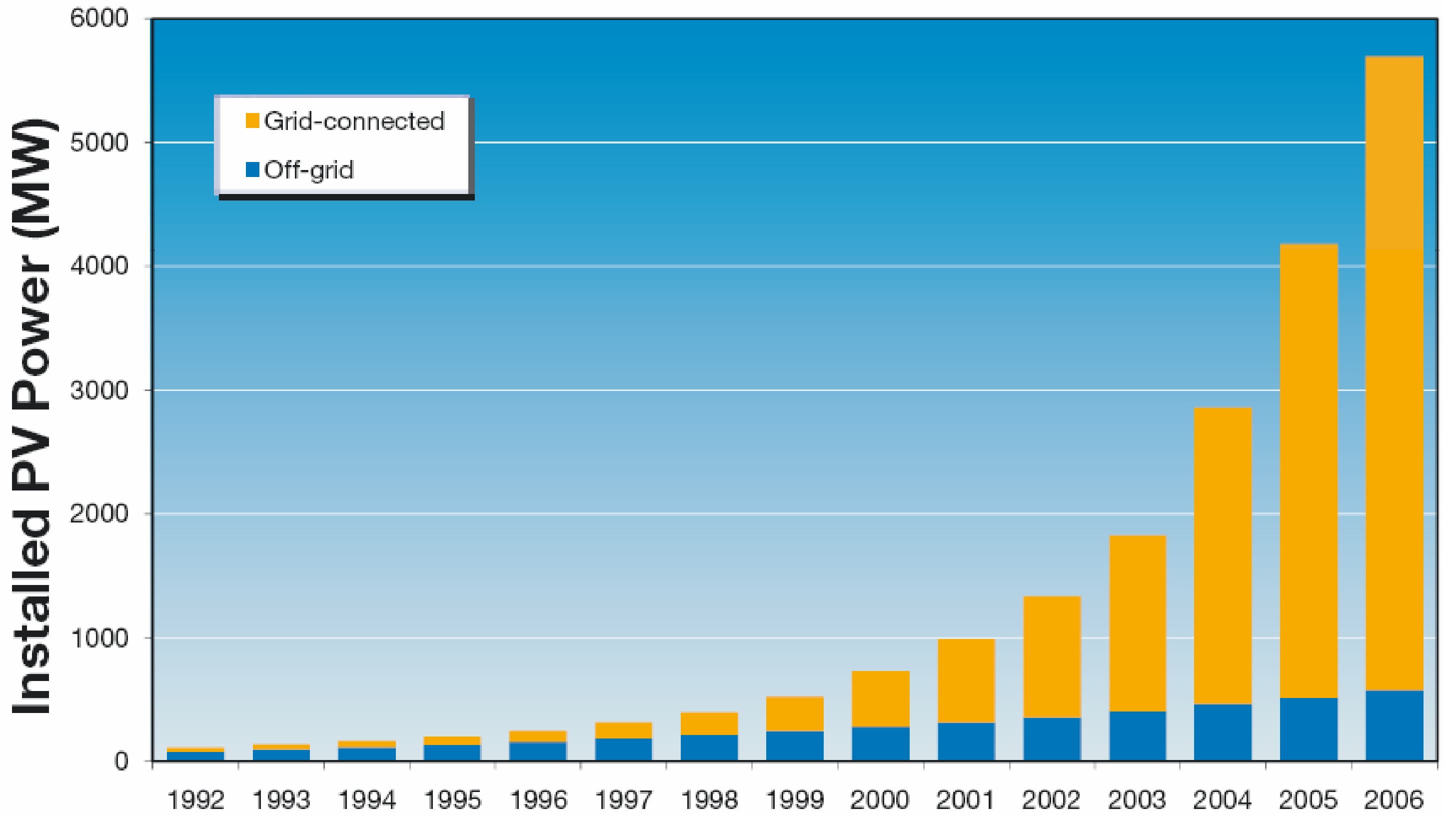
Photovoltaics with LEM

"Current measurement in PV applications need the appropriate transducer"

Photovoltaics: Grid Connected / Off-Grid



Source : EPIA – European Photovoltaic Industry Association

- **90 % of the market is grid-connected and use inverter**

  => main market for current measurement

- **10 % of the market is off-grid**

  => Need current measurement for charge control of the battery

Solar Inverter: Topology

Grid connected

With transformer

With battery — Only if backup power is needed

Without battery — Usual

Transformerless

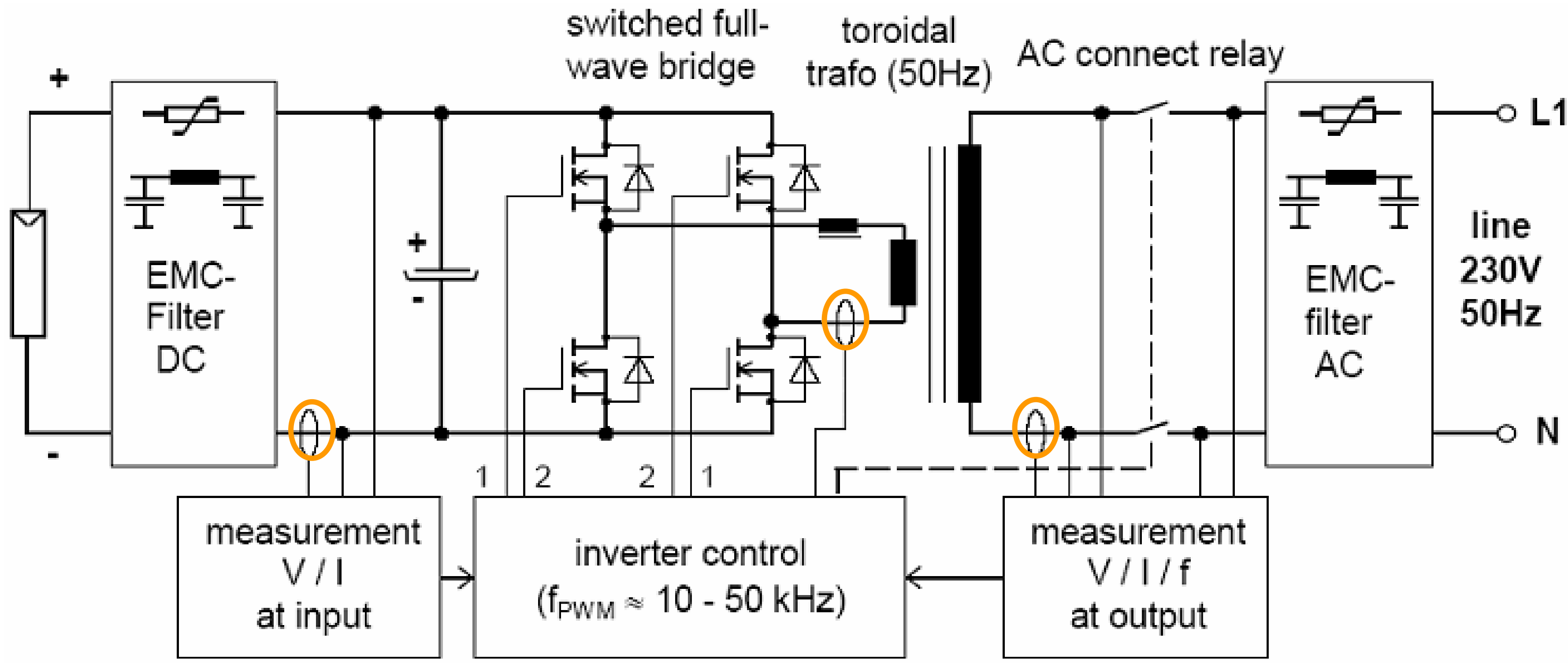
With battery — Only if backup power is needed

Without battery — Actual trend

Off-grid → **With battery** → **With transformer**

- To increase the panel voltage
- Isolation between the earth of the panel and the load

Grid Connected: Inverter with LF Transformer

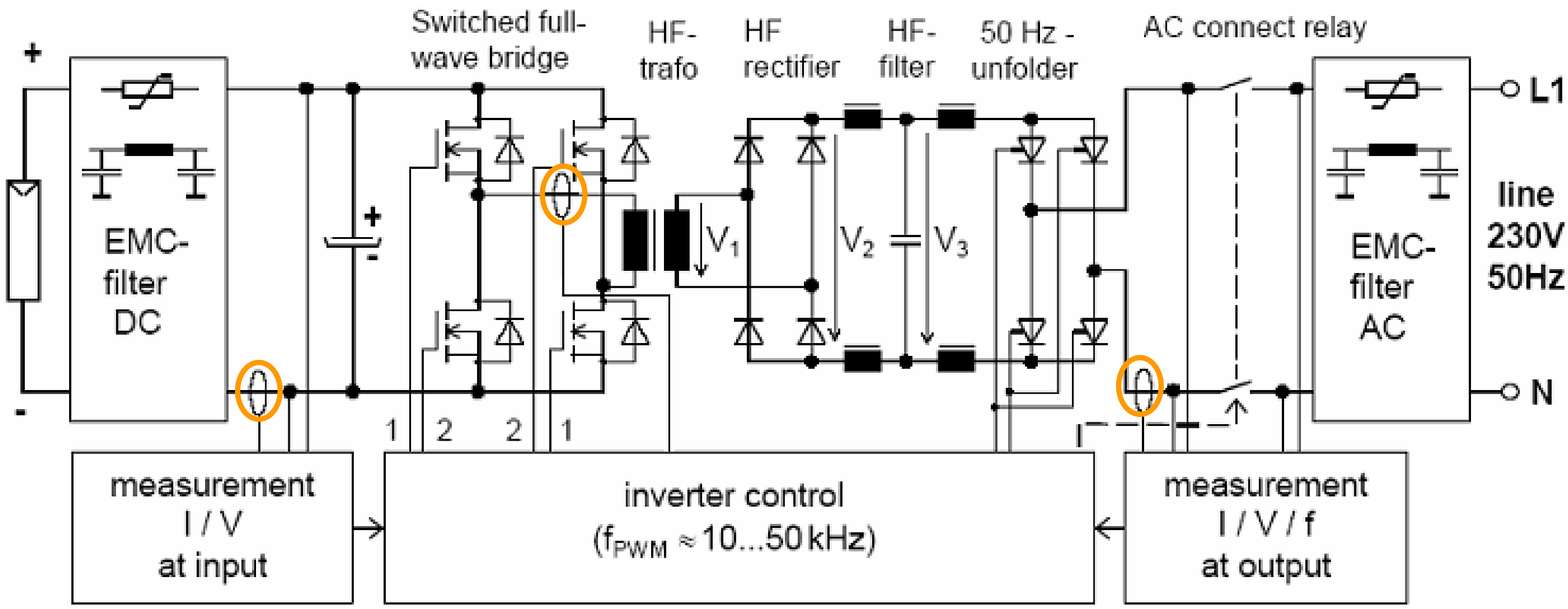


Source : Evolution of Inverters for Grid Connected PV-Systems from 1989 to2000, H. Haeberlin

<u>Advantages:</u> very reliable, cost effective, DC current injection not possible, efficiency up to 96 %

<u>Disadvantages:</u> weight, size

Grid Connected: Inverter with HF transformer (16…100 kHz)

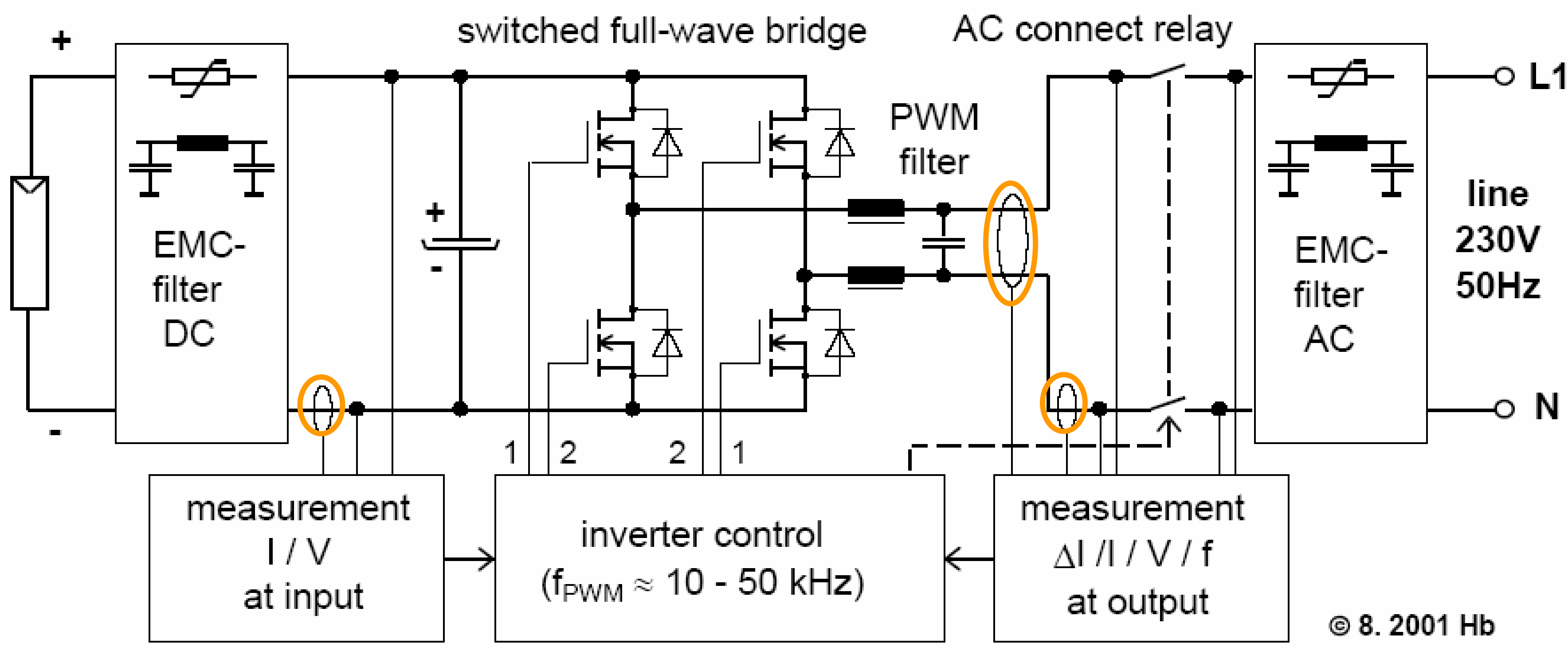


Source : Evolution of Inverters for Grid Connected PV-Systems from 1989 to2000, H. Haeberlin

<u>Advantages:</u> low weight, small size

<u>Disadvantages:</u> high number of components (reliability), DC injection possible, efficiency over 95 % difficult to achieve

Grid Connected: Transformerless Inverter without DC Chopper



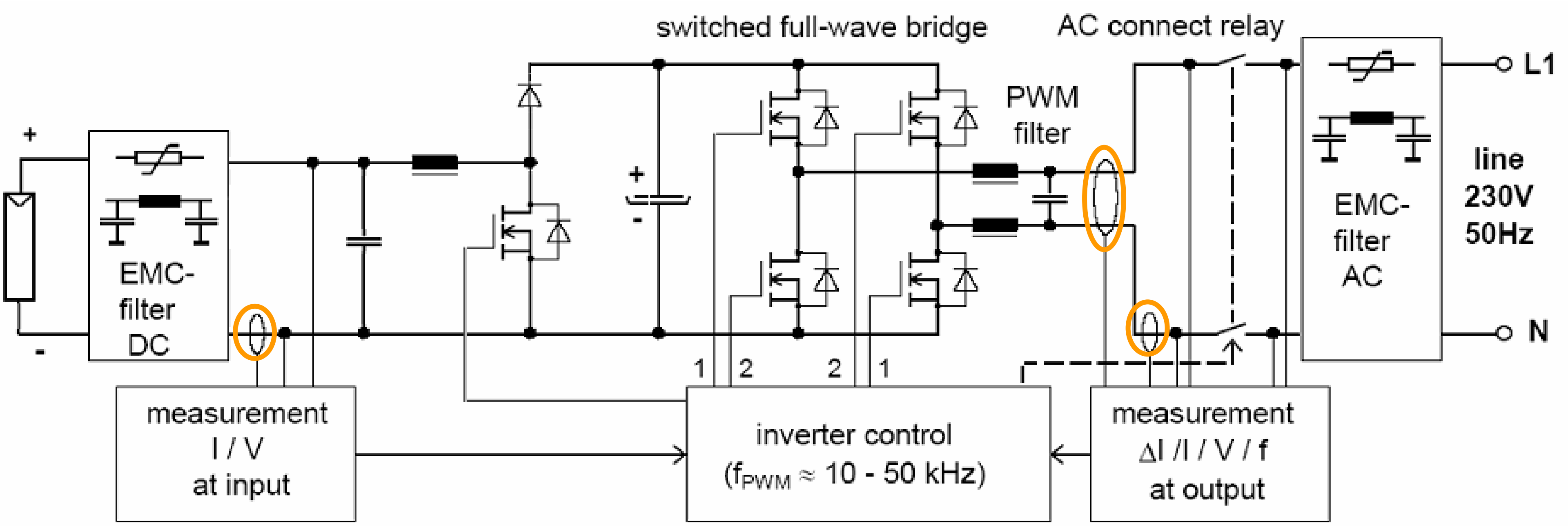
Source : Evolution of Inverters for Grid Connected PV-Systems from 1989 to2000, H. Haeberlin

Advantages: very high efficiency, low weight, small size

Disadvantages: small input voltage range, no galvanic isolation, DC injection < 5 mA difficult to achieve, leakage current due to the AC component in PV module to earth

At the heart of power electronics

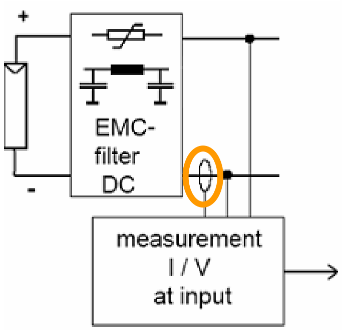
Grid Connected: Transformerless Inverter with DC Chopper

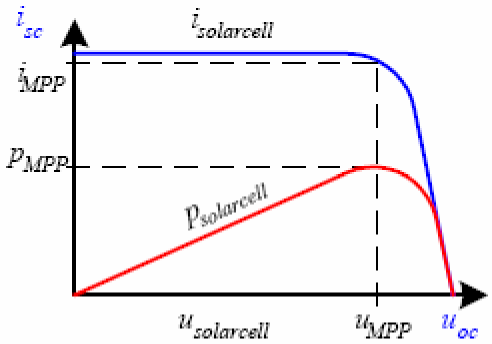


<u>Advantages:</u> very high efficiency, low weight, small size, wide input voltage range

<u>Disadvantages:</u> no galvanic isolation, DC injection < 5 mA difficult, leakage current due to the AC-component in PV module to earth

Current Transducers on the Solar Panel Side





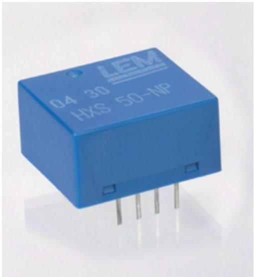
Current measurement :

- O-I technology is used to measure the current sourced by the solar panel and define the MPP
    - Accuracy: 1 % at 25 °C
    - Linearity: 1 %
    - Sensitivity error: 0.5 %
    - Response time: 5 µs

HX series

- I_{PN}: 2…50 A
- I_P: 3 × I_{PN}
- Power supply: +/- 15 V
- Offset drift: 1.5 mV/K
- Sensit. drift: 0.1 %/K

HXS series

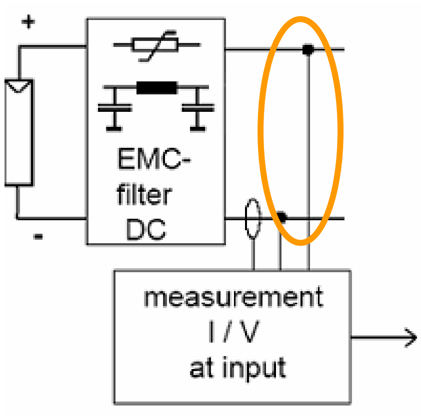


- I_{PN}: 5…50 A
- I_P: 3 × I_{PN}
- Power supply: + 5 V
- Offset drift: 0.2 mV/K
- Sensit. drift: 0.05 %/K

HMS series

- I_{PN}: 5…20 A
- I_P: 3 × I_{PN}
- Power supply: + 5 V
- Offset drift: 0.2 mV/K
- Sensit. drift: 0.07 %/K

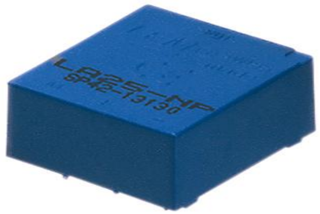
Voltage Transducers on the Solar Panel Side



Voltage measurement :

- C-I technology is used to measure the voltage of the solar panel
  - Accuracy: 0.9 % at 25 °C
  - Linearity: 0.2 %
  - Sensitivity error: depends on R_P (external)
  - Response time: < 40 µs

LV 25-P



- V_{PN}: 10…500 V
- V_P: 1.4 × V_{PN}
- Power supply: +/- 12…15 V
- Offset drift: 7.8 µA/K
- Sensit. drift: depends on R_P (external)

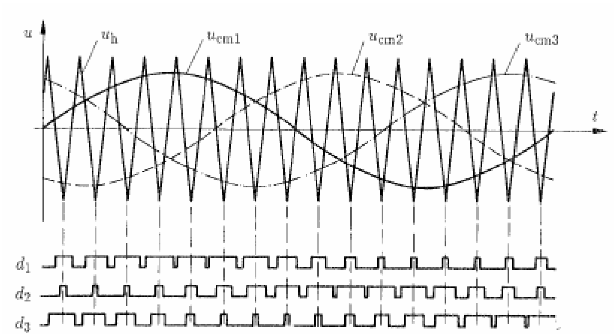
Current Transducers to Control the Inverter

Two tasks for the current measurement:

1. Control loop to control the inverter
2. Short-circuit or overload protection

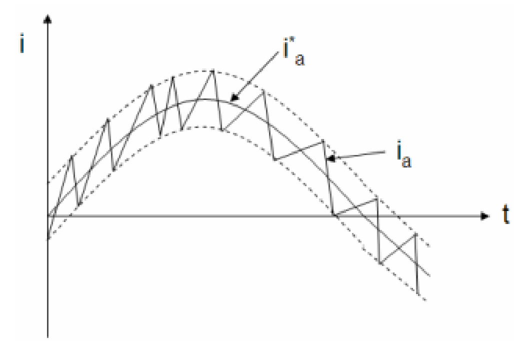
Control loop

PWM with carrier frequency



The current loop has a time constant between 500 µs…1 ms => the bandwidth of the transducer doesn't need to be high => o-l technology (> ~100 µs) or c-l technology (< ~100 µs)

PWM in closed-loop (sliding-mode, bang-bang, hysteresis, ...)



Output measurement and comparison with the reference => measurement needs to be fast and accurate => c-l technology

Current Transducers to Control the Inverter

Protection

Two types of protection:

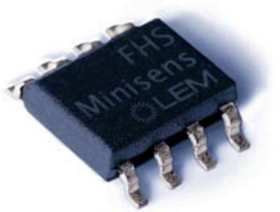
1. Short-circuit protection
=> needs a fast response time < 2…3 µs, accuracy not so critical => mainly c-I technology or o-l technology with faster output like FHS

LTSR series

HX series

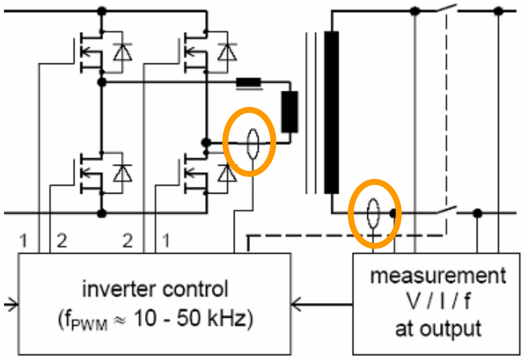
HMS series

FHS



2. Overload protection
=> response time and accuracy are not critical (< 5 µs and < 3…5 %) => o-l technology

Current Transducers to Control the Inverter



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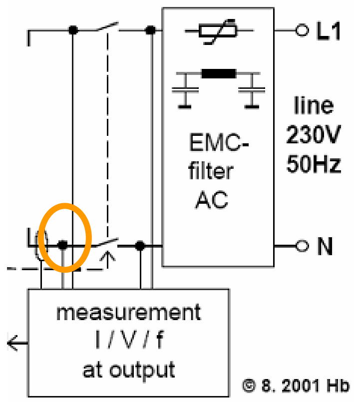


Current measurement :

- O-I technology similar as for the solar panels
- C-I technology
  - Accuracy: 0.2…0.6 % at 25 °C
  - Linearity: 0.1 %
  - Response time: < 1 µs

LTSR series

- I_{PN}: 2…25 A
- I_P: 3.2 × I_{PN}
- Power supply: + 5 V
- Offset drift: 0.375…0.1 mV/K
- Sensit. drift: 50 ppm/K

LF series

- I_{PN}: 100…2000 A
- I_P: 1.5…2.5 × I_{PN}
- Power supply: +/- 12…15 V
- Offset drift: 6.7…8.9 µA/K

Other products

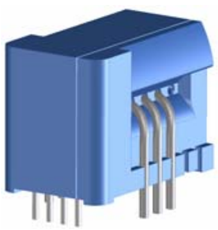
LA, LAH, LT, ...

Current Transducers to Measure the DC Current Injection

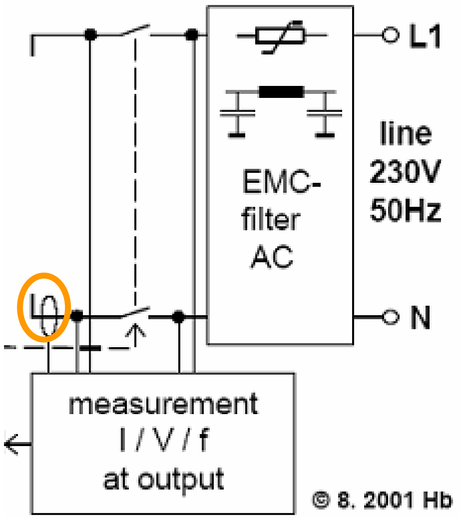
- **For transformerless design or HF transformer design, it's mandatory (IEC61727, IEEE1547, UL1741, ...) to control the DC current injection into the grid (10 mA…1 A)**
- **In terms of current measurement this means:**
  - **Good accuracy (< 1 %)**
  - **Very low offset drift**

=> LEM developed a new products family with a low offset drift technology

CAS, CASR, CKSR series

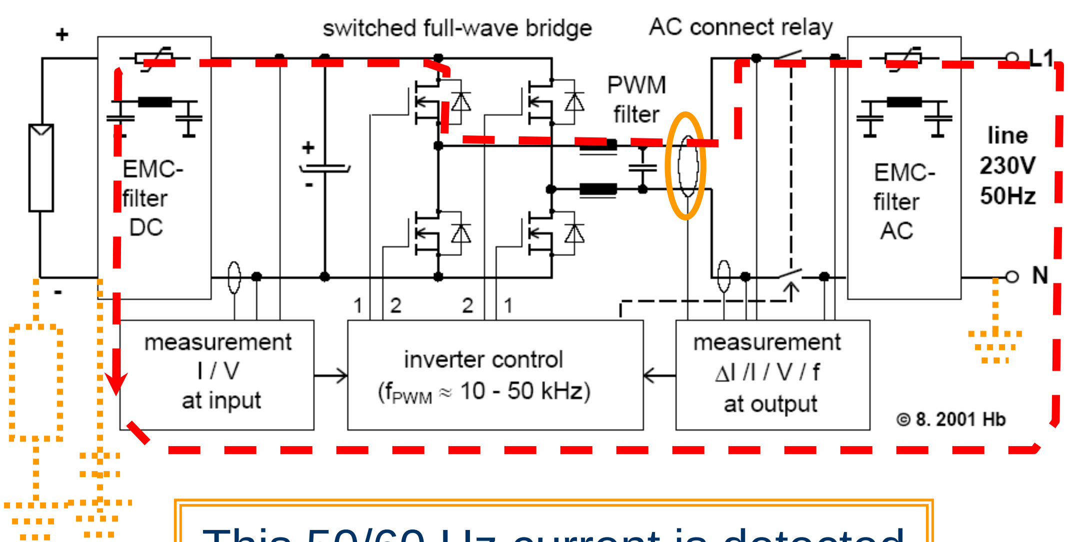


- **I_{PN}: 2…50 A**
- **I_P: 3 × I_{PN}**
- **Power supply: + 5 V**
- **Offset drift: 0.15…0.035 mV/K**
- **Sensit. drift: 40 ppm/K**



Current Transducers to Measure the Residual Current

- **CT 0.1..0.4-P transducers are used to detect the residual current for safety reason**



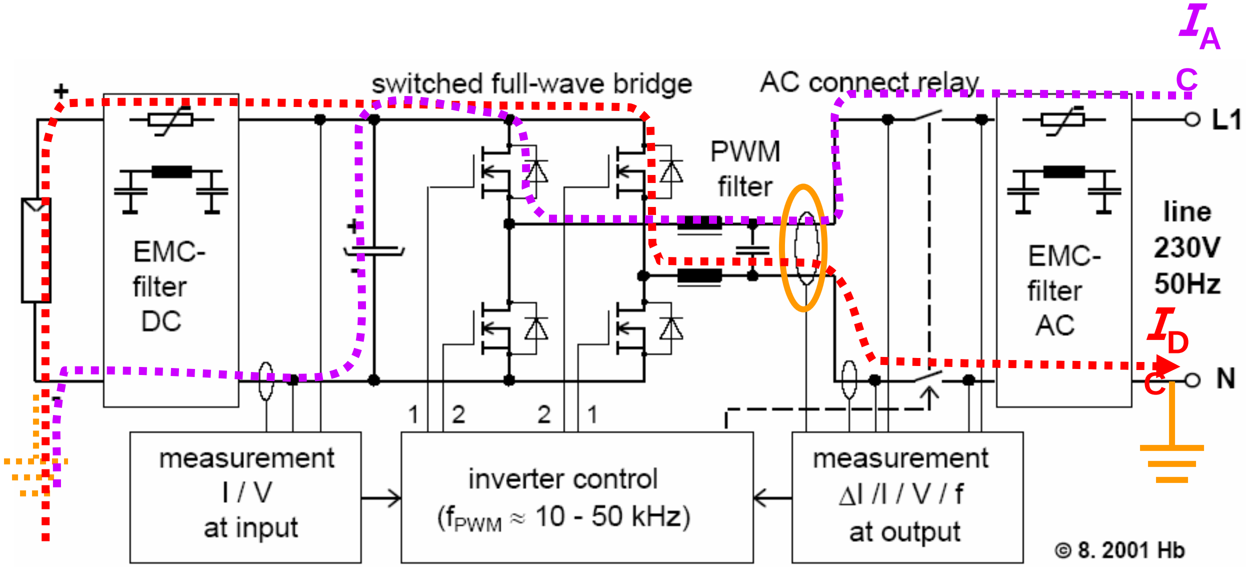
This 50/60 Hz current is detected by the transducer

CT series

- I_{PN}: 100…400 mA
- I_P: 1.8 × I_{PN}
- Power supply: +/- 15 V
- Offset drift: 2…8 mV/K
- Sensit. drift: 0.05 %/K
- Accuracy @ 25 °C: 1 %

Current Transducers to Measure the Earth Fault Current

- **With transformerless design for safety reason, the earth fault current or insulation fault has to be controlled**



CT series

- I_{PN}: 100…400 mA
- I_P: 1.8 × I_{PN}
- Power supply: +/-15 V
- Offset drift: 2…8 mV/K
- Sensit. drift: 0.05 %/K

Depending on the earth fault location and if the solar panel is grounded, the transducer can measure DC or AC current

Summary: Control

MPPT control

- Solar panel side → Low dynamics, medium accuracy → O-I technology

- inverter side
  - → PWM (carrier freq.) Low dynamic, medium accuracy → O-I technology
  - → PWM in closed-loop (bang-gang, sliding mode, ...) High dynamics, good accuracy → C-I technology

Inverter control

- → PWM (carrier freq.) Low dynamic, medium accuracy → O-I technology
- → PWM in closed-loop (bang-gang, sliding mode, ...) High dynamic, good accuracy → C-I technology

Summary: Protection

Short-circuit

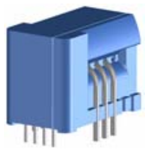
- High inductance, slow response time → O-I technology

- Low inductance, fast response time → C-I technology

Overload → Low speed (ms), Few % accuracy → O-I technology

Leakage current → Low speed (ms), Small current (mA) → Fluxgate c-I technology

DC current injection → Low offset drift, Good accuracy → Fluxgate c-I technology



Conclusions

Full range of products for:

- **Solar panel control**
- **Inverter control**
- **Protection**
- **DC current injection**

Questions?

Thank you for your attention