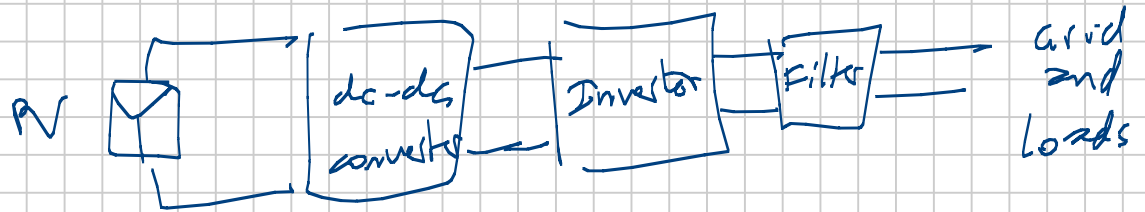


Grid interconnection

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

Typical configurations:



More specifically,

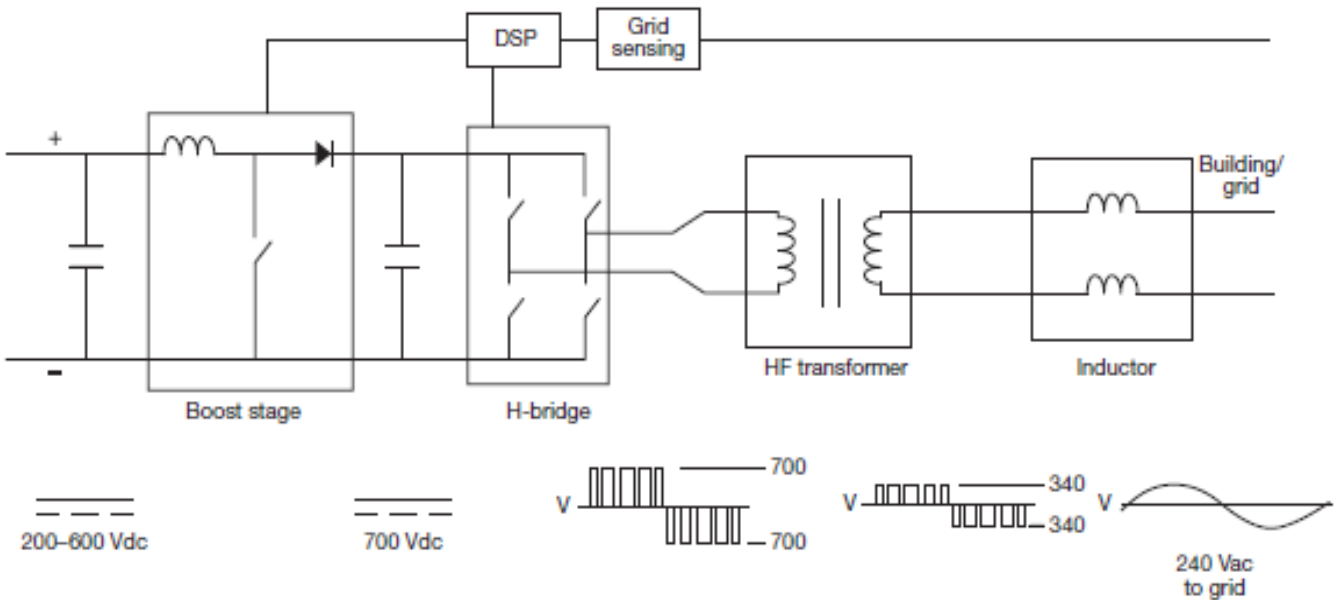
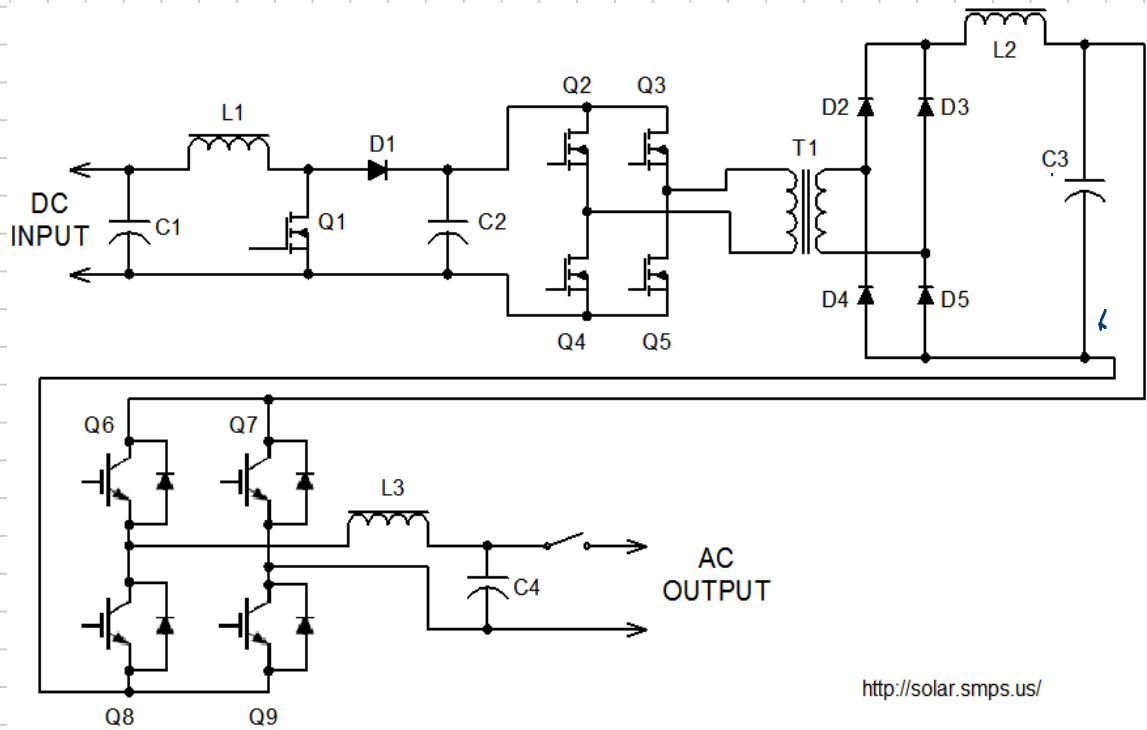


Diagram 7 A high frequency, transformer-based, single-phase inverter circuit.

And the more detailed circuit may look something like this:



<http://solar.smeps.us/>

For the 3 phase use

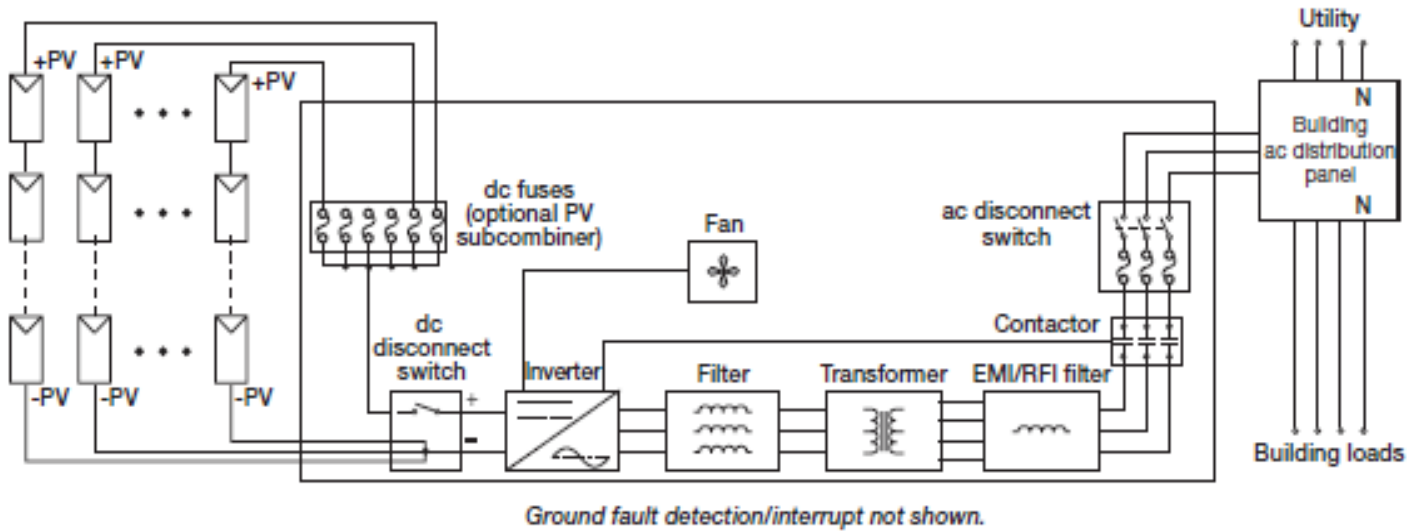


Diagram 3 The major equipment included in an integrated inverter package is detailed in this schematic for a representative 3-phase, central inverter.

(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

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* (I)

Individual Harmonic Order h (Odd Harmonics) ^a	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	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.

- 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 $\pm 15\%$ → disconnects it less than 0.2 to 2 sec depending the standard

frequency is outside $\pm 1\%$ → 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 islanding methods from

SAND2002-3591

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

Anti islanding methods

- Network → Power line carrier communications

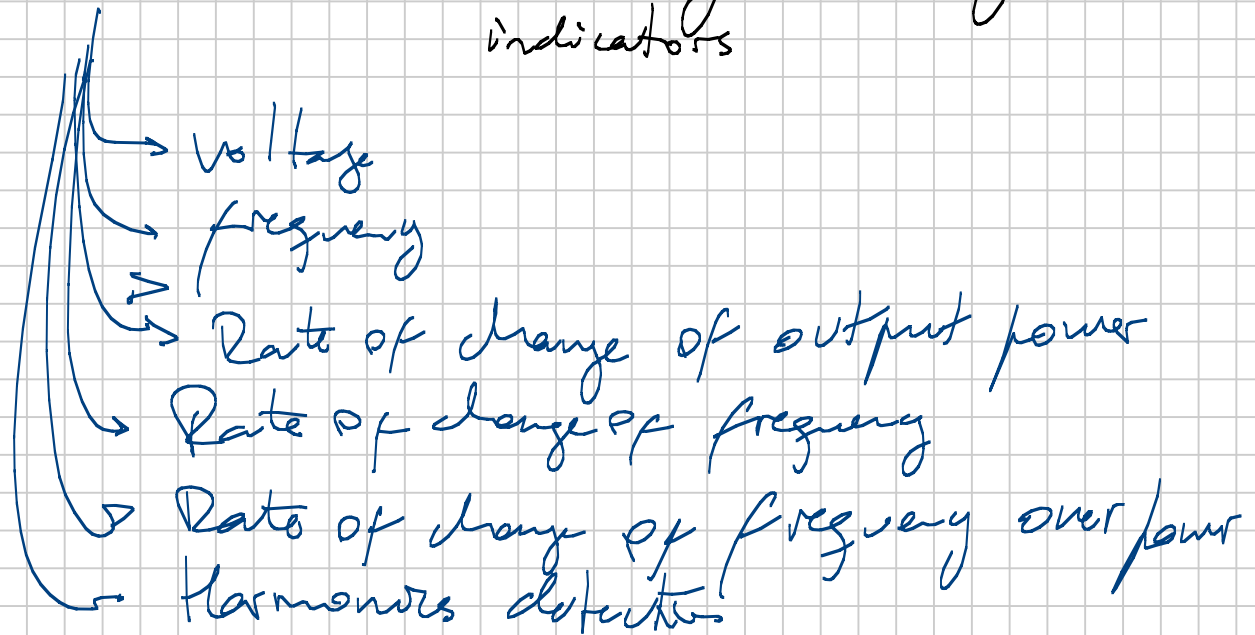
↳ SCADA

↳ Comparison of rate of change of frequency.

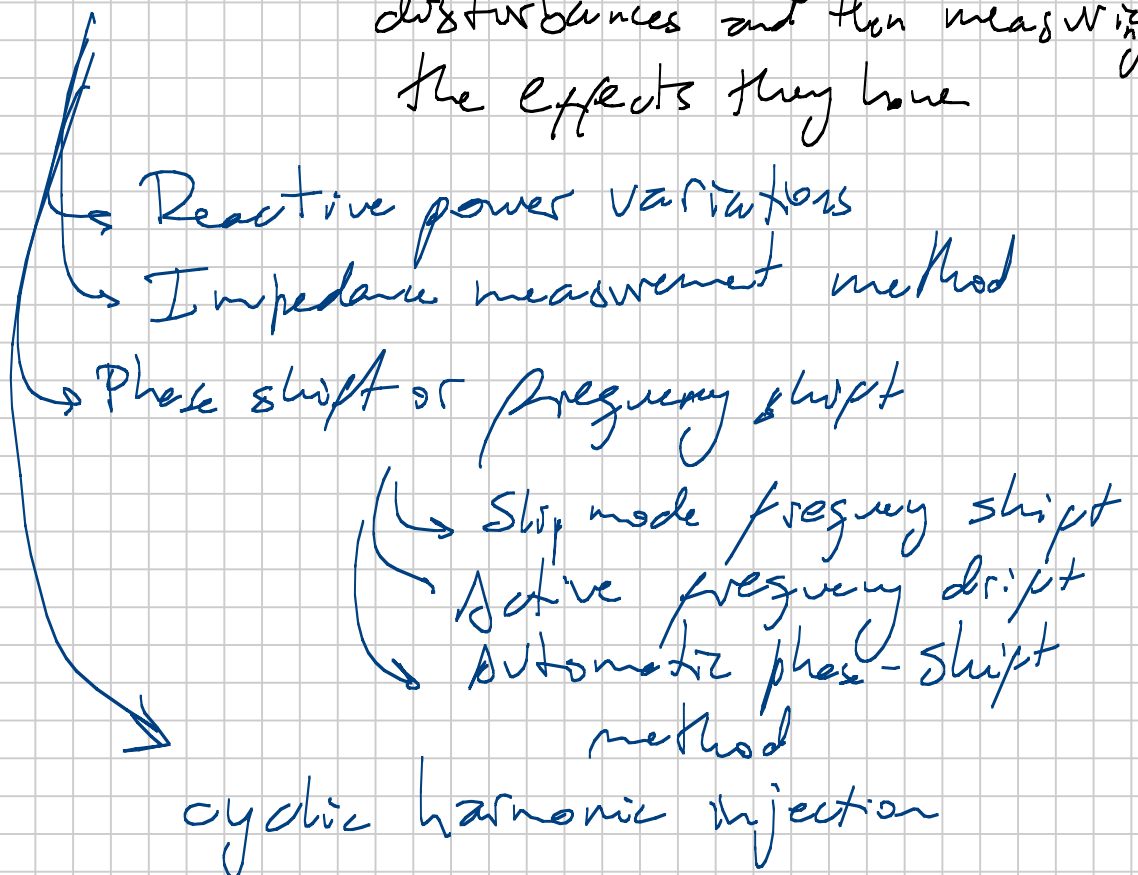
Problem → How to deal with cases when the issue leading to the need for disconnection to prevent islanding is a network problem!

- local methods → more reliable and cost effective

• Passive methods → involve only measuring certain indicators



• Active methods → involve directly controlled disturbances and then measuring the effects they have

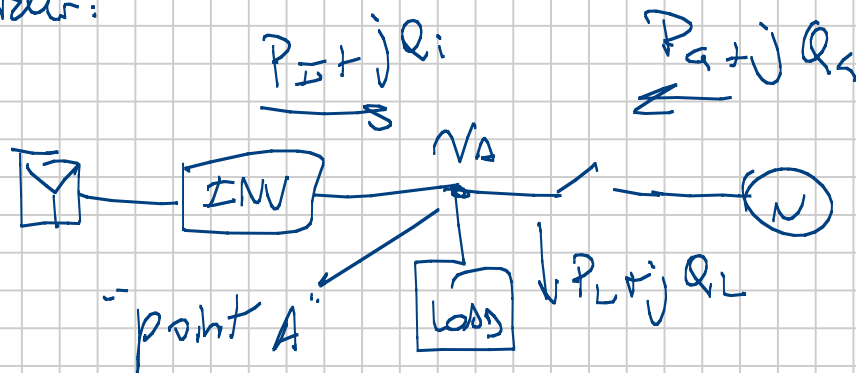


Important concept for evaluating anti-islanding methods:

"Non detection zone" \rightarrow 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:



$$\begin{cases} P_s = P_L - P_{\#} \\ Q_s = Q_L - Q_{\#} \end{cases}$$

We saw that

$$P_s = \frac{V_{grid} V_{inv} \cos \delta - V_{grid}^2}{R_{tot}}$$

$$Q_s = \frac{V_{grid} V_{inv} \sin(\delta)}{R_{tot}}$$

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

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

b) If $Q_c \neq 0$ 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 $P_c = 0$ or small and $Q_c = 0$ or small? \rightarrow then V_a will not change much and δ will not change much

\Downarrow
NNT

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

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 are synchronized (in phase). This synchronization

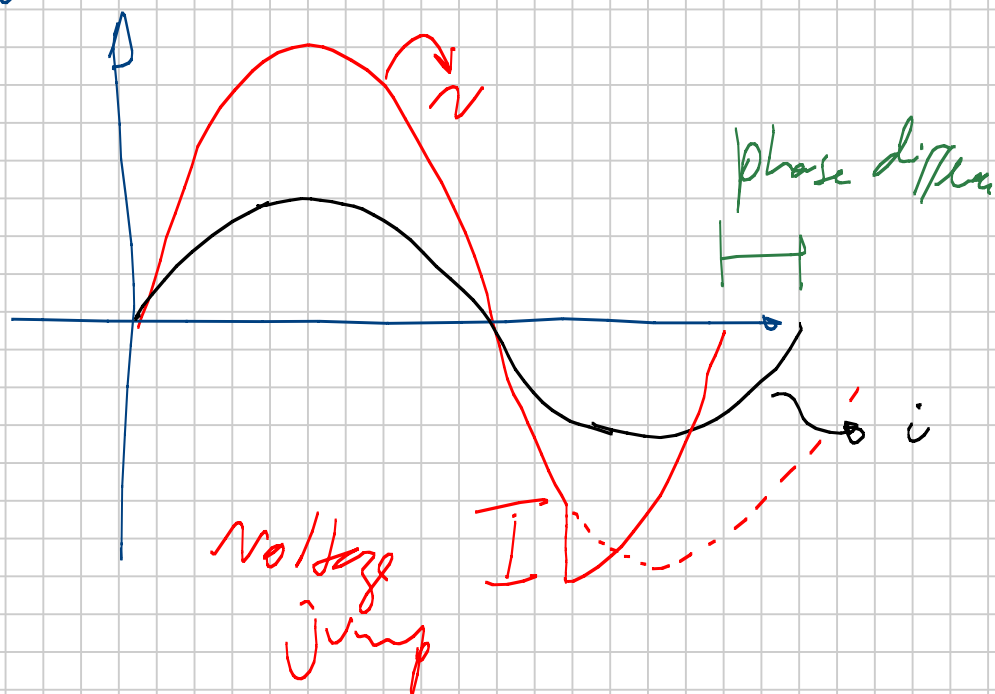
is done whenever v_a crosses zero. In between zero crossings there is no control

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

- If the grid does connect 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 its control reference for frequency will not change until v_a crosses zero again.

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



Advantages → low cost

Disadvantages \rightarrow NDI when load has $pf \approx 1$

\rightarrow Nuisance trips

\rightarrow Motors when starting create phase jumps.

3) Harmonics detection

Consider that the inverter measures T_{HD} 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 T_{HD}

When the grid goes off then the own inverter harmonics increase the current T_{HD} 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

\rightarrow Non-linear loads (electronic SM power supplies)

\rightarrow Grid distortion is in a more realistic

case 12 to 2%

Transients (like switching capacitors)

These \uparrow were passive methods \rightarrow All have problems with ΔV and nuisance tripping

These \downarrow are active methods \rightarrow 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 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_0 for a given ΔV .

The advantage is now a small NDZ because the measurement is performed at known times when an unintended disturbance is injected.

~ However \rightarrow The more inverters that are added in parallel the less significant the perturbation 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 \rightarrow This method is based on:

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

\uparrow ΔV

But it relies on a small R_{grid} .

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

5) Detection of impedance at specific frequencies

This is the active version of the harmonic detection 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 noticeable

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

Its advantages and disadvantages are similar to those in its passive equivalent but the performance of the active version is still better.

6) cyclic harmonic injection → see paper (overmodulation)

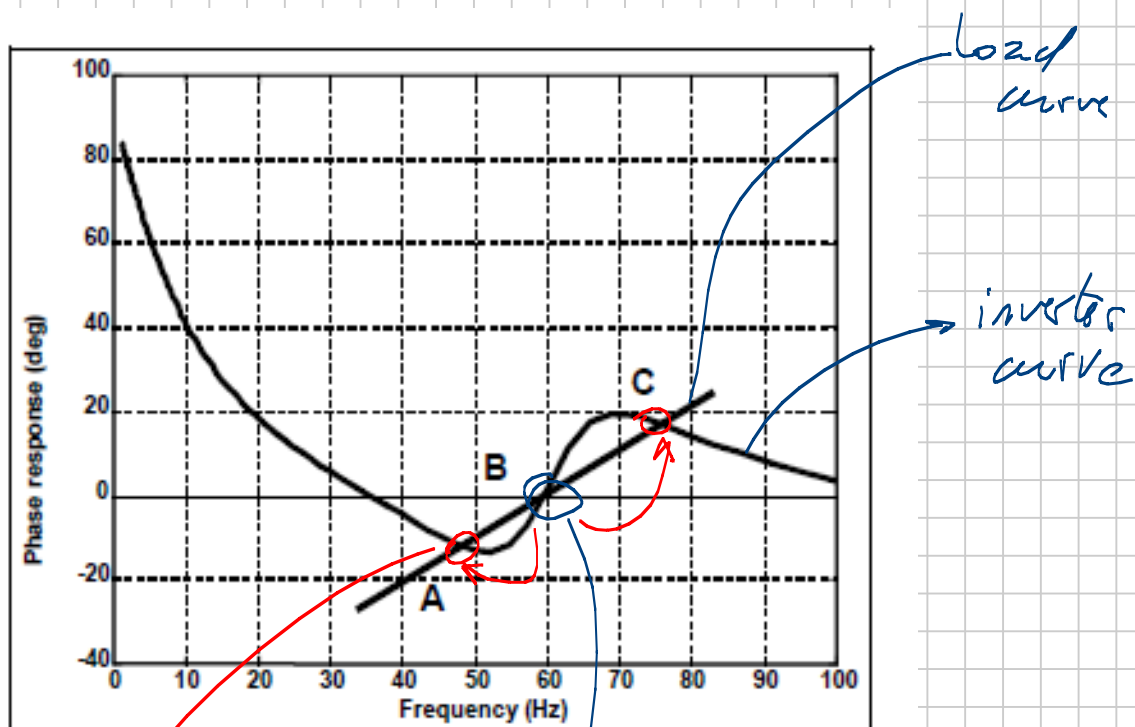
7) Slip mode frequency shift

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

(The same can be done based 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 \rightarrow if well designed they are beyond frequency disconnection thresholds.

Advantage \rightarrow easy to implement

NDZ / issue \rightarrow 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

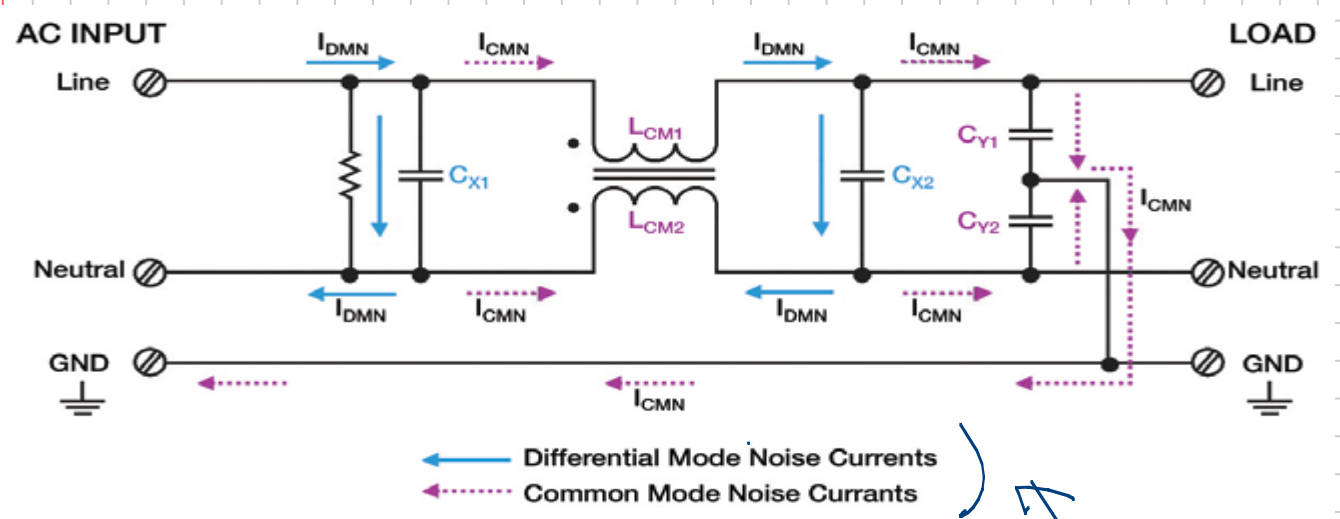
All about EMI filters

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

Note: Some more effects of microgrids on grids will be discussed next classes as part of the smart grid topic