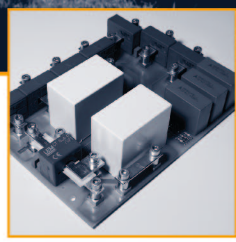
Application Note

Solar Inverters / Plants Control & Safety

Systems Control & Protection



The Copenhagener climatic conference in 2009 and the earlier Kyoto protocol (adopted in 1997 and enforced as of 2005) committed different national governments to decrease their CO2 emissions.

One of the possible ways to achieve these goals is to increase the production of sustainable energy and to issue a grant for every initiative taken. Governments have decided to support efforts oriented towards energy savings and for sustainable energy. Of course, this explains the revived interest in solar energy.

Solar energy had already been a source of interest in the past due to profitability analysis. However the investments made were significantly higher than the value of the energy generated.

The government's commitments and today's electronic technologies have made this energy source a more profitable one.

In Europe for instance, 4500 MWp were generated by the solar plants in 2007 versus 3000 MWp in 2006, this is a growth of 50 % in one year!

Worldwide, 9 GWp were installed in 2007 including 3 GWp coming from Germany, a pioneer country leading the way for production and profitable energy generation from the sun.

In 2008, 0.05 % of the global worldwide electricity was produced by solar energy.

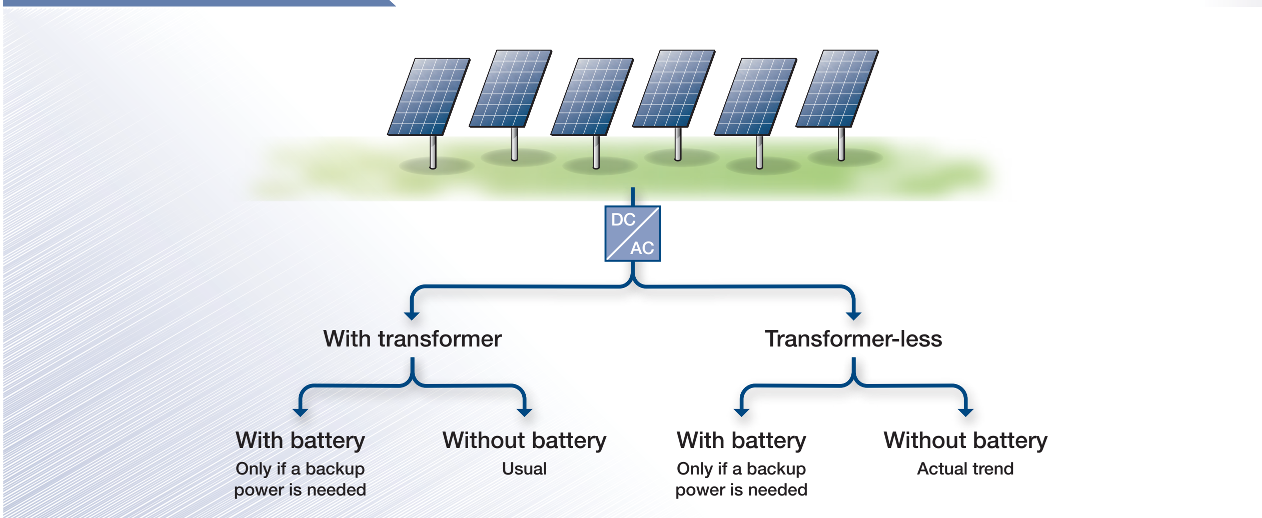
This strong growth is mainly due to the national programs in USA, Japan and Germany.

The actual forecast is to produce 10.91 GWp from solar energy in 2012:

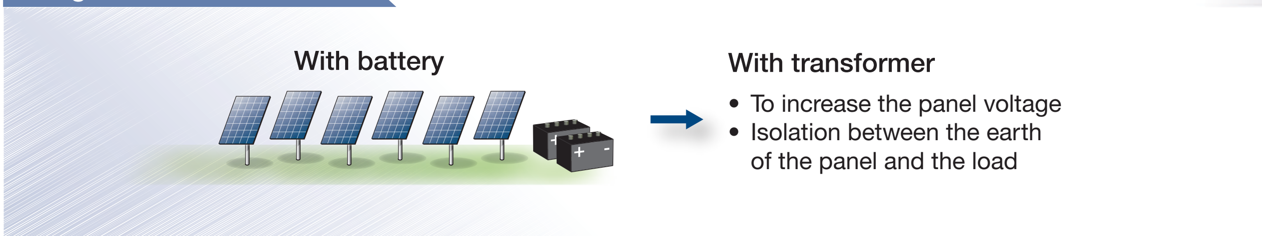
- 4.72 GWp in Europe (Germany as leader). Spain, Italy, France and Greece increase their solar
- installations due to strong governmental grants
- 2.55 GWp in USA
- 0.91 GWp in Japan: Here the growth will depend on the government decision to reintroduce the support program
- 0.91 GWp in South Korea and 0.73 GWp in India

About 90% of the energy produced by solar installations is connected to the grid by an inverter and called "grid-connected". The remaining 10 % which is not connected to an inverter is called "off-grid".

Grid connected



Off-grid



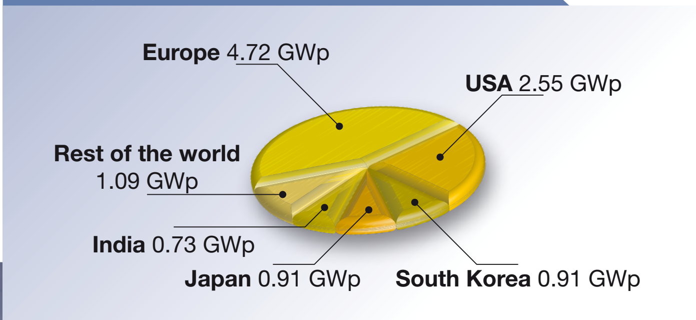
The off grid electricity is used to charge batteries needed for local applications.

Regardless if “grid-connected” or “off-grid”, a current measurement is required.

The connection of the solar array through an inverter to the grid can be made either by using a transformer or directly without transformer, so called transformerless, meaning without galvanic isolation; and for both cases with or without battery.

Depending on the purpose (size, efficiency, weight, range, galvanic insulation), there is a choice of different inverters in the market today.

Solar production in 2012 - Forecast



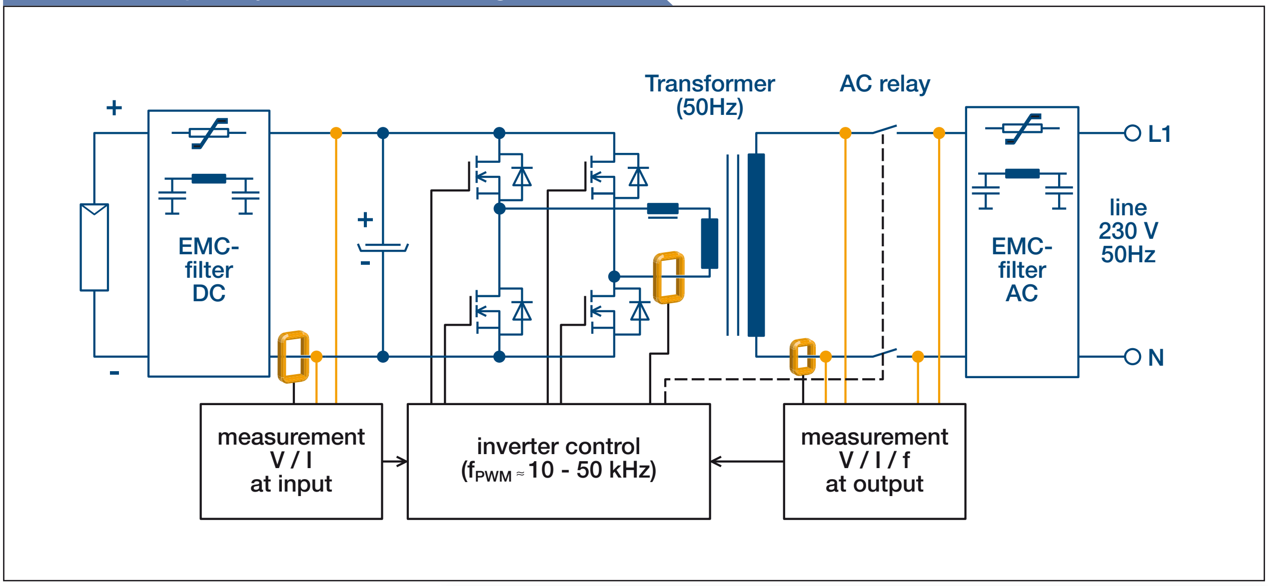
Different inverter designs according to needs (Grid connected)

With transformer

- Galvanic Insulation

- Lower efficiency

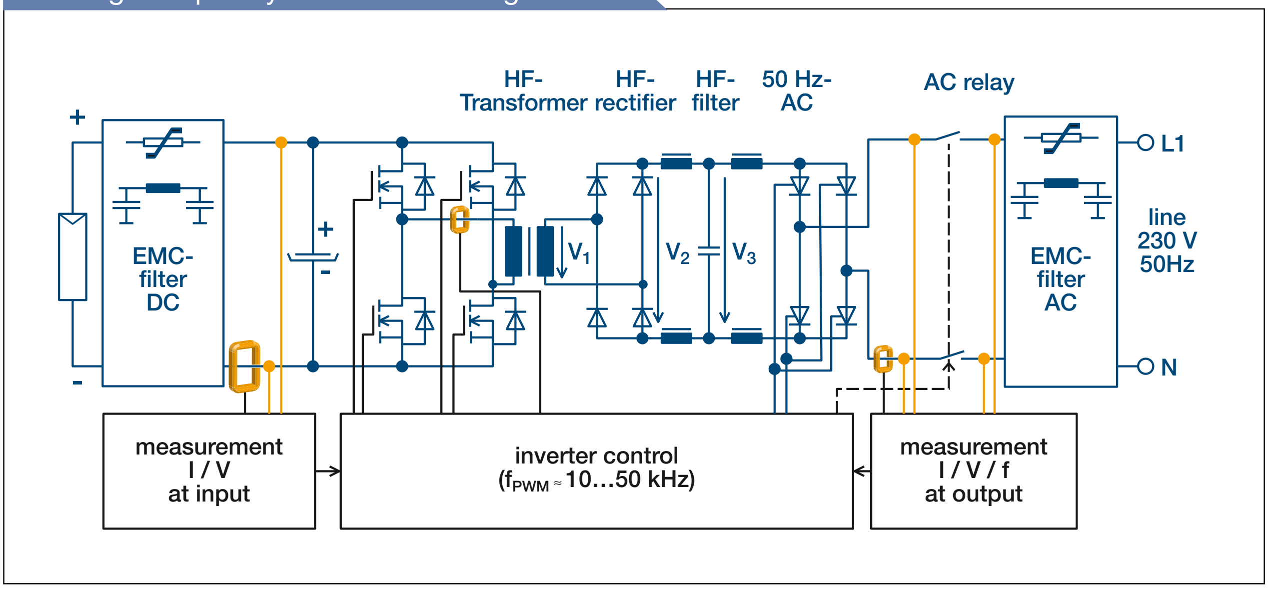
With low frequency transformer design



- No DC current injection in the grid
- Cost effective
- Reliable

- Big
- Heavy

With high frequency transformer design



- Small Size
- Light

- DC current injection in the Grid
- A lot of components -> Reliability

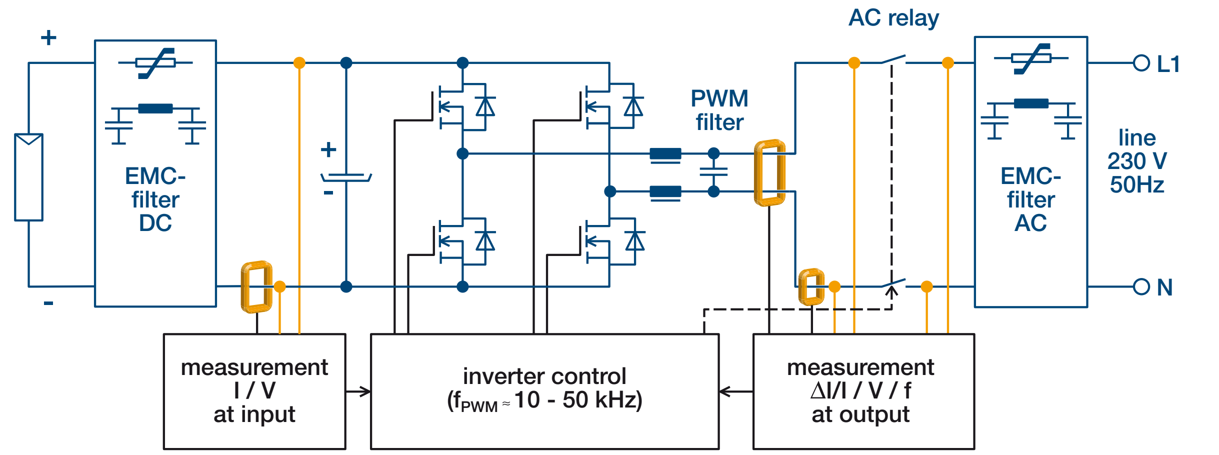
Different inverter designs according to needs (Grid connected)

Transformerless

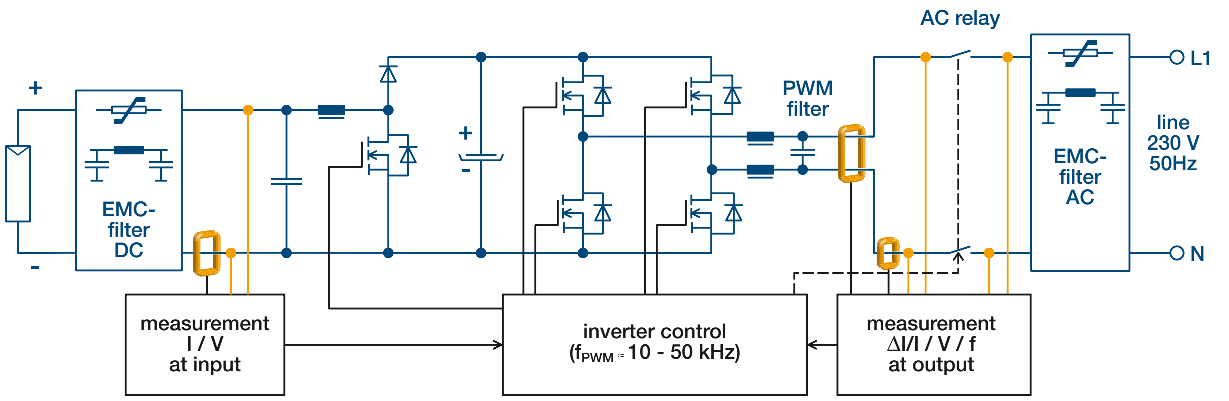
- Small Size
- Light
- High efficiency

- No galvanic insulation
- DC current injection in the Grid
- Leakage current

Without DC chopper



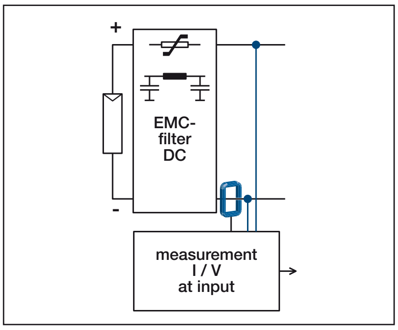
With DC chopper (or step up converter)



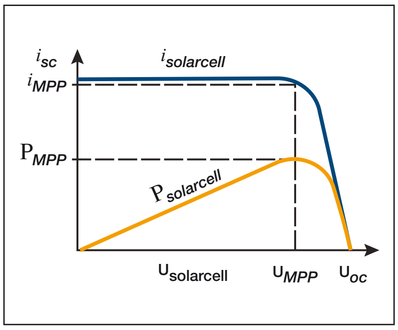
- Wide voltage Input range

Solar Inverters Control & Safety

MPPT Control:
current & voltage measurements of the solar panel



For each different topology, the **current and voltage measurement of the solar panel side** is done in order to know current and voltage generated and to define the MPP (Maximum of Peak Power Point) where the maximum output wattage can be extracted from the solar panel.



Low dynamic

Medium accuracy

Open Loop Hall effect current transducers

Closed Loop Hall effect voltage transducers

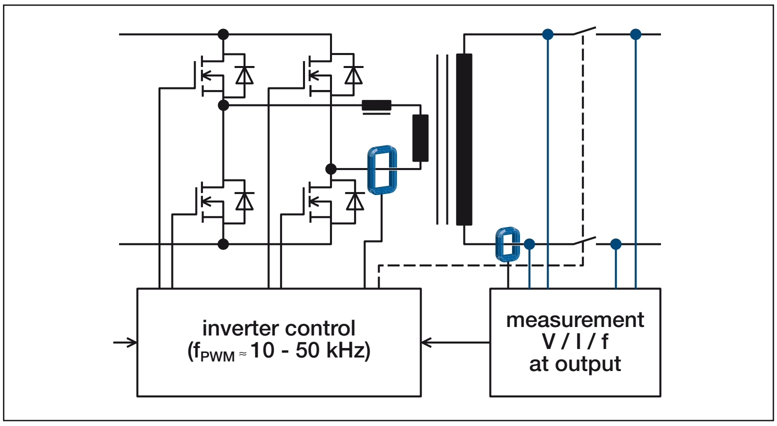
Current measurement	Accuracy at +25°C	Linearity	Gain error	Response time
Requirement	1 %	1 %	0.5 %	5 µS

Open Loop Hall effect current transducers	Nominal Range	Measuring range	Power Supply (DC)	Offset Drift	Gain Drift	Picture
HX series HXN series	2… 50 A	3 x I_{PN}	+/- 15 V	1.5 mV/K	0.1 %/K	
HXS series	5… 50 A	3 x I_{PN}	+ 5 V	0.2 mV/K	0.05 %/K	
HMS series	5… 20 A	3 x I_{PN}	+ 5 V	0.2 mV/K	0.07 %/K	

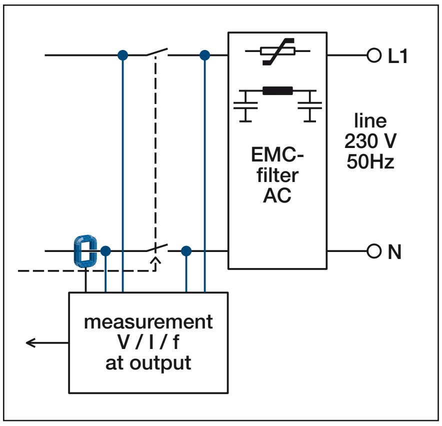
Voltage measurement	Accuracy at +25°C	Linearity	Response time
Requirement	0.9 %	0.2 %	40 µS

Closed Loop Hall effect voltage transducer	Nominal Range	Measuring range	Power Supply (DC)	Offset Drift	Gain Drift	Picture
LV 25-P	10… 500 V	1.4 x V_{PN}	+/- 12… 15 V	7.8 µA /K	Depending on external primary resistor used	

Inverter protection & control: current measurements



OR

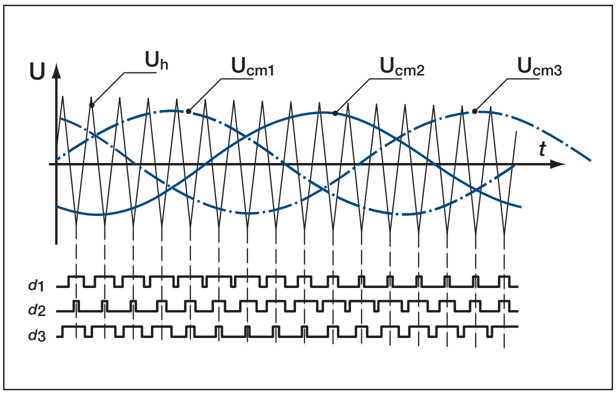


The current measurement can ensure 2 tasks:

1. **Control loop**: To control the inverter.
2. **Short-circuit or overload protection.**

1. **Control loop**: 2 kinds of signals:

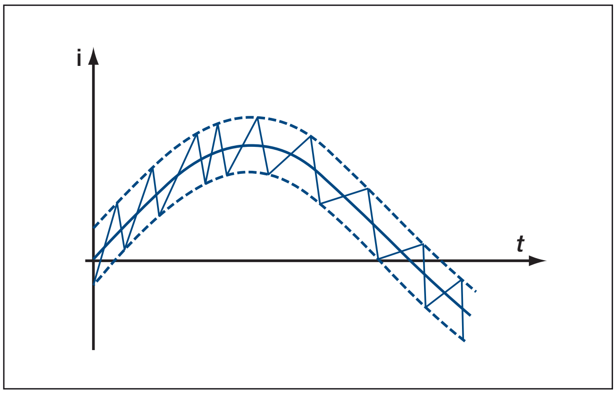
1.1 **PWM with carrier frequency:**



The current loop has a constant between 500 ns - 1 ms.

- Low dynamic
- Medium accuracy
- Open Loop Hall effect transducers

1.2 **PWM in closed loop (Sliding mode...)**



Output measurement and comparison versus reference.

- High dynamic
- Accurate
- Closed Loop Hall effect transducers

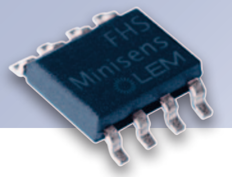
Inverter protection & control: current measurements

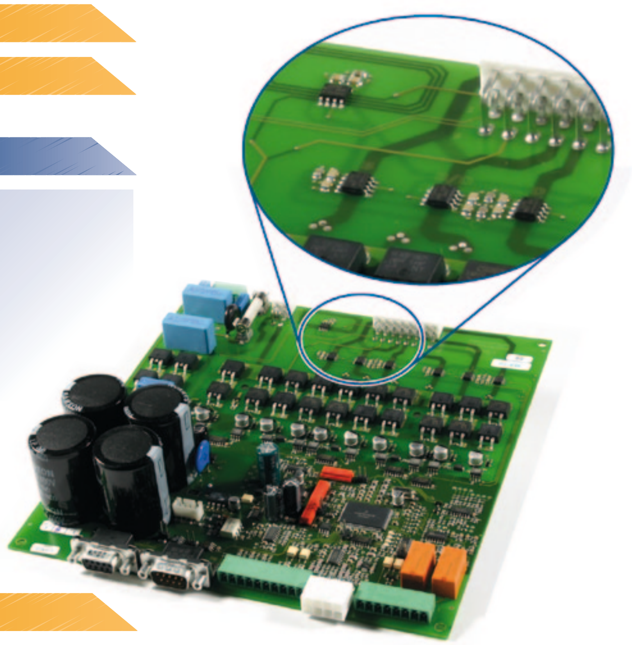
2 Protection: Short circuit and overload protection:

2.1 Short circuit protection:

- High dynamic (Response time < 2 - 3 µs)
- Medium accuracy

- Closed Loop Hall effect currrent transducers
- Open Loop Hall effect current transducers with fast output (FHS models)





Picture provided courtesy of PsiControl mechatronics

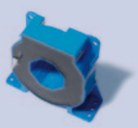
2.2 Overload protection:

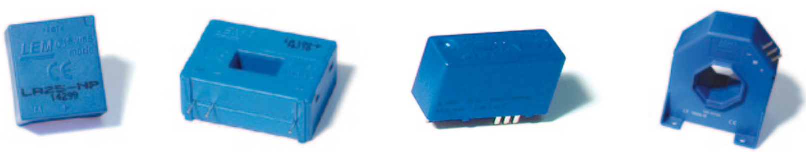
- Medium dynamic (Response time < 5 µs)
- Medium accuracy (3 - 5 %)

- Open Loop Hall effect currrent transducers

Current measurement	Accuracy at +25°C	Linearity	Response time
Requirement	0.2… 0.6 %	0.1 %	< 1 µS

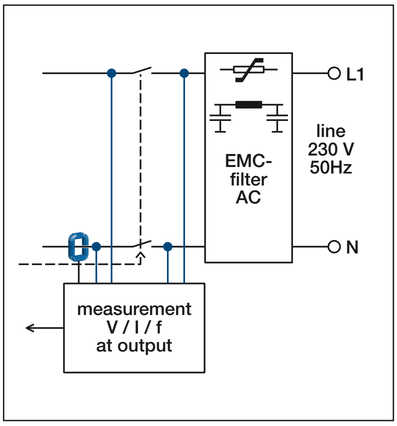
- High dynamic
- High accuracy

Closed Loop Hall effect current transducers	Nominal Range	Measuring range	Power Supply (DC)	Offset Drift	Gain Drift	Picture
LTSR series	2… 25 A	3.2 x I_{PN}	+ 5 V	0.375…0.1 mV/K	**50 ppm/K**	
LF series	100… 2000 A	1.5… 2.5 x I_{PN}	+/- 12…15 V	6.7… 8.9 µA/K	**N/A**	



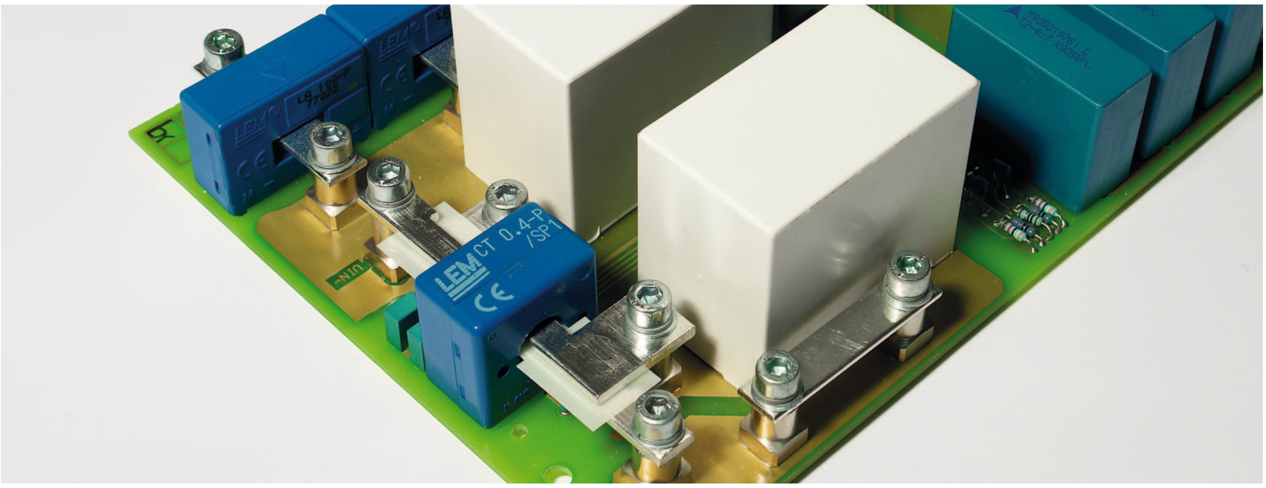
Current transducer solutions

DC current injection measurement



In the transformerless designs and in the High Frequency transformer designs, the DC current injected in the grid must be controled (10 mA… 1 A) according to different standards per country (IEC 61727, IEEE 1547, UL 1741…)

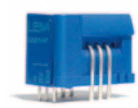
- High accuracy (< 1 %)
- Very low offset drift
- Closed Loop Fluxgate currrent transducers



Picture provided courtesy of SolarMax by Sputnik Engineering

Current measurement	Accuracy at +25°C	Offset Drift	Gain Drift
Requirement	< 1 %	Low	Low

- High accuracy
- Very low offset & gain drifts

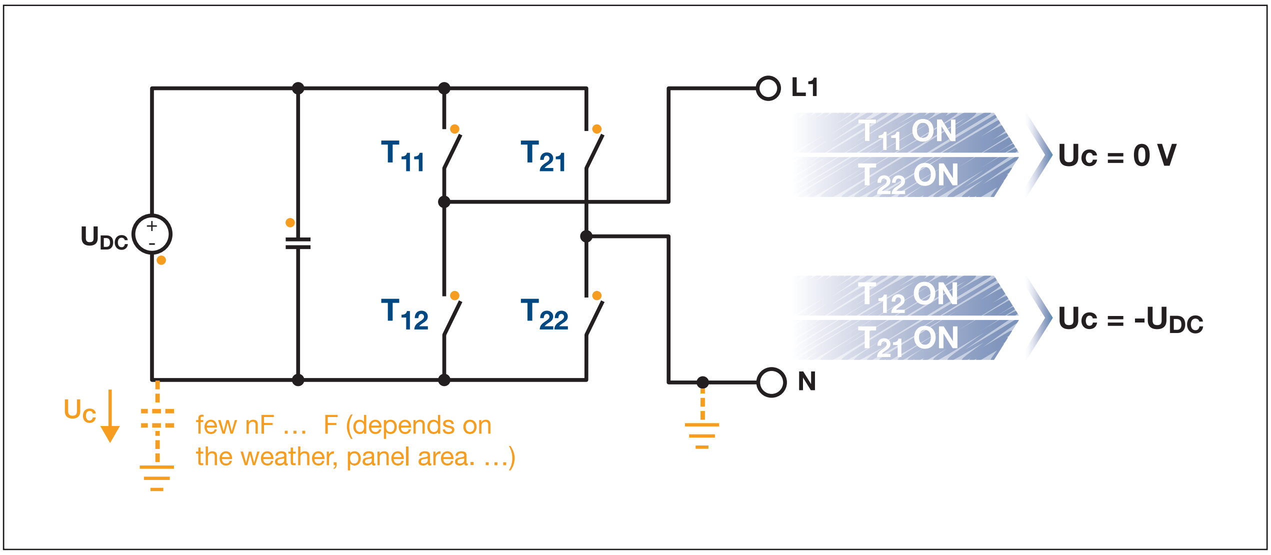
Closed Loop Fluxgate current transducers	Nominal Range	Measuring range	Power Supply (DC)	Offset Drift	Gain Drift	Picture
CAS /CASR / CKSR series	2… 50 A	3 x I_{PN}	+ 5 V	0.2…0.0175 mV/K	40 ppm/K	
CTSR 0.3-P	0.3 A	1.66 x I_{PN}	+ 5 V	0.64 mV/K	10 ppm/K	

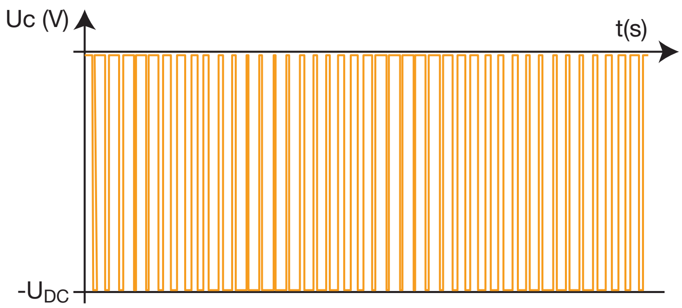
Leakage current measurement

Some leakage currents can happen in the transformerless inverter designs.

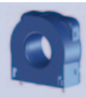
From the simplified representation of the transformerless inverter design (hereafter) (without resonance between components like PV panel, AC filter, grid impedance), this emphasizes that:

- Electric shock is possible if a person touches the PV panels,
- The leakage current can cause electromagnetic interferences, grid current distortion and additional losses in the system (depending on PWM).





Current measurement	Accuracy at +25°C	Nominal current range	Aperture
Requirement	< 1 %	Between 0.1… 0.4 V	Large for differential measurement

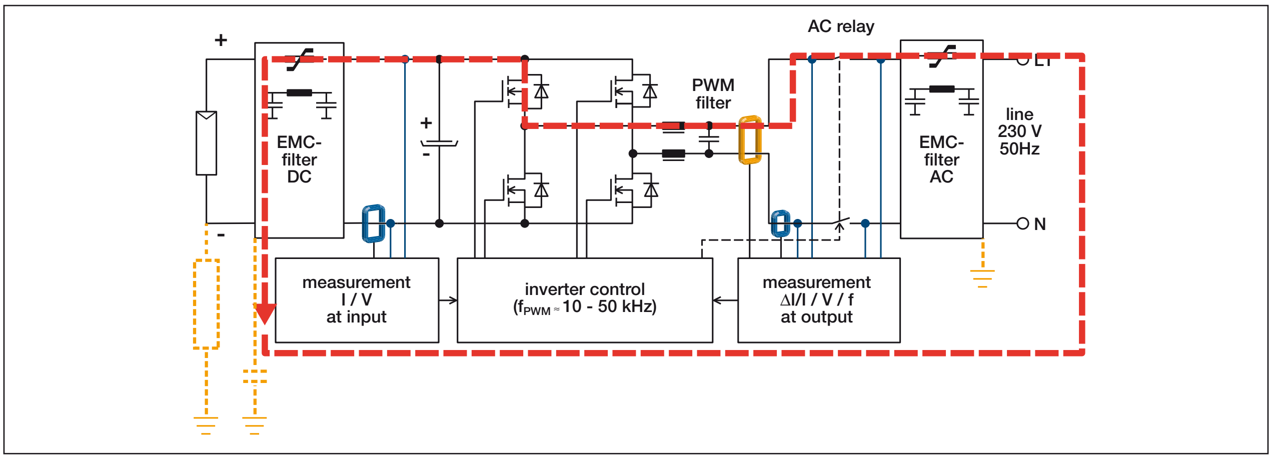
Open and Closed Loop Fluxgate current transducers	Nominal Range	Measuring range	Power Supply (DC)	Offset Drift	Gain Drift	Aperture	Picture
CT -P series	0.1… 0.4 A	2 x I_{PN}	+/- 15 V	2… 8 mV/K	0.05 %/K	11 mm diameter	
CTSR 0.3-P	0.3 A	1.66 x I_{PN}	+ 5 V	0.64 mV/K	**10 ppm/K**	20 mm diameter	

Current transducer solutions

Leakage current measurement

For safety reasons, the leakage current is measured for control.
As a safety device, the current measurement is prefered to be a non contact, non intrusive measurement.

- Small AC (50/60 Hz) current measurement (< 1 A)
- Aperture big enough for several primary conductors crossing (differential measurement)
- Open & Closed loop Fluxgate current transducers

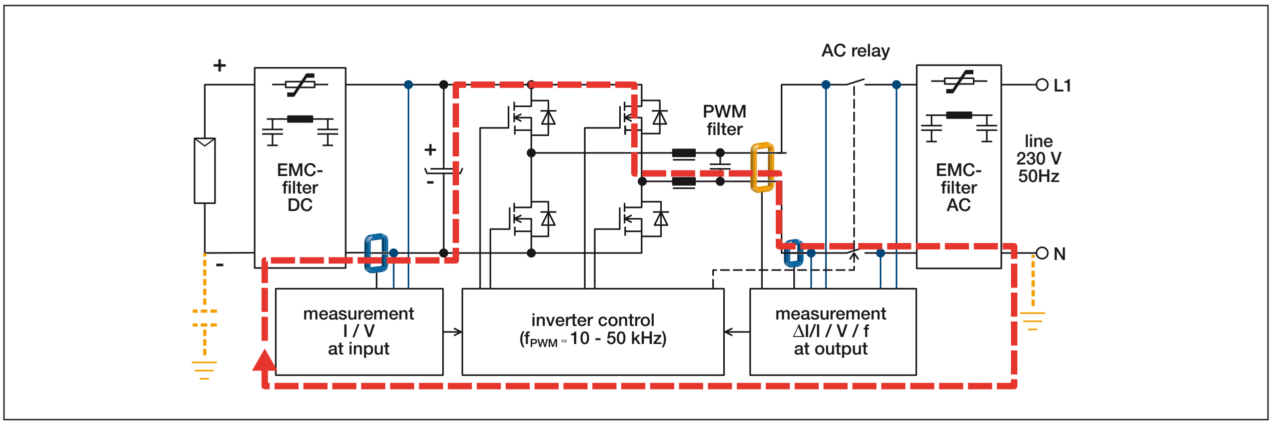


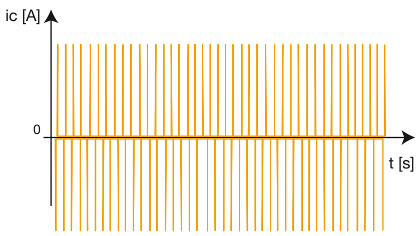
A high frequency (several 10 KHz) current spike and 50/60 Hz leakage current can also happen in the leakage capacitance.

Depending on the inverter topology, the spikes can be avoided.

These high frequency ones are not detected by the current transducer (limited bandwidth).

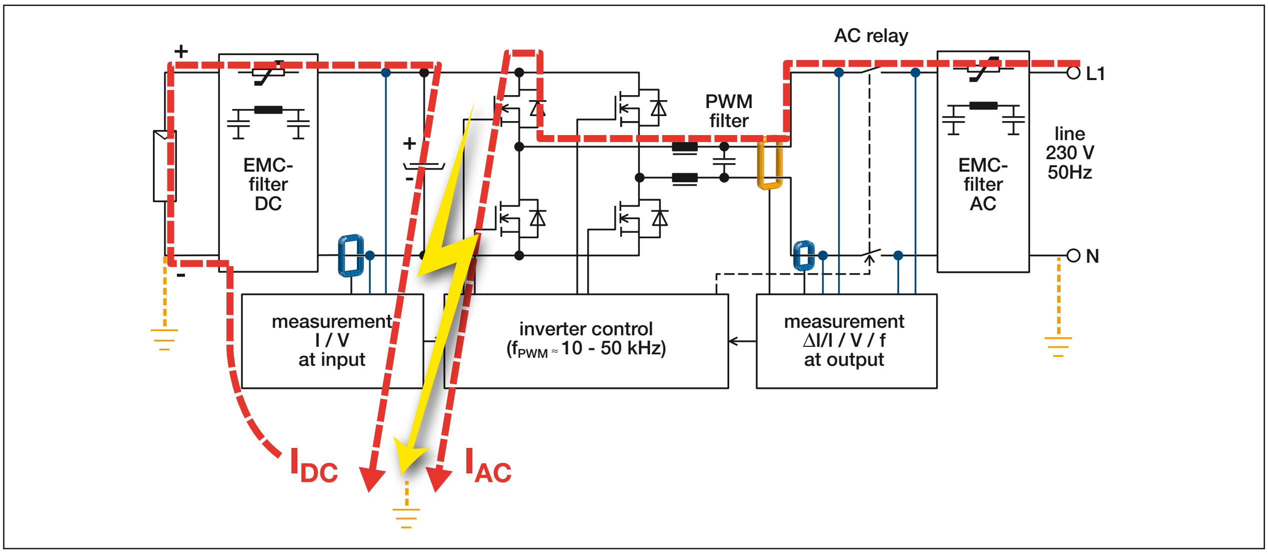
The value of the capacitive current (50/60 Hz) depends on the solar panel surface on weather conditions.





Earth fault current measurement

For safety reasons, the earth fault current or insulation defect has to be controlled in the transformerless designs.



The transducer used to measure the earth fault current must be able to measure AC and DC signals as the earth fault current could be AC or DC current depending where the fault (could be a short circuit for example) occurs and if the PV panel is grounded or not.

- Small AC & DC currents measurement (< 1 A)
- Aperture big enough for several primary conductors crossing (differential measurement)
- Open & Closed loop Fluxgate currrent transducers

Supervision and control of solar power plants

The construction of new solar power plants has increased significantly the last years.

A wide range of companies decided to invest into the construction of solar power plants to resell the energy generated to the energy providers.

The concept is simple; a lot of solar panels are connected in series to form what is called "PV Strings" (PV for Photovoltaic), they are connected in parallel to produce a lot of MWp and then inject into the grid.

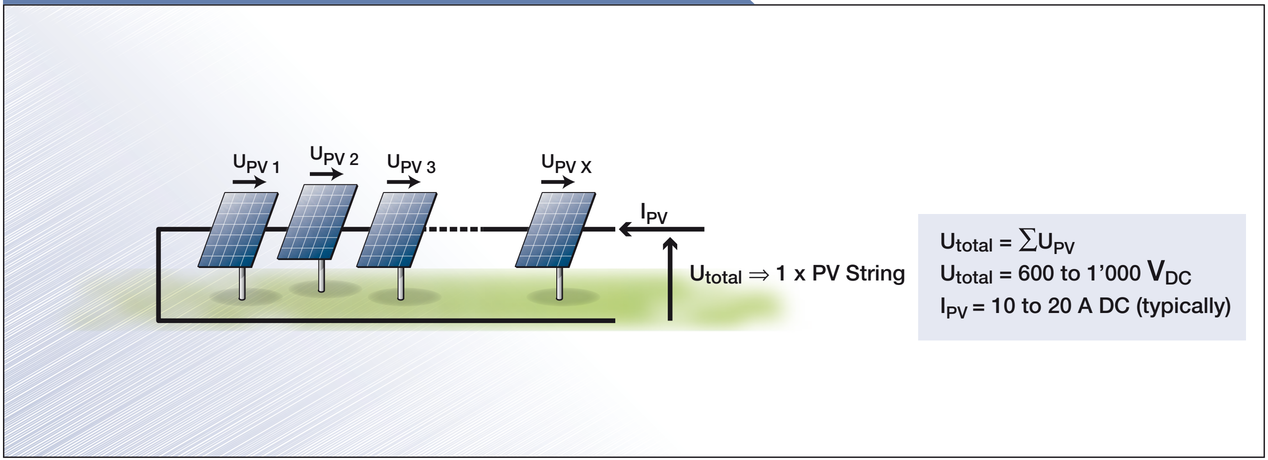
Recently we have seen the rise of "green" towns that have implemented this kind of solar power plants. Specialized companies are contacting towns to install these plants in the most appropriate areas (a lot of sunshine). This allows previously un-industrialized towns to benefit from renting out the land and also generates local taxes. These towns can also receive subventions granted by the various governments promoting sustainable energy.

Terrains without any value are becoming a non-negligible source of revenue for some areas.

How it works?

Generally, solar panels are connected in series in order to generate the required voltage and then to form a "PV String".

Solar panel connected in series -> PV String



Each PV string can be connected in parallel (to increase the generated current keeping the voltage at the required level). Then, they are connected to a multi-strings inverter, which will transfer the produced power to the grid.

The generated current and voltage must match the input values of the inverter.

The series and parallel connections of the solar panels and PV strings need to be compatible with the inverter used.

Thousands of solar panels are required to build a solar plant, and the performance of the overall installation has to be monitored in order to maximize its efficiency.

The inverter used for the conversion of the power to the grid will ensure a part of this efficiency by tracking if the MPP (Maximum Power Point for the generated current and voltage) is reached for the total installation.

At this level, just before going into the inverter, the detection of any defective solar panel, reducing the total efficiency of the installation, can be made in real time.

When several PV strings are connected in parallel to go to the inverter, a current inversion in a PV string can happen. This will lead to the destruction, as it will need to handle the power of all the other PV strings. A protection needs to be installed.

A simple way to detect a defective solar panel is to check the current produced by each PV string.

A comparison of the current generated by each PV string allows evaluating if they each produce the same level. Some levels of unbalance between PV strings can be set to trigger an alarm if they are reached.

The inverters integrate the current measurement, but the system integrators need more details or want to be independent from the inverter equipment.

In order to be the most efficient, the current has to be measured on each PV string.

This will allow adapting the parameters to adjust the MPP of the respective solar string, but also to detect any defective solar panel that is part of the solar string (reducing the efficiency of the solar string substantially).

For solar plants that are equipped with motorized panels, the current control will also allow the solar panel orientation tracking versus the sun position; this will give the best yield.

Some companies propose boxes for the parallel connection of the PV strings including these functions. They are often called "combiner boxes" (but also "smart combiner boxes" or "array boxes") integrating the current and voltage measurements for each string and checking several PV strings.

Additional electronics for the current measurement conditioning can also be integrated into these boxes in order to provide the acquisition system with the necessary signals.

Analysis is carried out, some alarms can be set if programmed thresholds are reached.

This allows maintenance to be planned; actions are targeted and realized straight away. Time is saved!

Solar plants can vary in size but in general each 100 kWp needs to go through a grid transformer.

It is possible to have strings from 3 to 40 PV (ideally: 8 PV strings) going through the combiner box, connected to the inverter before the grid transformer.

Each PV string can be under 600 to 1000 V_{DC} with a current from 10 to 50 (even 100, 200 and 300) A_{DC}.

The combiner box is connected to the inverter under 600 to 1000 V_{DC} and supplies the sum of all the currents delivered by each PV string (from 30 to 300 A_{DC}).

Usually the collected data (currents and voltages) are converted to digital signals for a RS-485 Modbus communication (RTU) to feed PLCs (Programmable Logic Controller) communicating with a control center that is able to change some remote parameters or to repair some defective solar panels.

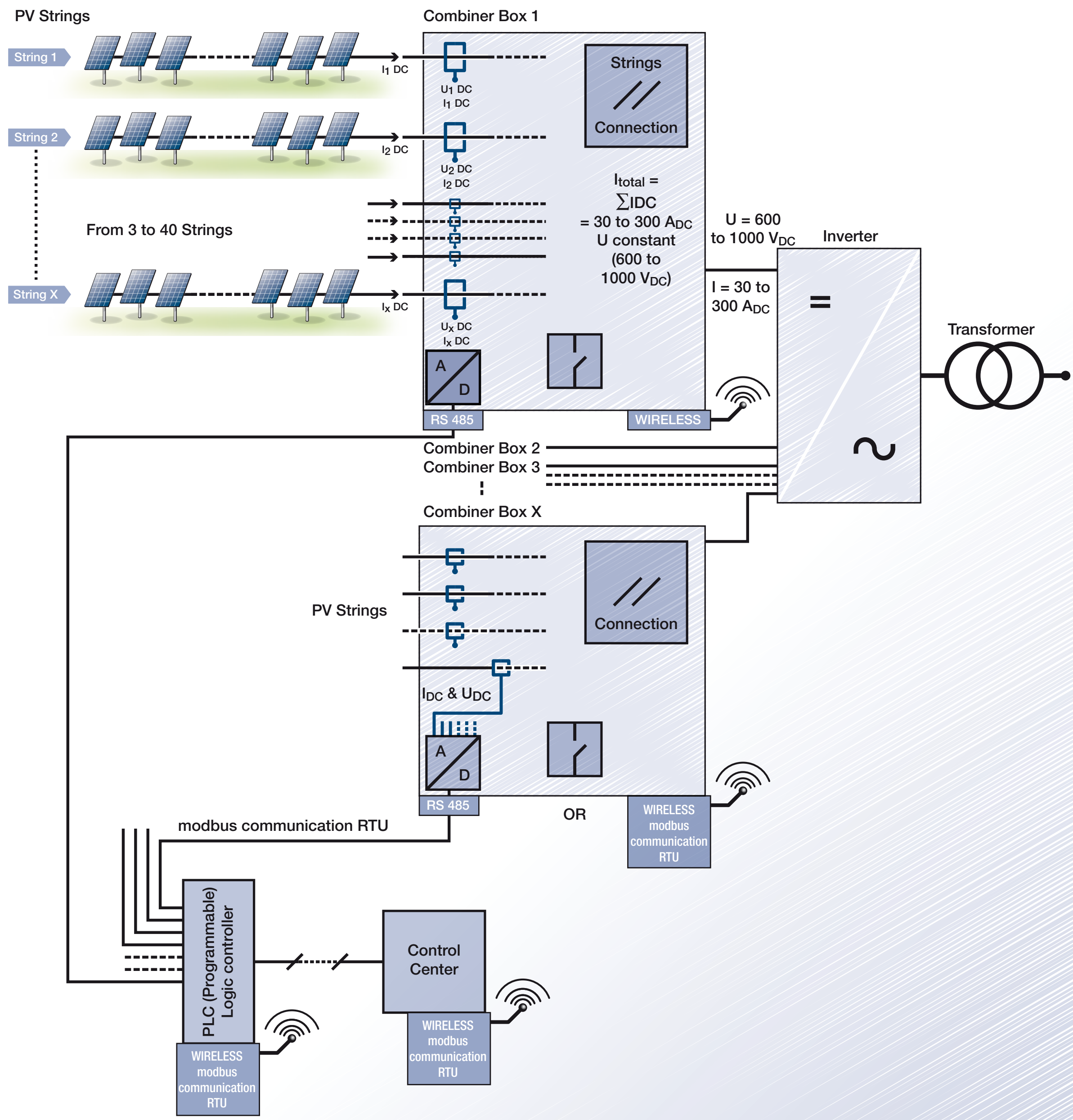
Systems can be fitted with other equipment for wireless Modbus communications, to acquire data on dedicated servers for online checking or for a remote detection of any incident, and real time information.

Circuit breakers can also be part of the combiner box for each PV string as well as protections that for lightning, hotspots, back load among strings where current measurements can be really active for these functions.

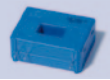
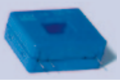
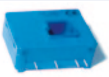
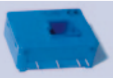
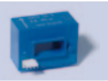
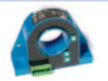
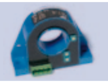
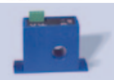
A site of 1 MWp would need around 25/30 measuring combiner boxes (8 strings) i.e 200/240 current DC transducers and 200/240 voltage DC transducers.

This kind of installation is also becoming popular for large roofs of plants, farms or public buildings where the principle is exactly the same.

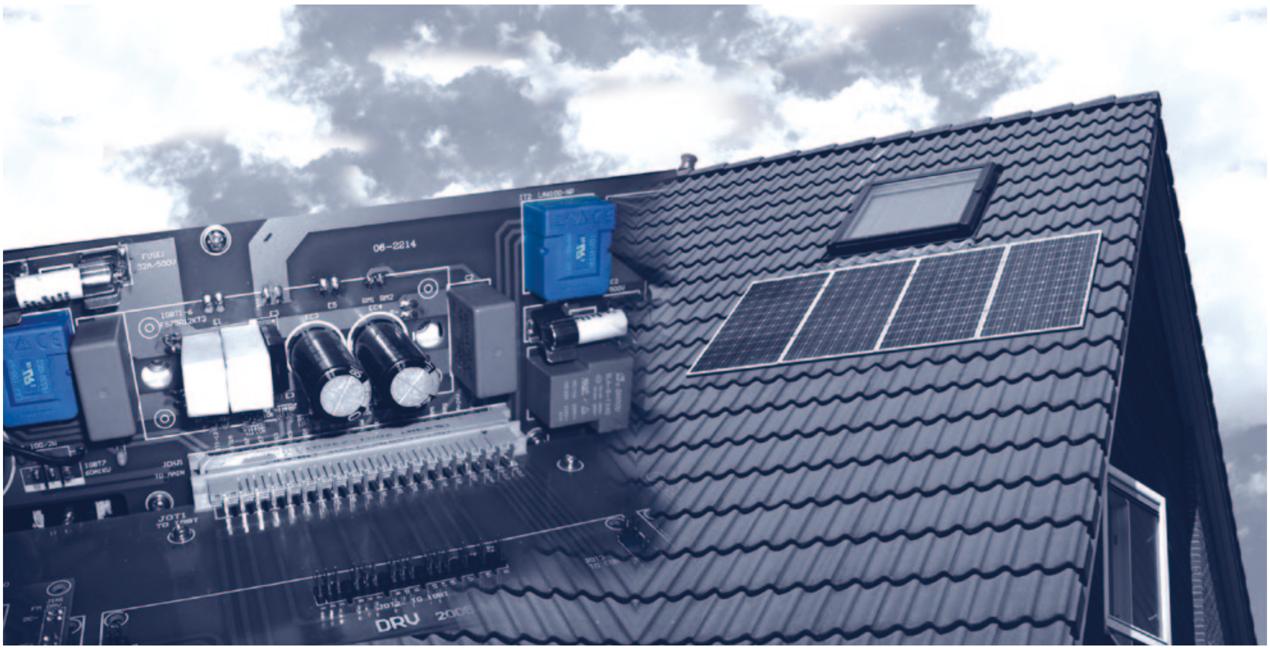
Combiner Box



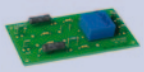
Current measurement	Accuracy at +25°C	Nominal current range	Aperture	Output	Mounting	Isolation
Requirement	0.5 % to 2 % 3 % if split core	Between 0… 300 A	1.6 to 30 mm diameter Solid or split core	Instantaneous current or voltage output or conditioned voltage or current output 0-10 V 4-20 mA to fit to PLCs	PCB, DIN rail or panel mounting	1500 V

Open and Closed Loop Hall effect current transducers	Nominal Range	Measuring range	Power Supply (DC)	Accuracy at +25°C	Mounting	Aperture	Primary conductor inserted	Output	Picture
LTS/LTSR series	2… 25 A	3.2 x I_{PN}	+5 V	0.7 %	PCB	YES	YES	Inst. Voltage	
CAS/CASR/ CKSR series	2… 50 A	3 x I_{PN}	+5 V	0.8 %	PCB		YES	Inst. Voltage	
HXS series	5… 50 A	3 x I_{PN}	+5 V	1.4 %	PCB		YES	Inst. Voltage	
LA 25-NP	5… 25 A	1.4 x I_{PN}	+/- 15 V	0.5 %	PCB		YES	Inst. Current	
LAX 100-NP	16.7… 100 A	1.6… 3.2 x I_{PN}	+/- 12… 15 V	0.55… 0.7 %	PCB		YES	Inst. Current	
LA 55-P	50 A	1.4 x I_{PN}	+/- 12… 15 V	0.65 %	PCB	YES		Inst. Current	
LA 100-P	100 A	1.5 x I_{PN}	+/- 12… 15 V	0.45 %	PCB	YES		Inst. Current	
LA 150-P	150 A	1.3 x I_{PN}	+/- 15 V	0.85 %	PCB	YES		Inst. Current	
LA 125-P	125 A	1.6 x I_{PN}	+/- 12… 15 V	0.8 %	PCB	YES		Inst. Current	
LA 200-P	200 A	1.5 x I_{PN}	+/- 12… 15 V	0.65 %	PCB	YES		Inst. Current	
LF 205-S	200 A	2.1 x I_{PN}	+/- 12… 15 V	0.4 %	Panel	YES		Inst. Current	
LF 305-S	300 A	1.6 x I_{PN}	+/- 12… 20 V	0.3 %	Panel	YES		Inst. Current	
HAS 50…600-S series	50… 600 A	1.5… 3 x I_{PN}	+/- 15 V	3 %	Panel	YES		Inst. Voltage	
HASS 50…600-S series	50… 600 A	1.5… 3 x I_{PN}	+5 V	1.4 %	Panel	YES		Inst. Voltage	
DHR 100 …400C420	100… 400 A		20… 50 V	1 %	Panel	YES		4-20 mA	
DHR 100 …400C10	100… 400 A		20… 50 V	1 %	Panel	YES		0-10 V_{DC}	
DK 100B420	50, 75, 100 A		20… 50 V	1 %	Panel	YES		4-20 mA	
DK 20C420	5, 10, 20 A		20… 50 V	1 %	Panel	YES		4-20 mA	

Current transducer solutions



Voltage measurement	Accuracy at +25°C	Nominal voltage range	Output	Mounting
Requirement	1 %	Up to 1000 V	Instantaneous current or voltage output or conditioned voltage or current output 0-10 V, 4-20 mA to fit to PLCs	PCB, DIN rail or panel mounting

Closed Loop Hall effect current transducers	Nominal Range	Measuring range	Power Supply (DC)	Accuracy at +25°C	Mounting	Primary resistor inserted	Output	Picture
LV 25 P/SP2	10… 1500 V	1.4 x V_{PN}	+/- 15 V	0.9 %	PCB	NO	Inst. Current	
LV 25-800 **LV 25-1000**	800 V 1000 V	1.5 x V_{PN}	+/- 12… 15 V	0.9 %	Panel	YES	Inst. Current	
AV 100-1000	1000 V	1.5 x V_{PN}	+/- 12… 24 V	0.7 %	Panel	YES	Inst. Current	

Voltage transducer solutions

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