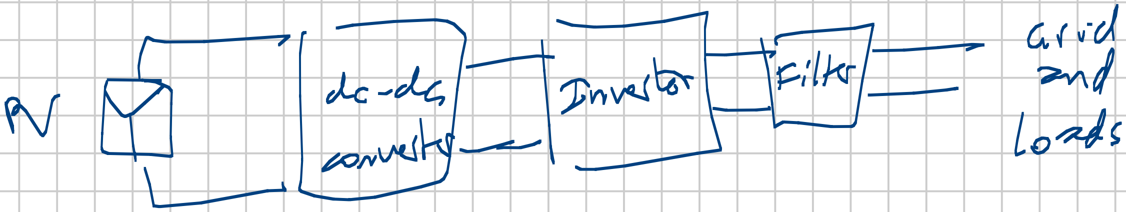
Grid interconnection

Note Title 11/14/2011

- The focus now is to study how PV inverters interact with the grid.

- Typical configuration:



More especifically,

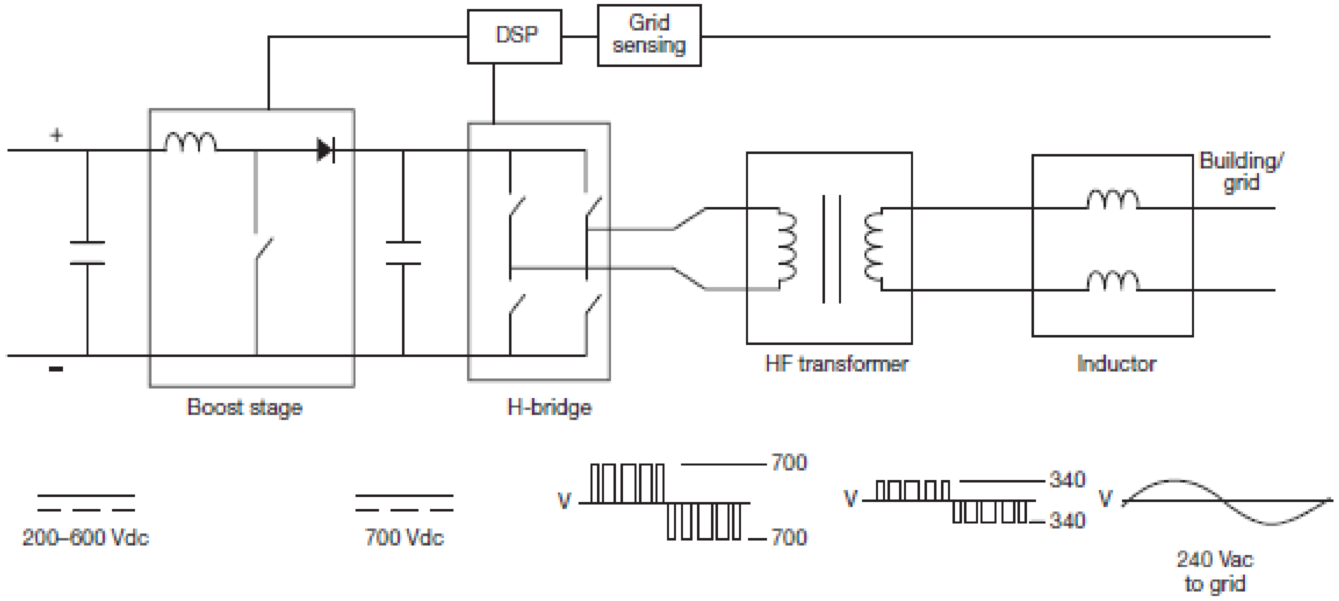
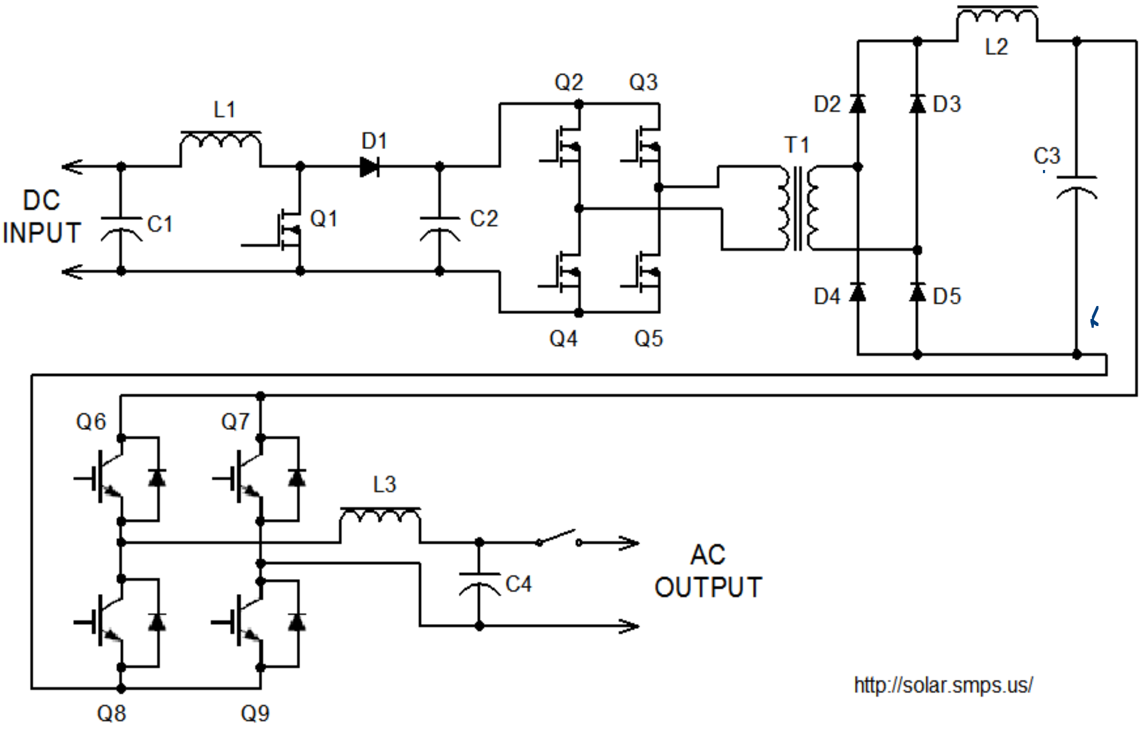


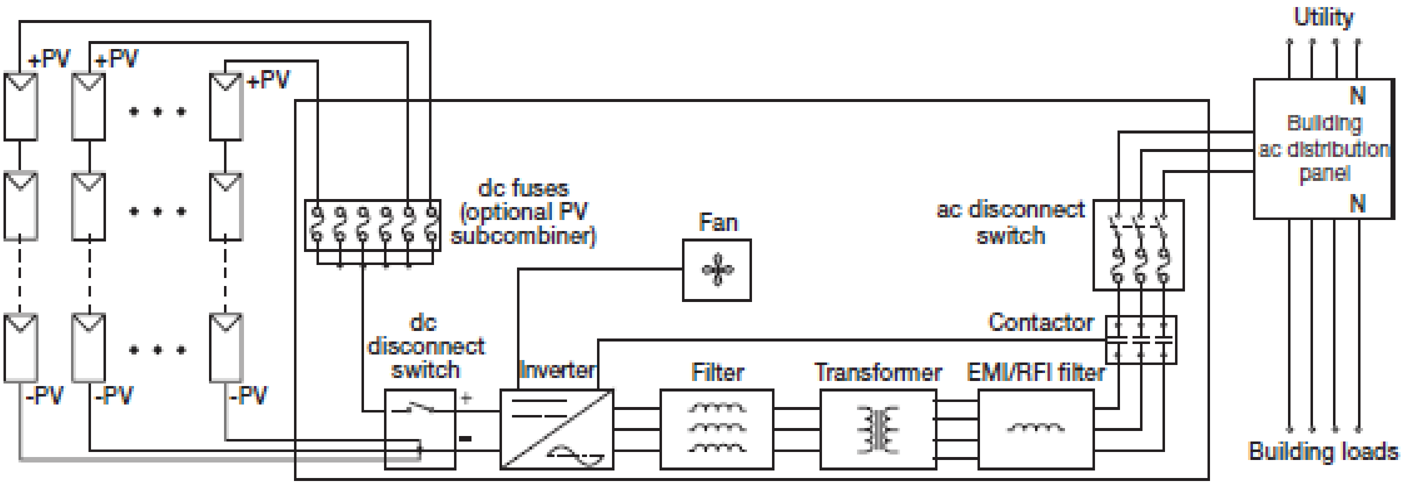
Diagram 7 A high frequency, transformer-based, single-phase inverter circuit.

And the more detailed circuit may look something like this:



http://solar.smps.us/

For the 3 phase case:

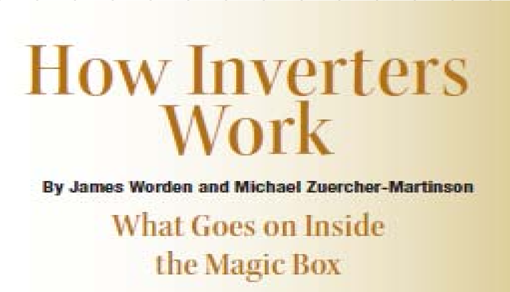


Ground fault detection/interrupt not shown.

Diagram 3 The major equipment included in an integrated inverter package is detailed in this schematic for a representative 3-phase, central inverter.

(Note: Diagram 3 and diagram 7 were obtained from:

http://solar.gwu.edu/index_files/Resources_files/How-Solar-Inverters-Work-With-Solar-Panels.pdf



How Inverters Work

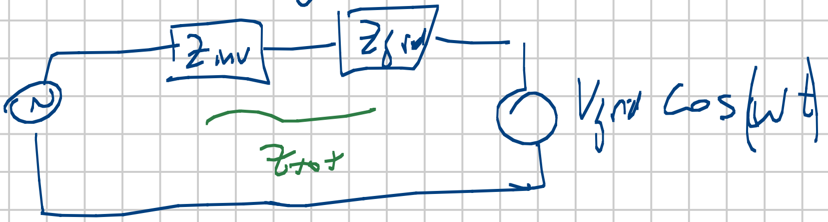
By James Worden and Michael Zuercher-Martinson

What Goes on Inside the Magic Box

- 1st issue: can we inject power into the grid? If so, how do we control it?

So consider the following equivalent circuit for the above PV connected inverter system:

$V_{inv}\cos(\omega t+\delta)$



↓

$$V_{inv} = \frac{V_{dc}}{\sqrt{2}}\, m$$

At 60Hz both Z_{inv} and Z_{grid} are mostly resistive

So, $$S = V_{grid}\angle 0 \left(\frac{V_{inv}\angle\delta - V_{grid}\angle 0}{Z_{tot}}\right)^{*} =$$

$$= \frac{V_{grid}V_{inv}\angle -\delta - V_{grid}^{2}\angle 0}{R_{tot} - jX_{tot}}$$

↓ Since Z_{tot} is mostly resistive

$$S = \frac{V_{grid} V_{inv} \angle \delta - V_{grid}^2 \angle 0}{R_{TOT}}$$

$$P = \frac{V_{grid} V_{inv} \cos\delta - V_{grid}^2}{R_{TOT}}$$

$$Q = \frac{V_{grid} V_{inv}}{R_{TOT}} \sin(-\delta)$$

With the inverter I can control
- → V_{inv} through m
- → ω
- → δ

Of course ω is synchronized with the grid.
If I also choose $\delta = 0$ (I may or may not do this but since no utility is providing incentives for reactive power and, actually, too much reactive power is not good for the grid (low power factor) or the inverter (higher currents leading to higher losses) Then ____ $\delta = 0$

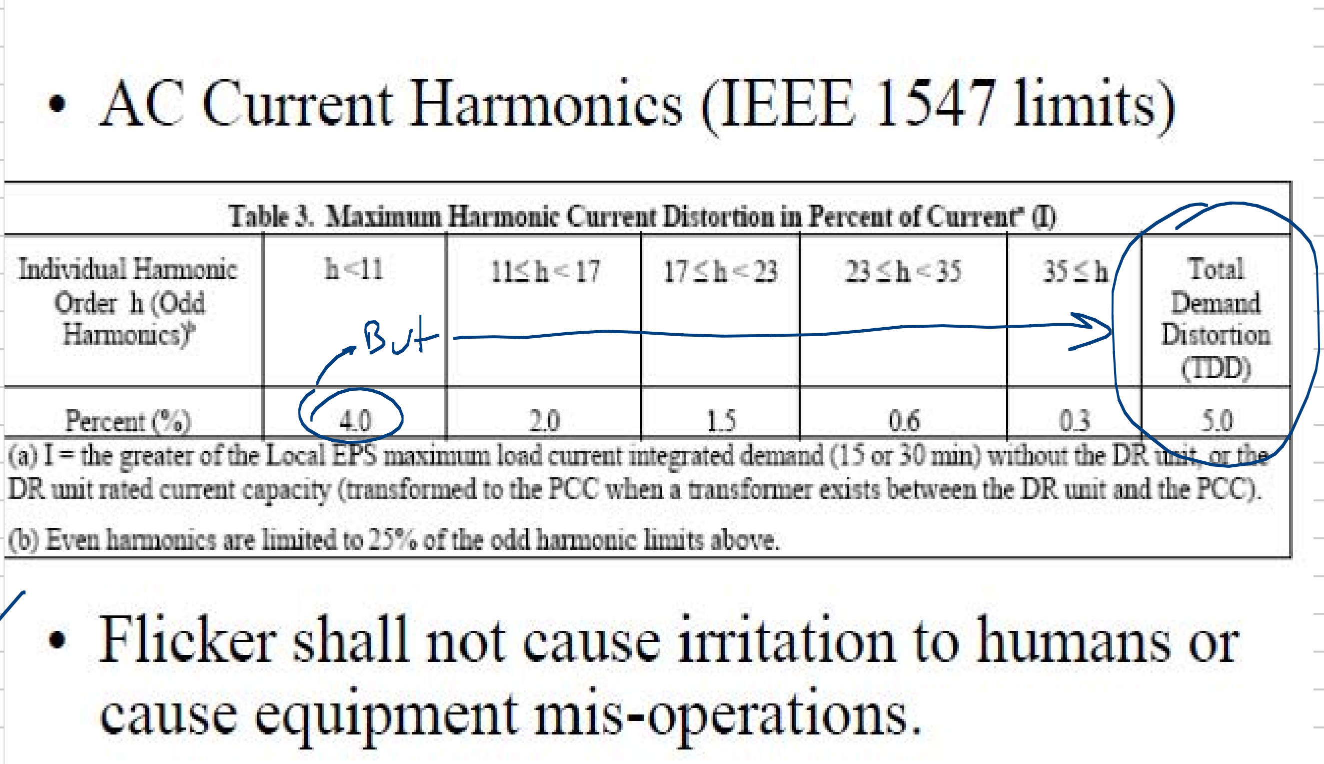
Hence:

$$Q = 0$$

$$P = \frac{V_{grid}}{R_{tot}} (V_{inv} - V_{grid})$$

↳ controlled through m

What parameters are important when connecting the inverter to the grid?



- AC Current Harmonics (IEEE 1547 limits)

Table 3. Maximum Harmonic Current Distortion in Percent of Current[a] (I)

Individual Harmonic Order h (Odd Harmonics)[b]	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	Total Demand Distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

(a) I = the greater of the Local EPS maximum load current integrated demand (15 or 30 min) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

(b) Even harmonics are limited to 25% of the odd harmonic limits above.

But →

- Flicker shall not cause irritation to humans or cause equipment mis-operations.

And no dc.

Also → anti islanding prevention

it means that it cannot operate when the grid is off → for safety reasons

It means that the inverter needs to get disconnected if grid → voltage is outside ±15% → disconnection in less than 0,2 to 2 sec depending the standard

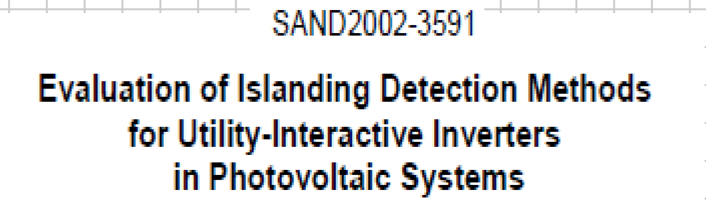
→ frequency is outside ±1% → disconnection within 0,2 sec

Islanding → A condition in which a part of an electric grid which contains both load and generation is isolated from the rest of the grid and continues to operate

Problems with islands → Utilities cannot control voltage and frequency so customer equipment may be damaged

→ hazards for repair crews working on a "live" conductor that they thought had no power.

Anti islandings methods from ↗



SAND2002-3591

Evaluation of Islanding Detection Methods for Utility-Interactive Inverters in Photovoltaic Systems

Anti islanding methods

- Network → Power line carrier communications
  - → SCADA
  - → Comparison of rate of change of frequency.

Problem → how to deal with cases when the issue leading to the need for disconnection to prevent islanding is a network problem!

- Local methods → more reliable and cost effective

- Passive methods → involve only measuring certain indicators
  - voltage
  - frequency
  - Rate of change of output power
  - Rate of change of frequency
  - Rate of change of frequency over power
  - Harmonics detection

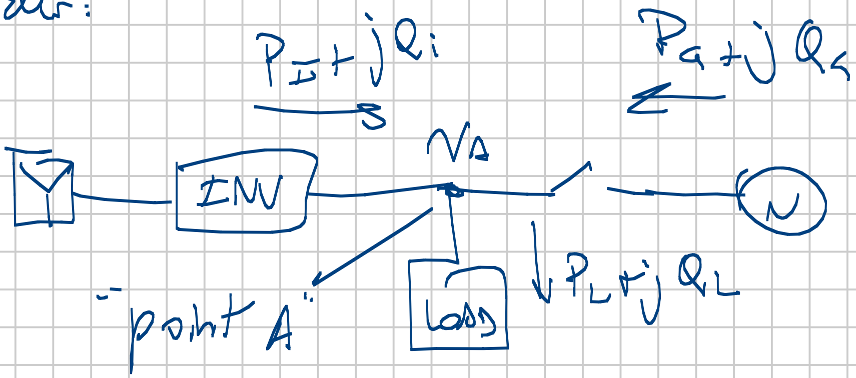
- Active methods → involve injecting controlled disturbances and then measuring the effects they have
  - Reactive power variations
  - Impedance measurement method
  - Phase shift or frequency shift
    - Slip mode frequency shift
    - Active frequency drift
    - Automatic phase-shift method
  - cyclic harmonic injection

Important concept for evaluating anti-islanding methods:

"Non detection zone" → A range of local conditions (e.g. loads within the island) for which an island prevention method fails to detect islanding

1) Under/over voltage and under/over frequency

Consider:



$$\begin{cases} P_G = P_L - P_I \\ Q_G = Q_L - Q_I \end{cases}$$

We saw that

$$P_G = \frac{V_{grid} V_{inv} \cos\delta - V_{grid}^2}{R_{TOT}}$$

$$Q_G = \frac{V_{grid} V_{inv}}{R_{TOT}} \sin(-\delta)$$

The general idea is that if the grid goes out then:

a) If $P_G \neq 0$ when the grid goes out the V_a will drop and the inverter will disconnect

b) If $Q_G \neq 0$ when the grid goes out then δ will change and the inverter will disconnect

But, what happens if at the time of the grid going out $P_G = 0$ or small <u>and</u> $Q_G = 0$ or small? ⟶ then V_a will not change much and δ will not change much

$$\Downarrow$$

NDZ

Hence, this is a low cost approach but it has a large NDZ and it has slow reaction times.

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2) Phase jump detection

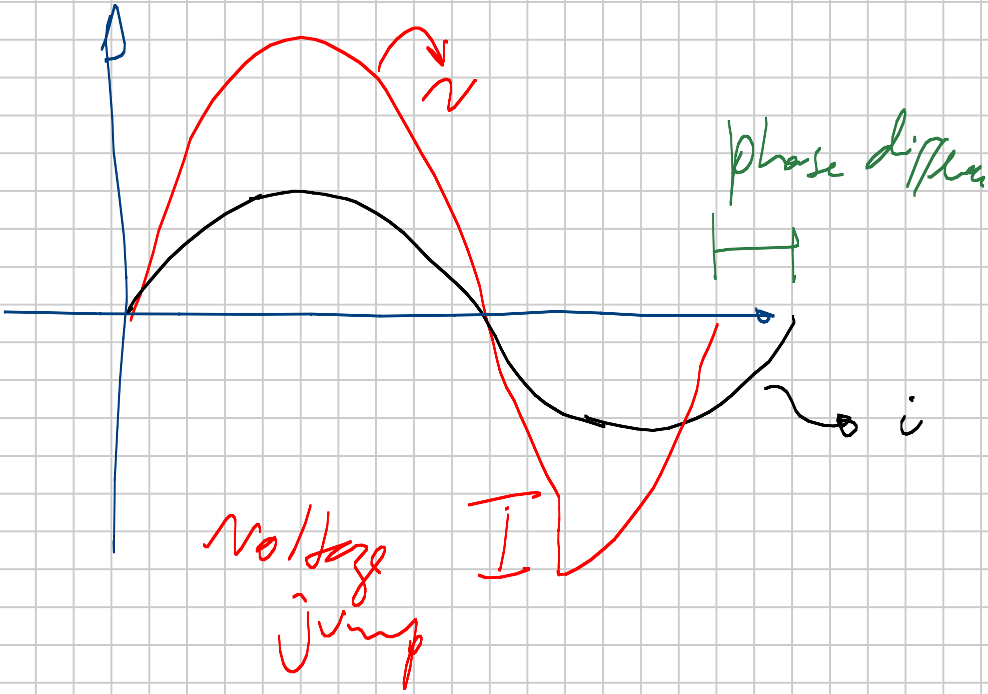
The idea is to look for sudden differences in phase between the inverter's voltage and current

Remember that usually the inverter presents unity power factor. Also the inverter output and v_a synchronized (in phase). This synchronization is done whenever v_z crosses zero. In between zero crossings there is no control

Consider a current source inverter (if it is a voltage source inverter just change "currents" by "voltages").

- If the grid disconnects then the inverter output needs to change its output from power factor =1 to power factor = load's power factor.
- However the current output of the inverter is still "synchronized" and it control reference for frequency will not change until v_z crosses zero again.

Then what change is the phase of the inverter output voltage:



Advantages → low cost

Disadvantages → NDZ when load has pf ≅ 1

→ Nuisance trips

→ Motors when starting create phase jumps.

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3) Harmonics detection

Consider that the inverter measures THD in point A. Since the grid is an "infinite" power source it forces V_A to have low distortion (the grid stiffness forces V_A to be what the grid wants it to be)

Assuming a linear load, it forces its current to have low THD

When the grid goes off then the own inverter harmonics increase the current THD which is detected and island is cleared

Although it works for the multiple inverter case and has potential for wide range of conditions it is still very difficult to set a threshold that does not produce nuisance trips due to

→ Non-linear loads (electronic SM power supplies)

→ Grid distortion is in a more realistic case 12 to 2%

↓ Transients (like switching capacitors)

These 3 ↑ were passive methods → All have problems with NDZ and nuisance tripping

These ↓ are active methods → based on injecting a perturbation and measuring its effects.

4) Impedance measurement

This is like method #1 but through an active approach.

The idea is to periodically perturb V_{inv}. If a ΔV_{grid} of a given magnitude leads to a certain ΔP to the grid also influenced by the power going to the load. However if the observed ΔP is not what it should be if the grid were present, then it means that the grid has gone off and that the inverter needs to be disconnected.

The name of the method comes from the fact that ΔP is measured as Δi so what is being evaluated is $\Delta V / \Delta i$

This method can also be applied by disturbing

$i_{inverter}$ (Δi) and measuring V_Δ for a given ΔV.

- The advantage is now a small NDZ because the measured is performed at known times when an intended disturbance is injected.

- However ⟶ The more inverters that are added in parallel the less significant the perturbance of each inverter is. with many inverters (as in the case of module-integrated inverters

Power quality problems particularly in high-impedance grids such as voltage flicker

NDZ → This method is based on:

$$P = \frac{V_{grid}}{R_{tot}} \underset{\substack{\uparrow \\ \Delta V}}{(V_{inv} - V_{grid})}$$

But it relies on a small R_{grid}.

If not the ΔP (or ΔV) caused by a give ΔV (or ΔP) may not be noticeable enough.

5) Detection of impedance at specific frequencies

This is the active version of the harmonic detectio method. → Now a distortion is intentionally continuously injected at a given frequency

with the grid present and because of its stiffness the distortion is not noticiable

The added distortion is only noticiable when the grid is off.

It's advantages and disadvantages are similar to those in its passive equivalent but the performa of the active version is still better.

6) cyclic harmonic injection → see paper
(overmodulation)

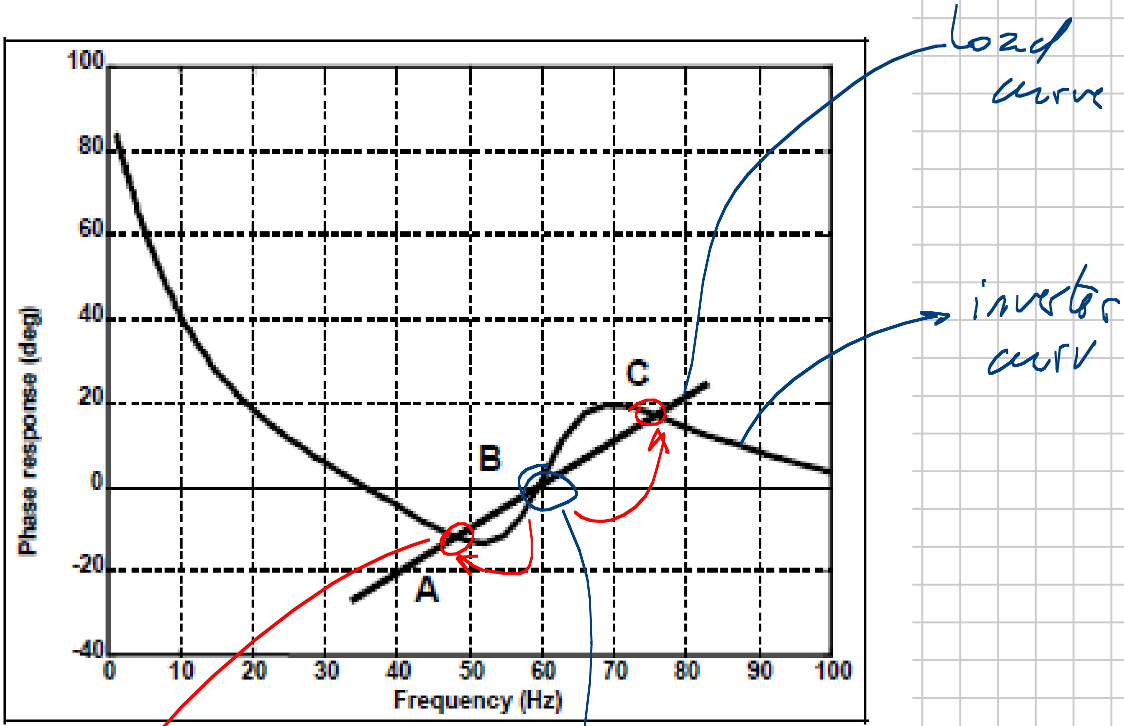
7) Slip mode frequency shift

Consider $V_{inv} = V_{inv} \sin(\omega_{inv} t + \delta_{inv})$

(The same can be done base on the current).

Usually inverters are controlled so their power factor is 1.

However, in this method δ is controlled so δ is a function of the frequency at V_a.



Normal operation imposed by the grid when it is present

New operating points driven by the applied perturbation → if well designed they are beyond frequency disconnection thresholds.

Advantage → easy to implement

NDZ / issue → some loads have phase-frequency characteristic that increases at a faster rate than that in the inverter.

2) Frequency bias

Now the perturbation is applied to the frequency so it takes advantage of natural resonating frequencies

small continuous trend to change frequency.

with the grid present, the frequency cannot be changed.

when the grid is off the frequency will drift up or down until the thresholds are exceeded and the inverter is disconnected.

Advantage → easy to implement in micro-controller based inverters.

Weaknesses → requires coordination in multiple inverter systems to avoid mutual cancellation of disturbances.

Power quality is degraded.

Some notes about EMI

electromagnetic interference.

high frequency signals

caused by switching power

From

All about EMI filters

BY MEL BERMAN
TDK-Lambda Americas
San Diego, CA

Two types → Radiated → Radio waves

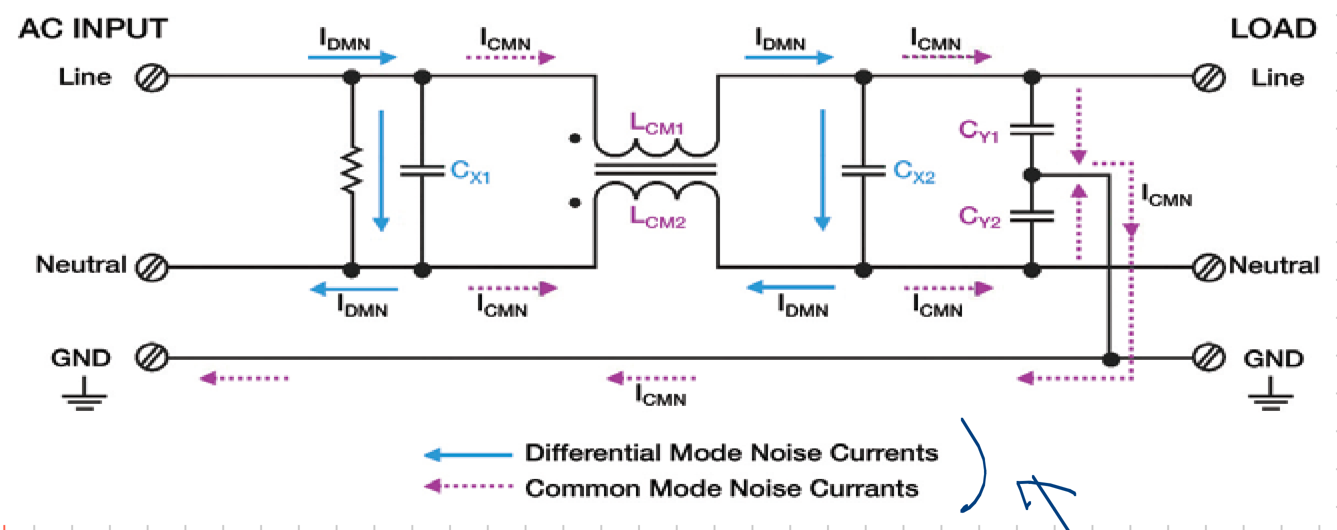
controlled through shielding

Requires good grounding

conducted → through cables

controlled through filters

transmitted through parasitic inductances and capacitances



two types