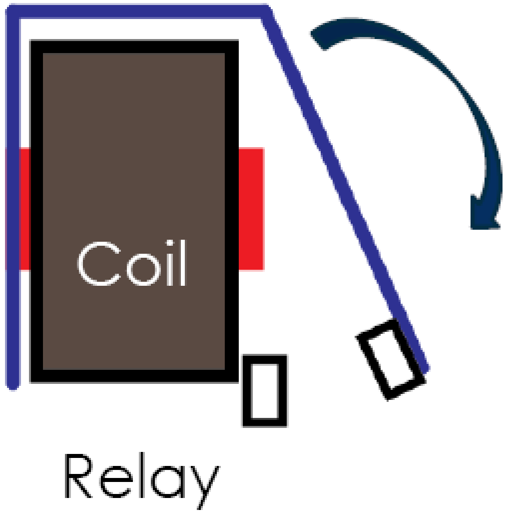
Photo: Ross Engineering Corp. USA

A quick word about definitions

Relay = coil with solid iron core, armature is hinged and pulled to core, contacts move through an arc (even if very small).

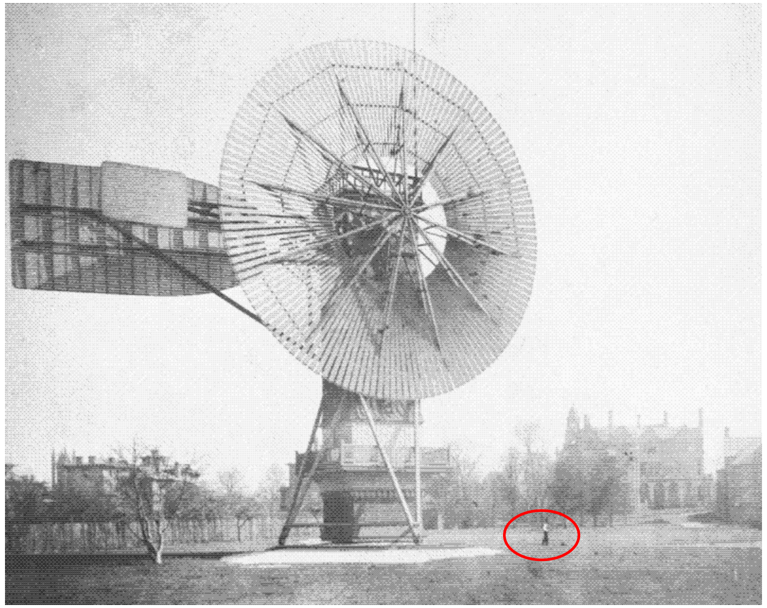
Contactor = coil with hollow core, plunger is pulled into coil, contacts move in a straight line, usually configured as double make/break contacts (single or many poles), big contact gap.





1898

1887



Electric Vehicles are not new!

Top speed = 40mph
Range = 50 miles
Won 1st automobile race in the USA (1896)

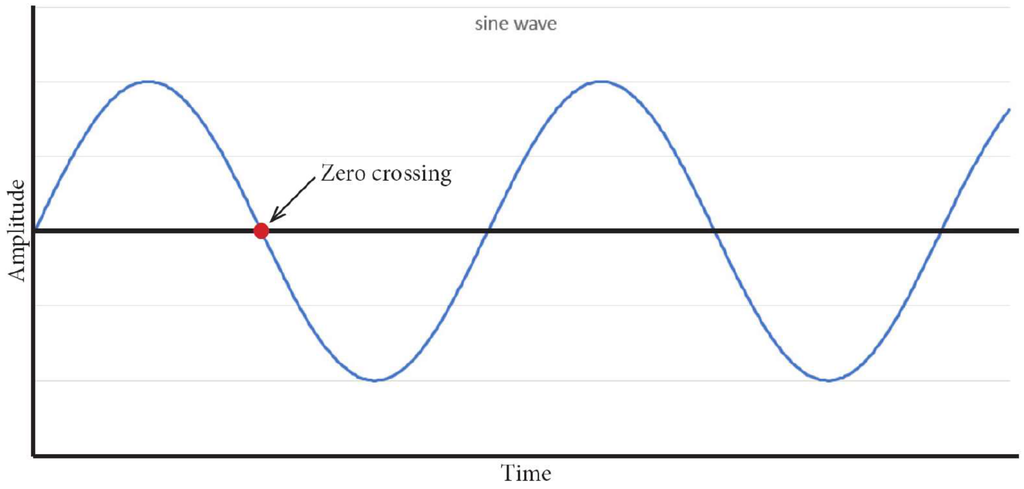
Nor is DC switching for alternative energy sources

12kW c. 70V ~ 75VDC
Brush was lighting New York streets
2 years before Edison!

DC Considerations

Switching low frequency (50/60Hz) AC is relatively easy

Any switching arc is self extinguishing at the zero crossing point



With DC there is no zero crossing to extinguish any arc formed when the contacts open

To extinguish a DC switching arc, a big gap is needed. The gap size is dependent on the voltage

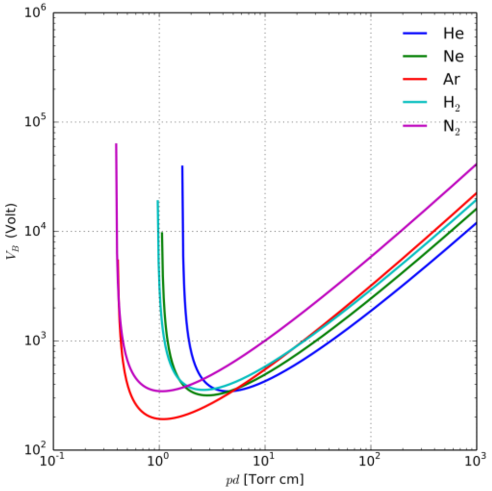
Paschen’s law

Describes the breakdown between two electrodes and gives an equation for the voltage required to start an arc.

Equation is for fixed gaps between the electrodes and for specific gas types and at defined pressures.

In a relay or contactor, as the contacts open, there is an infinitesimally small gap and a plasma forms between the contacts. A stable arc is drawn out from the contacts until the gap is too big for the voltage to sustain the arc.

This is the principle of arc welding!

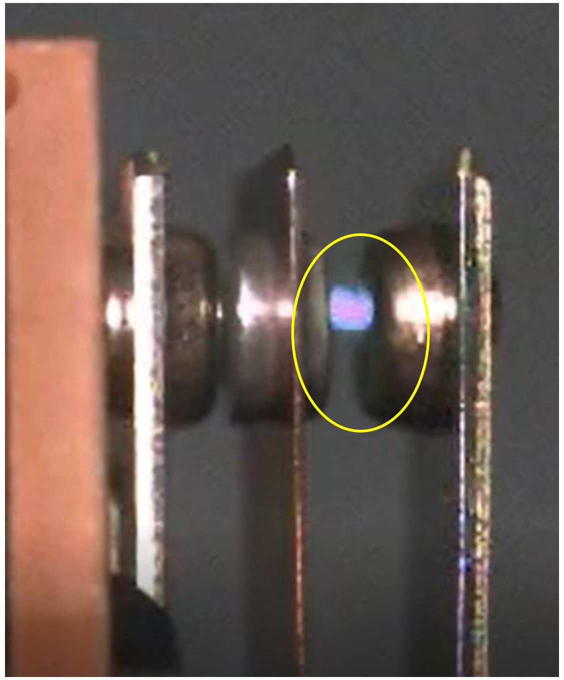


Source: Wikipedia / Krishavedala

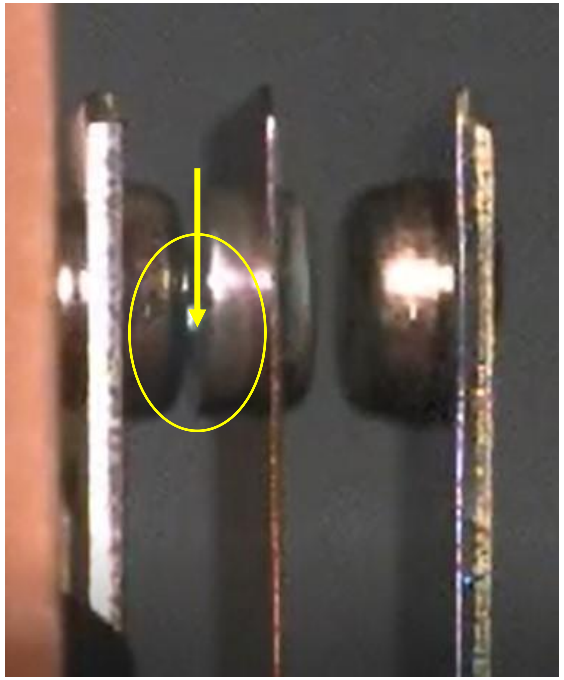
When DC currents & voltages are high enough

- Very significant contact damage can occur very quickly
- Arc temperatures can be anywhere from 3000˚C to 20,000 ˚C
- Contacts will melt and may even vaporise

NB: Most DC switching issues occur when the contacts open but, when the contacts close there will always be some contact bounce



Arc on contact opening



Bounce arc on contact closing

Principles of DC switching

1. Make the contact gap as big as possible
2. Open the contacts as fast as possible
3. Stop the arc from forming
4. Reduce contact bounce time
5. Robust contacts and terminals to manage heat dissipation

We can make a big contact gap but how do we make the contact gap bigger if space is limited?

If we have a big contact gap, we need a big coil as it has to exert a pull over a bigger distance, bigger than would otherwise be necessary to keep the contacts closed. Bigger coil means more weight, more current (and more heat), greater cost and the increase in size.

Arc extinguishing – Big contact gaps

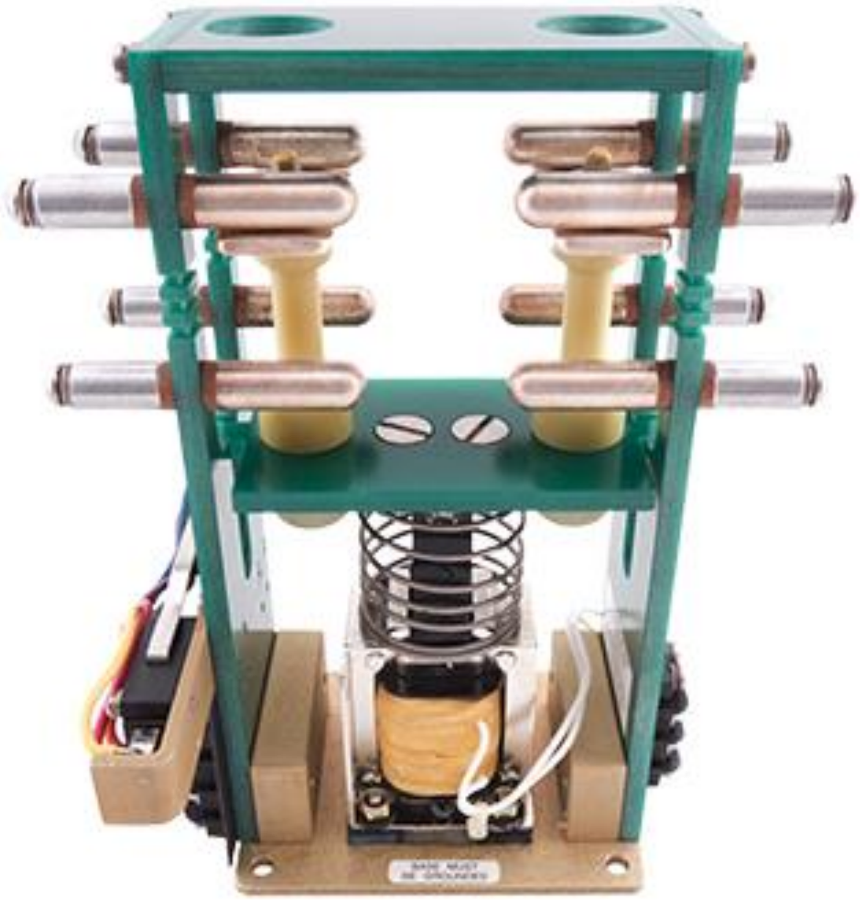
Shown on the right is a DPNC+DPNO relay designed to switch high voltage RF power

Big contacts!

Big coil!

Big contact gaps!

Switching RF power approximates DC as far as relays & contactors are concerned



Source: Ross Engineering Corp.

Arc extinguishing – Big contact gaps & magnets

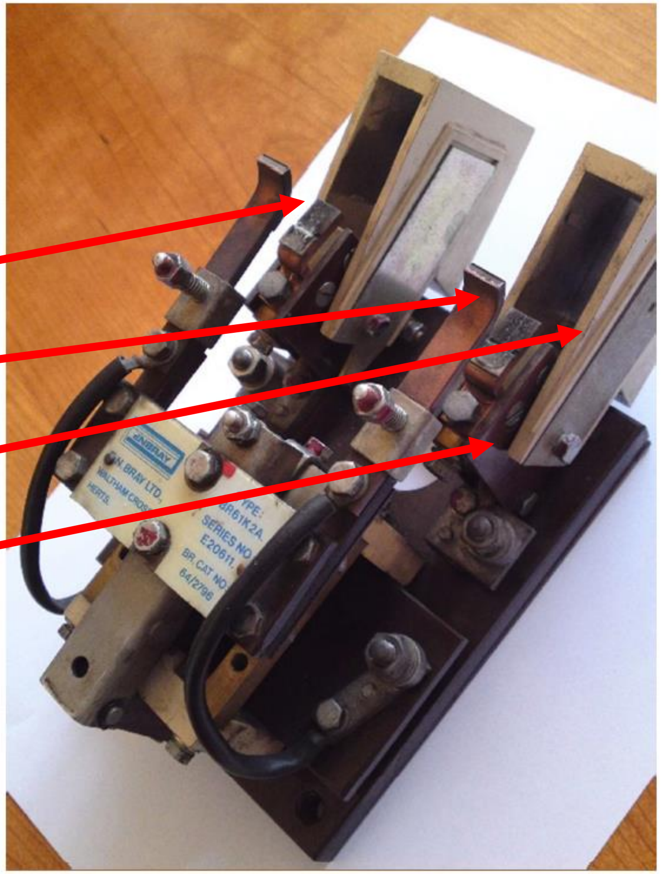
Shown on the right is an old DPST-NO relay designed to switch 15kVDC at 15A. It is from a British railway carriage where they are still in use today.

Big contact gap

Contact arms shaped to deflect arc

Ceramic arc chute

Magnet



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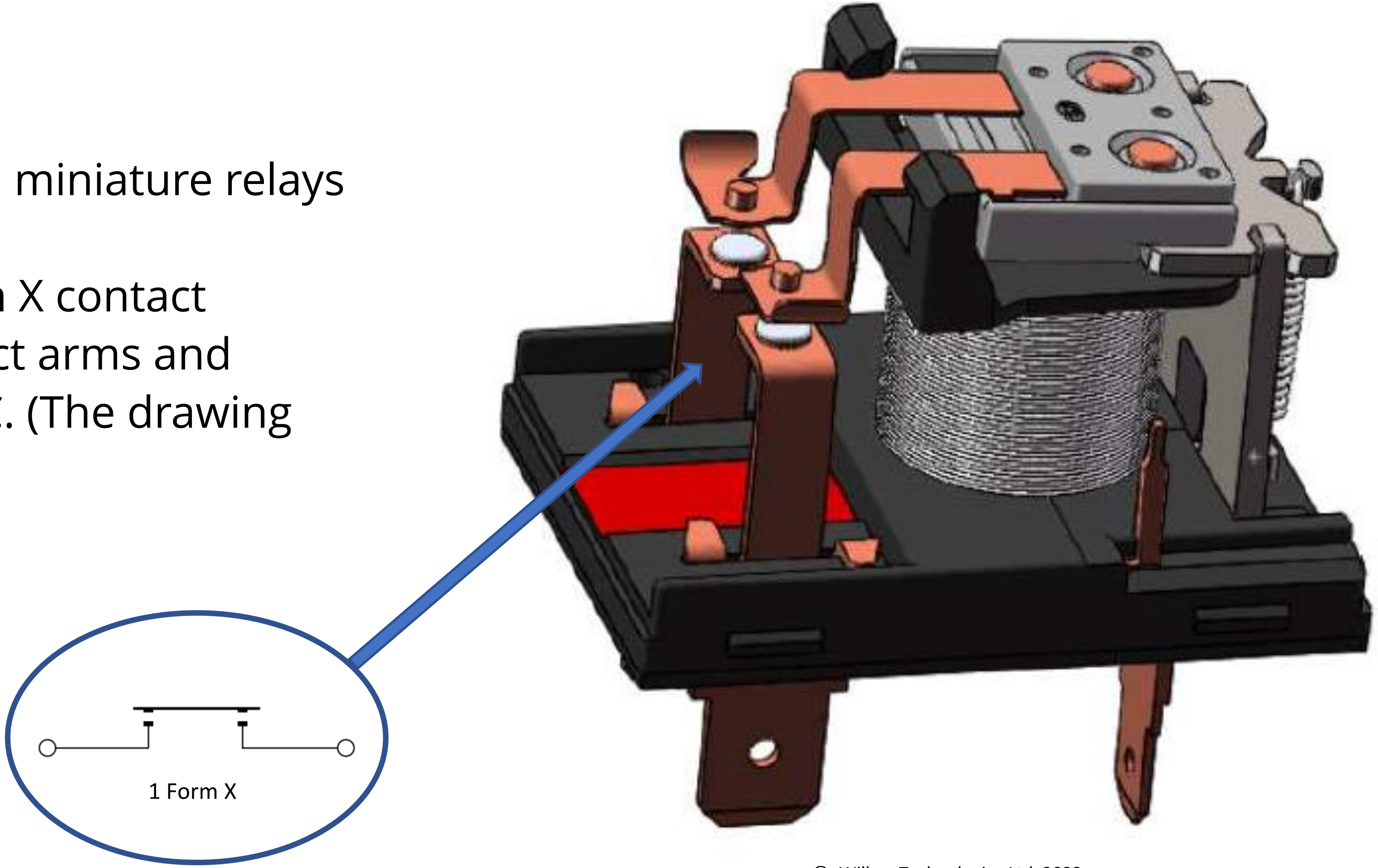
If you look closely you can see the arc traces!

Arc extinguishing small relays

Similar techniques can be used in miniature relays

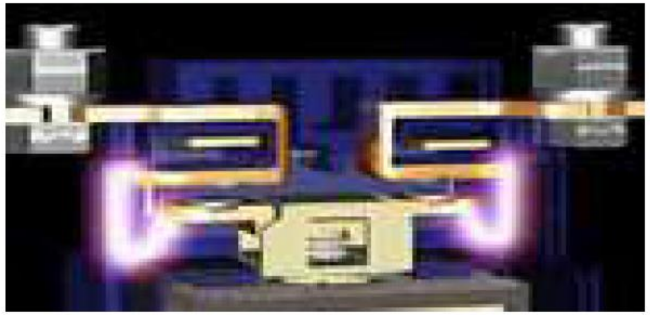
The Durakool DE20 uses a 1 Form X contact configuration, with shaped contact arms and magnets to switch 20A @ 450VDC. (The drawing doesn't show the magnets)



Arc extinguishing with magnets

NB: Polarity of magnets and current direction is important

Arc Ignition as contacts open



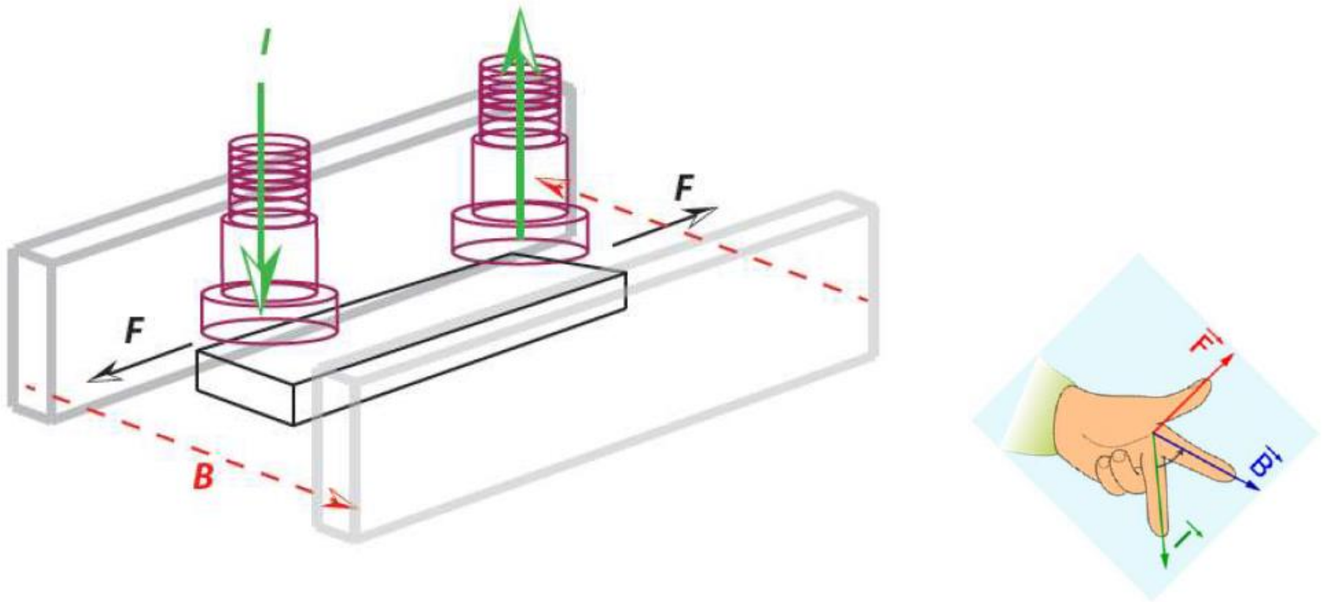
Arc elongation by magnets

Arc extinguished

Arc extinguishing with magnets

Direction of arc is controlled by Fleming's Left-Hand Rule

If terminals are incorrectly polarised, opening arcs will be deflected inwards and may not be stretched far enough to be extinguished.



Stop the arc from Forming

The arc that forms when the contacts open is a drawn arc – like an arc welder.

If arc forms in air a stable arc will form only limited by the ability of the source to keep it supplied.

Replacing the air around the contacts with a gas with known arc limiting properties, or a vacuum, removes the Oxygen which sustains the arc.

For this to work, contents must be inside a gas tight environment (hermetically sealed). If the seal leaks and air gets in, then there can be catastrophic results!

Stopping the arc from forming

Various gasses have been tried with varying degrees of success:
Sulphur hexafluoride (SF_6), Hydrogen (H) and Nitrogen (N) plus other more complex mixes.

Vacuum is the best solution but very difficult to achieve in production, even with steel cans and glass to metal seals. There will always be some gaseous mix which will ionise and allow an arc to form even if it is weak and easily extinguished.

Of course, it is possible to stay with air but this usually either results in a larger contactor than would be achievable with a gas fill or with reduced switching capacity.

Terminal considerations

Even if the arc can be extinguished, it can still melt the contact surface.
This will eventually lead to a contact weld.

It is important to keep the contacts as cool as possible, both during the switching process and when the contacts are closed and conducting.

Terminals can be used to dissipate the heat into the surrounding cables and busbars.

Therefore it is important to keep the busbars (or cables) at least as large as the manufacturers recommendations and bigger if possible.

For example, Durakool DEVR60 is rated for 600A with 200mm^2 busbars, but increase to 300mm^2 and it can carry 1000A for 10 minutes and still remain well within acceptable terminal temperatures.

Terminal considerations

IEC (EN) 60947.1 (Table 2) defines the acceptable limits for the temperature rise, above ambient, for relay and contactor terminals.

Typically, contactor terminals will be silver plated, or nickel plated, copper or brass.

So, according to Table 2, the maximum temperature rise is 70°K.

At least one HVDC Contactor manufacturer quotes their data with a terminal temperature rise, above ambient, of 85°C, i.e. 15°K above the limit specified in IEC (EN) 60947.1

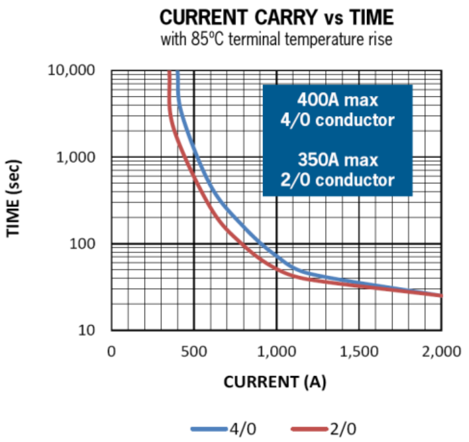
Table 2 – Temperature-rise limits of terminals
(see 7.2.2.1 and 8.3.3.3.4)

Terminal material	Temperature-rise limits [1] [3] K
Bare copper	60
Bare brass	65
Tin plated copper or brass	65
Silver plated or nickel plated copper or brass	70
Other metals	[2]

[1] The use in service of connected conductors significantly smaller than those listed in Tables 9 and 10 could result in higher terminals and internal part temperatures and such conductors should not be used without the manufacturer's consent since higher temperatures could lead to equipment failure.

[2] Temperature-rise limits to be based on service experience or life tests but not to exceed 65 K.

[3] Different values may be prescribed by product standards for different test conditions and for devices of small dimensions, but not exceeding by more than 10 K the values of this table.



Source: Gigavac® data sheet

4/0 ≈ 100mm²
2/0 ≈ 60mm²

The operating temperature range for this contactor is -55°C to +85°C which means the terminals could be at 170°C when fully loaded!

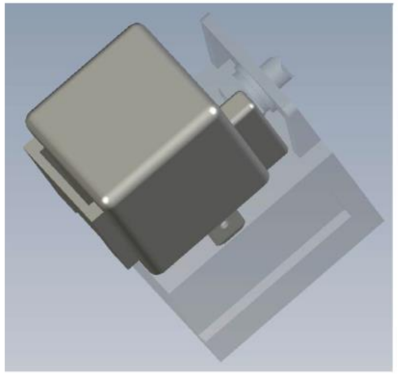
Automotive relay design for DC switching

Automotive Relays are relays optimized to switch DC voltages, usually between 6VDC & 24VDC with currents from 5A to 100A.

Industry standard ISO 7588 defines the outline and foot print.

Increased demand for automotive relays to switch 48VDC, or higher, in an ISO 7588 style package due to introduction of “48V mild hybrid” systems and the use of lithium ion batteries in industrial vehicles.

<145VDC: 1 Form A contact (single break) Magnet deflects arc to side. >120VDC, 1 Form X (double break) Magnet deflects arcs to sides.



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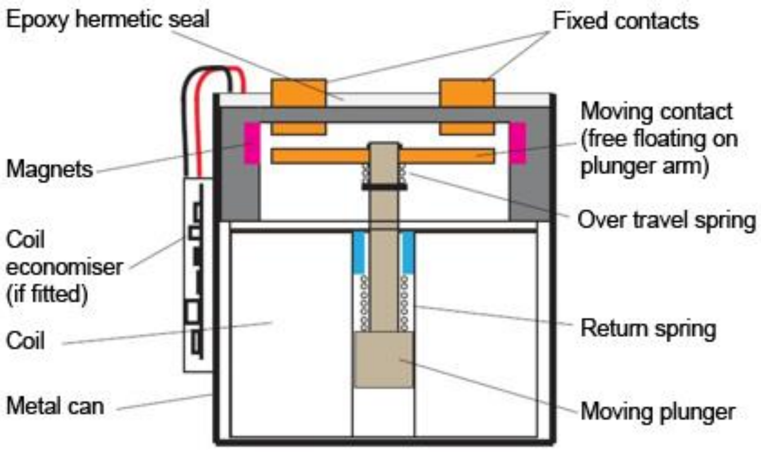
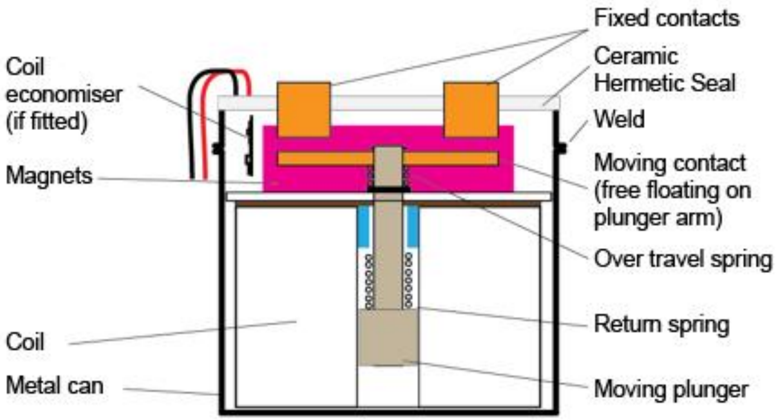
Magnet to deflect the arc

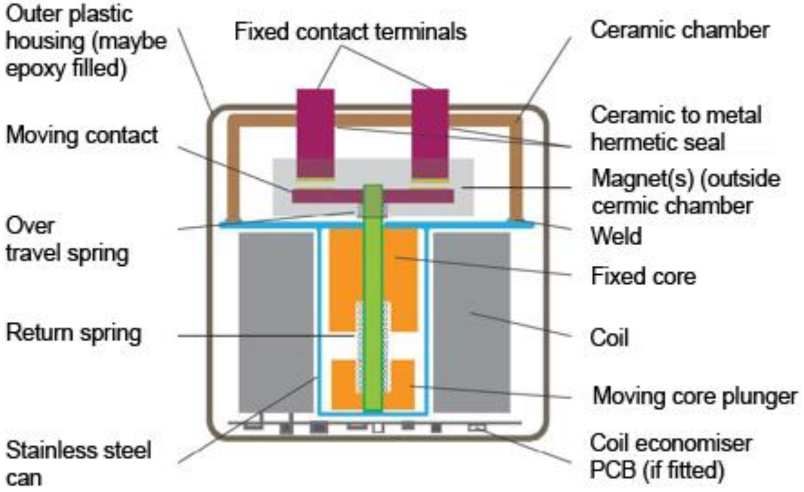
25mm x 19mm x 19.5 mm

Using a magnet with a concentrator results in a very small relay capable of switching 10A @ 450VDC

HVDC Contactor design







Epoxy seal (USA type)

Epoxy seal, coil and contacts inside metal can

Gigavac EPIC® type

Ceramic header, coil & contacts inside metal can

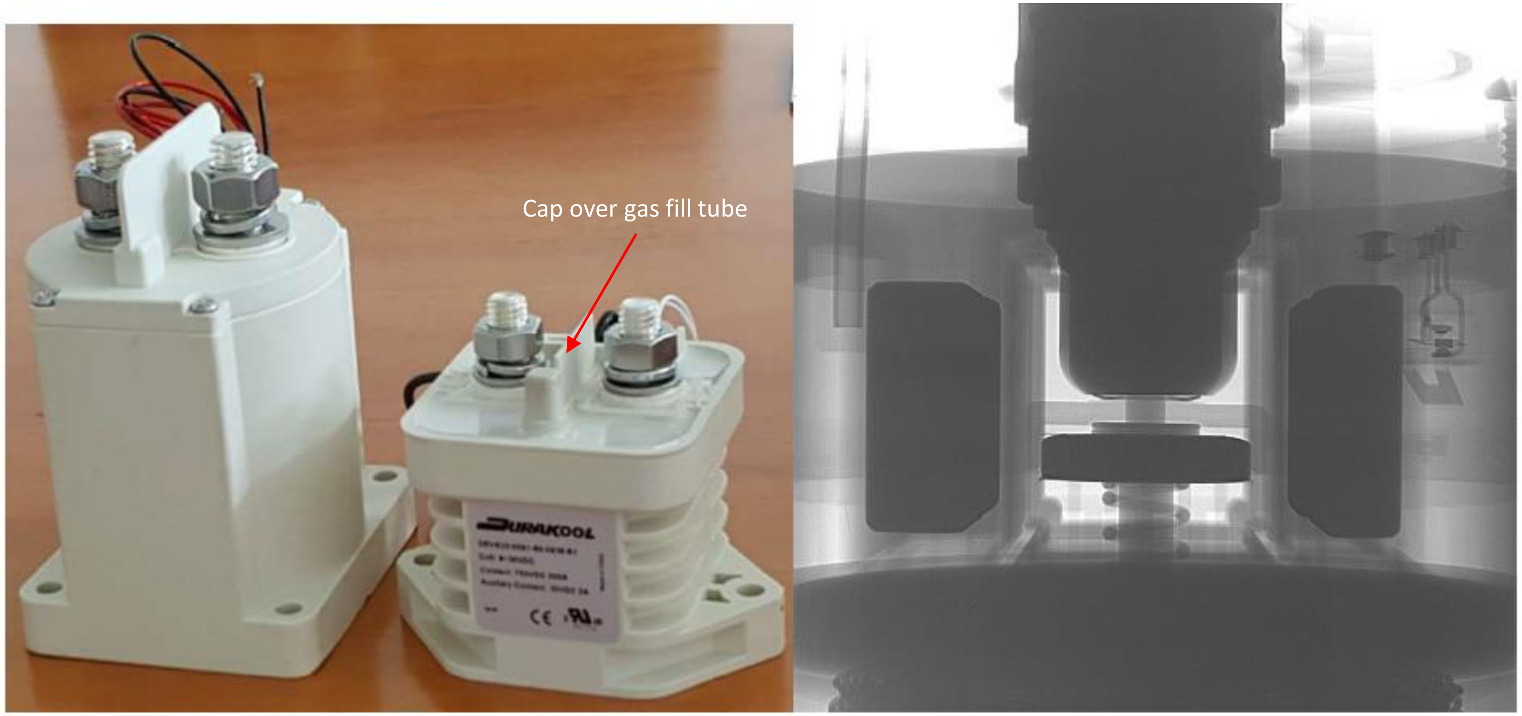
Ceramic seal (Japanese) style

Contacts inside ceramic arc chamber,
coil outside metal can

Epoxy sealed type

- One, two or three magnets (2 here)
- Double break Contact Gap
- Gas filled contact chamber
- Easy to manufacture in small batches

Epoxy seal: Production is limited by curing oven capacity and time



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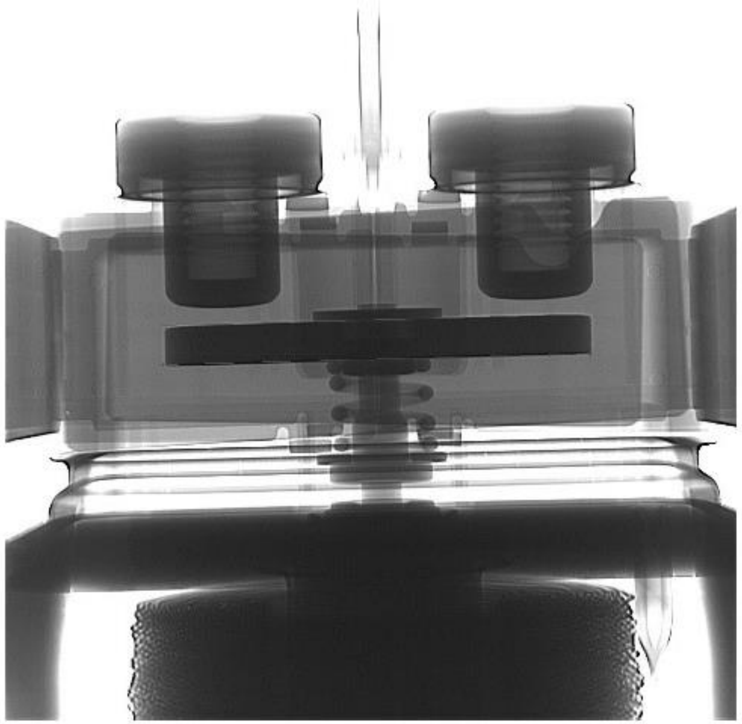
‘Japanese’ style

Coil & PCB external to contact chamber

More costly to manufacture with heavy initial investment in assembly equipment But good for automation and quick assembly. No curing time for epoxy. Fully automatic assembly possible.



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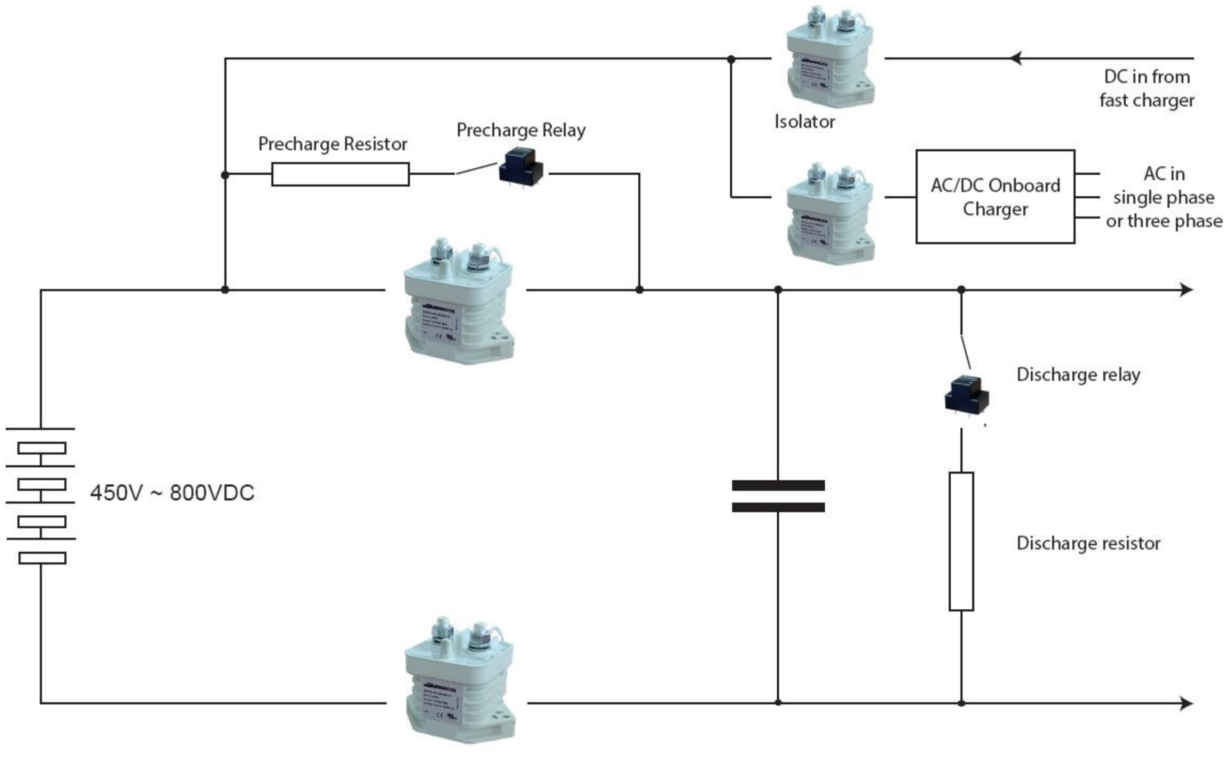
Typical application in an EV



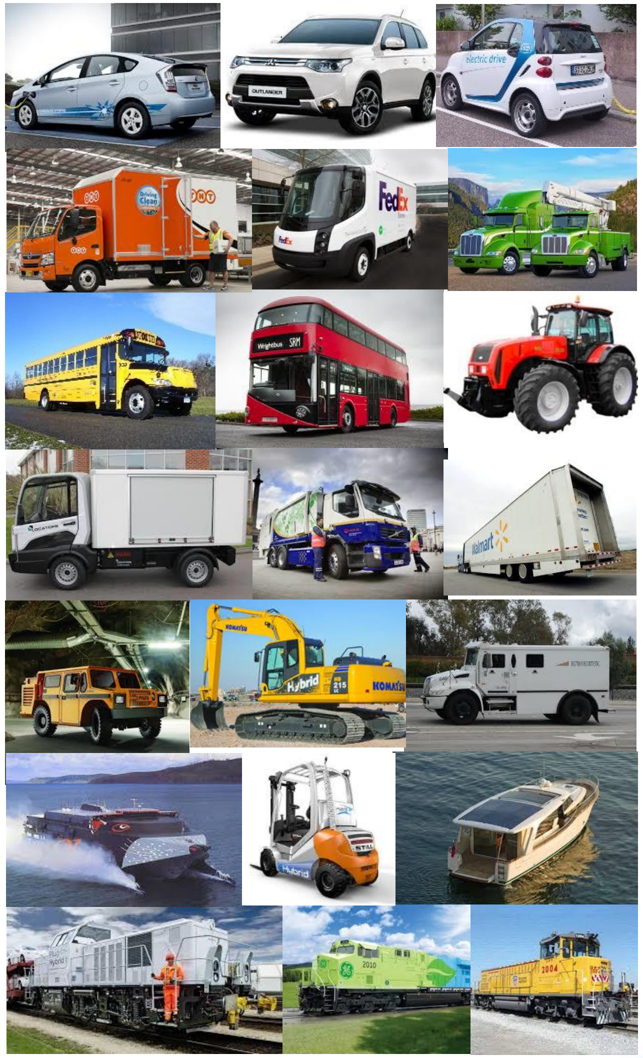
Contactors are used to provide safety isolation of the battery. They do not normally switch under load, but they must withstand high peak currents when vehicle accelerates, for example.

Sequence of operation

1. Discharge contactor opens (often a NC type).
2. Pre-charge relay closes and filter capacitors start charging. Current is limited by the Pre-charge resistor.
3. Main contactors close when capacitors are at about 80% charge.
4. Pre-charge relay opens until next cycle.
5. EV comes to a stop and switched off. First Main contactor opens and Discharge relay closes to drain excess voltage from capacitors - safety – and then Second Main contactor opens to isolate battery.

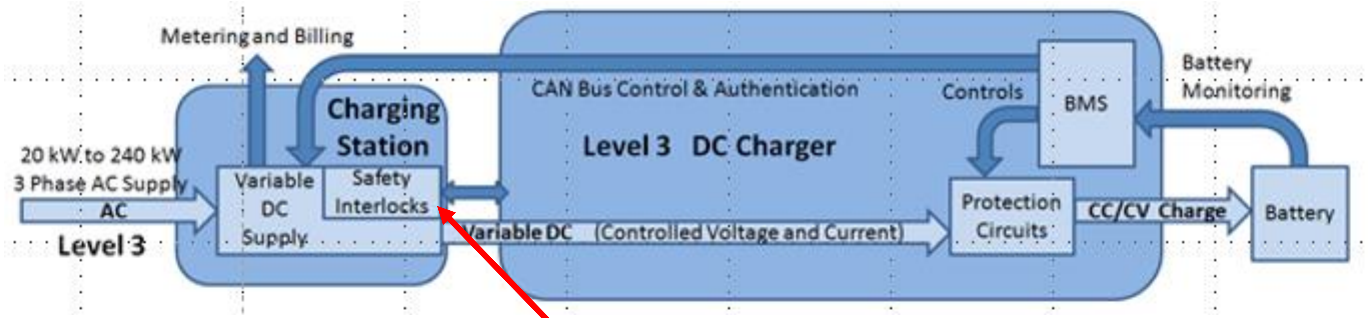
Not all EVs are cars!

Photo: Airbus



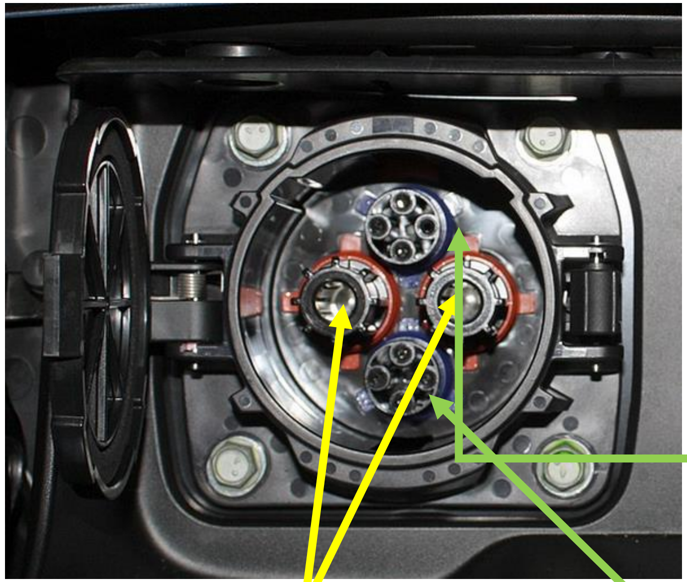
DC Fast charging

DC Fast Charging



HVDC Contactors (2pcs) in here!

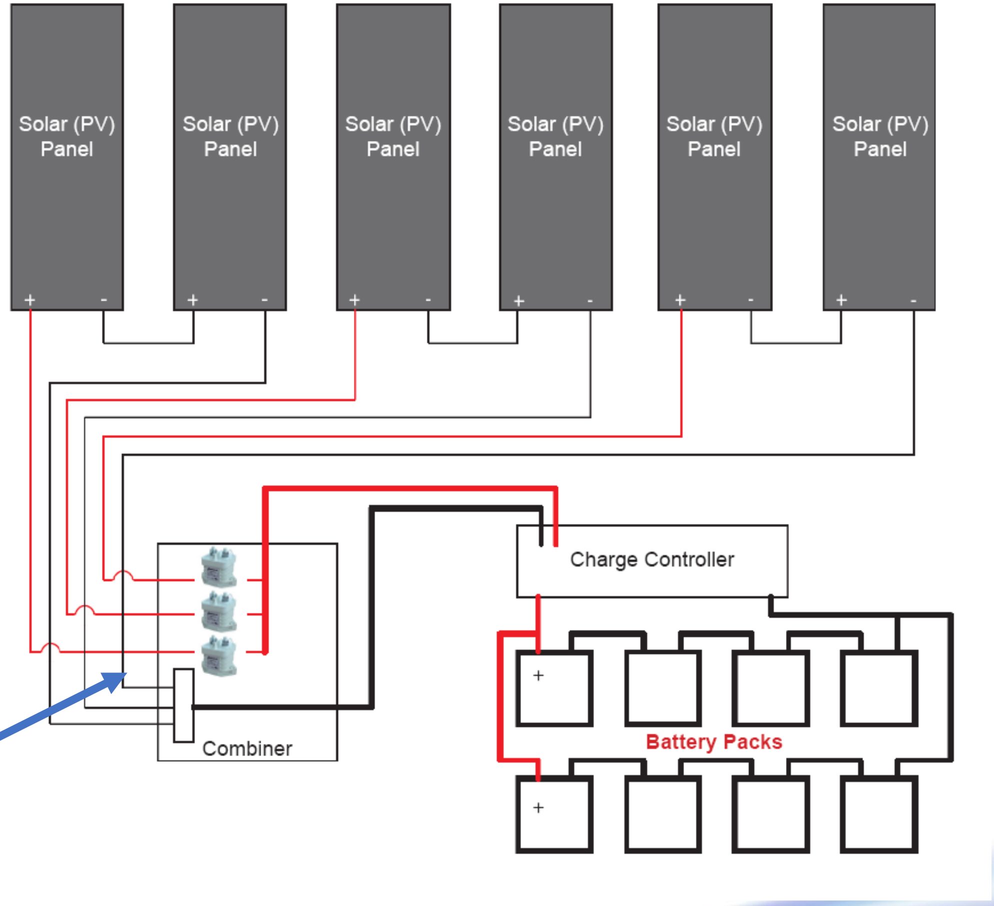
CHAdeMO Socket (from a Nissan Leaf)



Main Charging Terminals

Communications

Solar & wind power



Not all solar panel installations are in huge fields

New designs of solar cells enable portable applications for disaster recovery, emergency power or military applications.

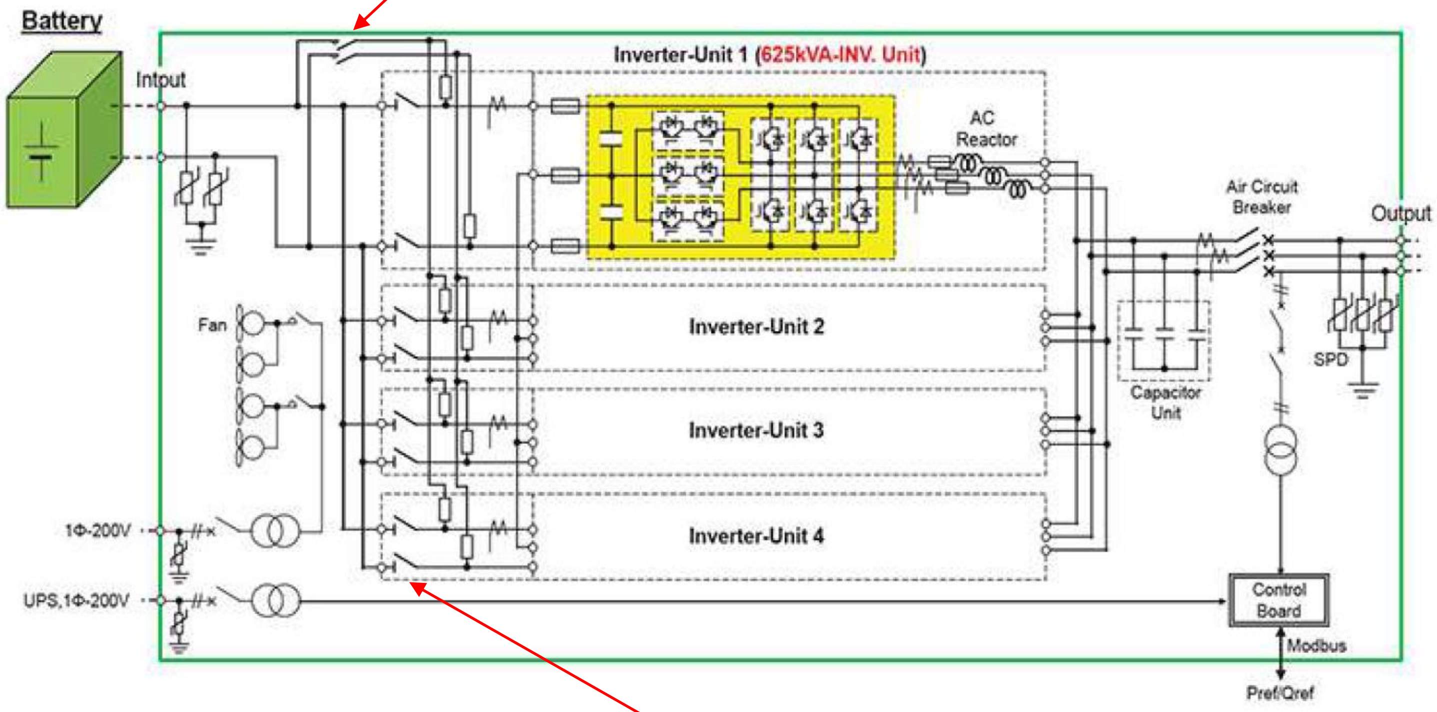
HVDC relays or Contactors used for safety disconnect.

50A / 750VDC

Photos: Renovagen

Large scale solar panels with battery storage

Pre-charge Contactors x 2



Main Contactors x 8

Photo: Scottish Power

Summary

One person’s HVDC is another person’s LVDC! HVDC for many = >24VDC and <1500VDC.

Switching DC above 24VDC is not a new problem, but increasing use of new batteries, together with new technology, is generating fresh challenges for relay and contactor makers.

Switching HVDC is all about coping with switching arcs and maintaining insulation and isolation.

Innovations in batteries mean high power batteries which for safety must be isolated from the rest of the system when not in use or in the event of a fault.

Relays & Contactors used in EV applications have to be as small as possible but still carry high currents whilst maintaining isolation and insulation distances for voltages in excess of 1000VDC.

Summary

Contactors in EV’s must be capable of breaking a fault (short circuit) current at least once but do not normally switch under full load.

They must carry the full load current for long periods and cope with short term peak currents for several minutes.

Contactors for PV and Battery Storage Systems must be capable of breaking fault currents at least once but may also have to switch full load current several times during the expected life.

Contactors used in battery storage DC to AC systems share much in common with EV’s except higher voltages and currents.

Get it wrong and the results can be dramatic!

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