Evaluating the effect of 2-stage EMI filter interaction with LCL filter and grid source impedance

By Arief Noor Rahman – Power Control Design

Filter resonant is a commonly known knowledge (though not as commonly understood). In case of inverter application, the most commonly studied phenomenon on filter resonant is in the case of LCL filter where the inverter side and grid side inductors form a resonant interaction with the filter capacitor.

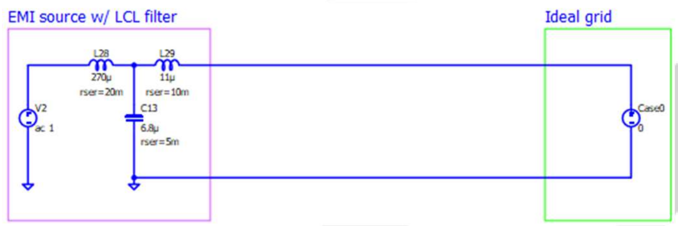

Fig. 1. LCL filter structure.

This resonant if not addressed properly will resulting in uncontrolled oscillation as shown in the Fig. 2. In the Imperix's literature, they presented about active damping method to solve the filter resonant problem which shows good result until the active damping is turned off then the system becomes unstable immediately. Another alternative for damping method is by passive damping by adding some damping element one of the LCL's limb. However, the passive damping on the LCL side is often avoided on high power density design due to 1) the bulky size and lossy damping elements and 2) damping often reduce the LCL ripple attenuation capability, though it depends on the specific damping placement.

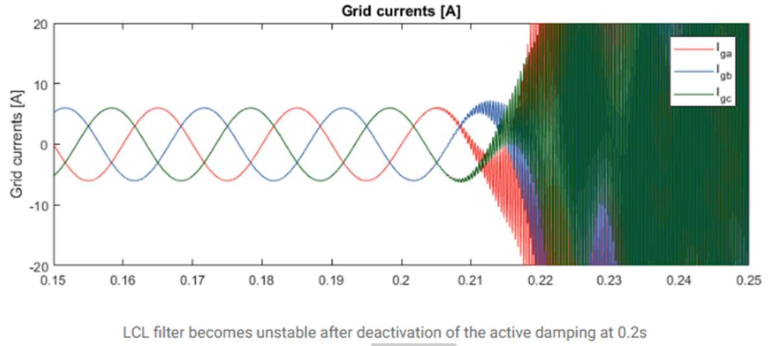

Fig.2. LCL filter resonant.
https://imperix.com/doc/implementation/active-damping-of-lcl-filters?currentThread=back-to-back-three-phase-converter-with-grid-tied-lcl-filter
*note the waveform is generated from simulation, in actual hardware the instability tends to be not as dramatic due to the parasitic resistance in the inductors and capacitors acted as passive damping.

Anyway, enough with the damping method as there have been enough literature to do just this either with passive or active method. What is not yet properly studied is the effect of EMI filter insertion on the overall resonant behavior. Furthermore, with the resonant characteristic with addition of grid side source impedance. This report focus specifically on for 2-stage EMI filter.

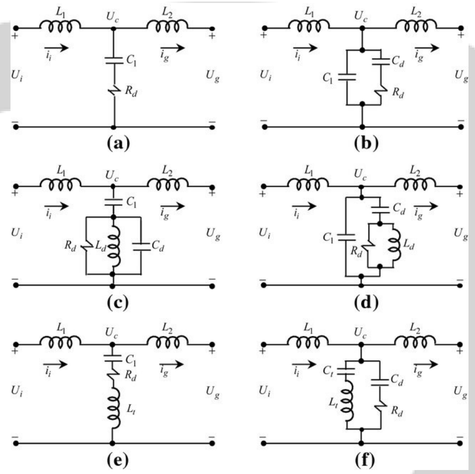

Fig.3. Variations of possible damping structures for LCL filter.
Albatran, Saher & Koran, Ahmed & Smadi, Issam & Ahmad, Hamzeh. (2018). Optimal design of passive RC-damped LCL filter for grid-connected voltage source inverters. Electrical Engineering. 100. 10.1007/s00202-018-0725-5.

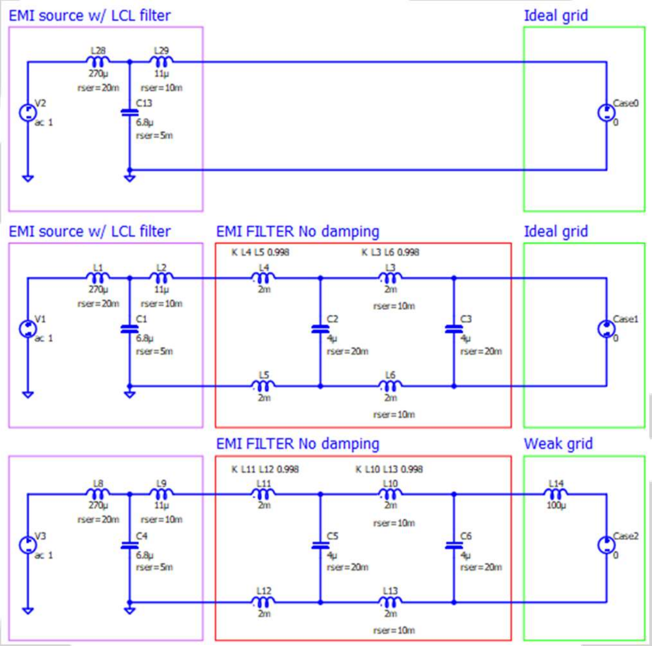

Fig.4. LCL-filter, LCL-filter + EMI-filter, LCL-filter + EMI-filter + source impedance.

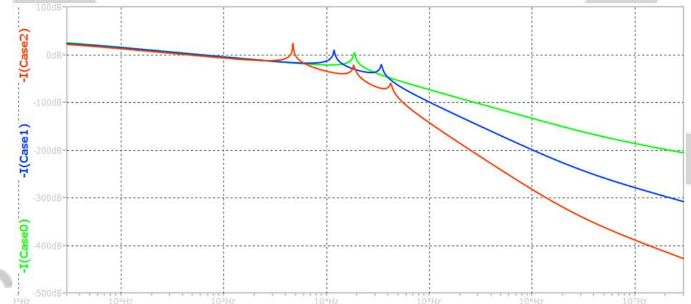

Fig.5. Output current to inverter voltage frequency characteristic. Case 0: LCL, Case 1: LCL+EMI filter, Case 2: LCL+EMI filter+Grid Impedance.

From Fig.5, we can see that a simple addition of EMI filter create the second resonant peak and furthermore the grid impedance create the third resonant peak. These 2nd and 3rd resonant peak have a potential of causing system instability and unfortunately these two peaks are not covered by the damping method reported in the literatures.

To damp the resonant caused by the EMI filter insertion, here we can try to add damping resistor in series with the EMI-filter capacitor on two different configurations in Fig. 6.

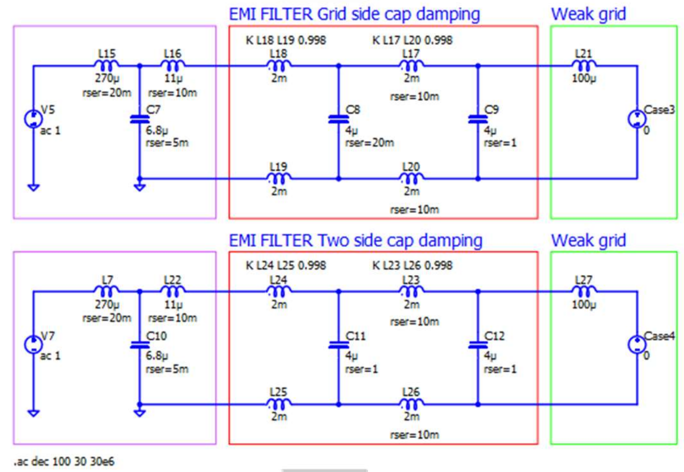

Fig.6. Addition of series damping resistor on two different configurations.

In Fig. 7 we can see that the damping resistor between the two configurations significantly helps to suppress the resonant peak roughly similarly. However, the case 4 shows better attenuation at higher frequency upwards to 30MHz (conducted EMI frequency limit). Thus, the case 4 is the considered to be the better configuration moving forward.

This passive damping on the EMI side is considered to be acceptable from power density and losses POV due to the low ripple current at these capacitors in contrast of the capacitor on the LCL filter. Single 2W 2012-package 1R damping resistor can be used with little to no effect on the power density.

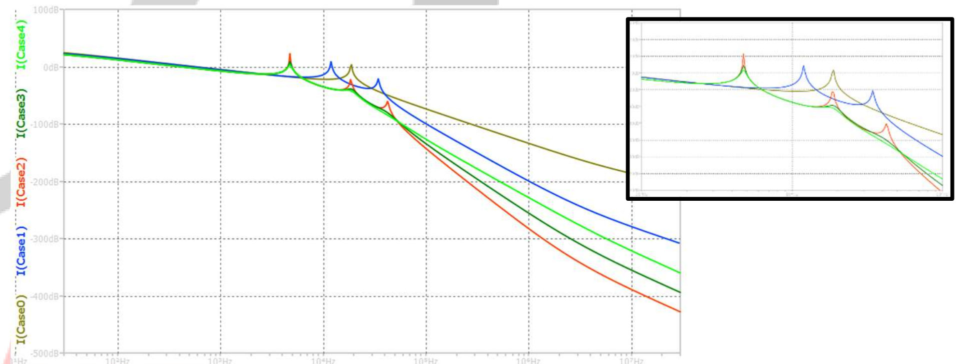

Fig. 7. Output current to inverter voltage frequency characteristic. Case 0: LCL, Case 1: LCL+EMI filter, Case 2: LCL+EMI filter+Grid Impedance, Case 3: LCL+EMI filter+Grid Impedance+Grid side cap damping, Case 4: LCL+EMI filter+Grid Impedance+Two side cap damping.