# A Study about Output Filter of Paralleled Three-Phase Grid-Connected PV Inverters

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## Abstract

The rising popularity of renewable energy sources resulted in development of the units of higher rated powers. As a result of the limited power handling capacity of individual devices, paralleling is the choice to increase the equipment rating, while keeping the THD of the current at the PCC within the agency specified standards. And their typical power circuit configuration limits the stress on individual devices to an appreciable extent. The main scope of this paper is the analysis of filter structure in paralleling inverter system's operation. Simulation results are shown to verify the theoretical analysis.

## 1. Introduction

High power applications demand high reliability due to the strict grid codes requirements. In such power applications parallel operation of inverters is an usual practice. This feature is crucial in high-capacity generation where an inverter based on a single power module may not be enough to handle all the produced power. Another benefit is that parallel inverters can be built in a modular way, which means they can operate independently. Thus, it provides a ride-through capability when a module fails. Parallel inverters are frequently used to reduce the PWM switching frequency and resulting harmonics [1], [2].

There are many possible configurations of parallel inverter systems: using separate [3] or using a common [4] dc source. Fig. 1 shows the paralleled three-phase inverters using two-winding isolation transformer with separately dc voltage sources.

This paper is focused on the analysis of filter structure during system performance in case of paralleling operation of power inverters used in PV applications. When designing filter for paralleling inverters, one has to be aware of proper placement of the capacitor. This is due to the non-ideal properties of the capacitor. In other words it is difficult to obtain two capacitors having the same value. Moreover one should consider aging of the elements, which influences the capacitance. If one capacitor bank differs from the others, this results in different angles for the fundamental component of the other line currents. In other words the desired ripple cancellation cannot be obtained.

## 2. Output Filter Analysis

### 2.1 LC-Filter

The system parameters are listed in Table 1 (for both LC- and LCL-filter cases). Due to the configuration shown in Fig. 1, Fig. 2 shows the LC-filter's frequency responses in two cases:

- Case (1): only one inverter is connected and operates at time (Sw1 is ON, Sw2 and Sw3 are OFF)
- Case (2): three-inverter are connected but only one inverter operates at time (Sw1, Sw2 and Sw3 are ON).

Case (2) occurs when the first inverter is in steady-state, but the second and third inverters are in initial-state. In the other words, the second and third inverters are connected to system (Sw2 and Sw3 are ON), but not generate the power yet. During this short period, the LC-filter structure may be modified as illustrated in Fig. 3. As shown, the capacitor size may be increased three times and

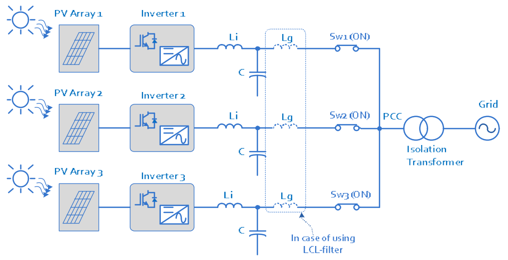

Fig. 1 Configuration of paralleled three-inverter system using two-winding isolation transformer

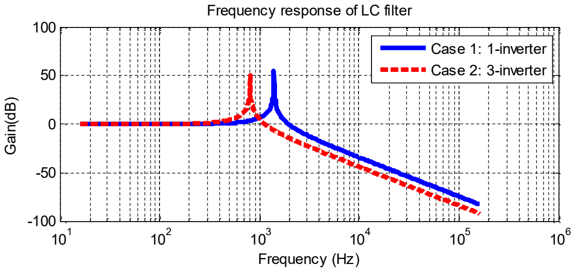

Fig.2 LC-filter's frequency responses

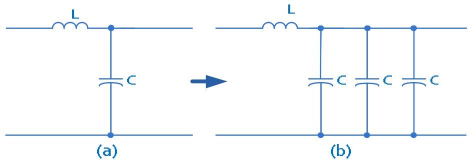

Fig. 3 The change in LC-filter's per-phase structure

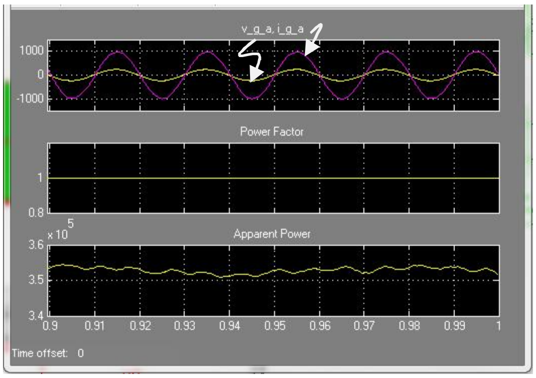

Fig. 4 Simulation results of case (2) using LC-filter

this will result in reducing the filter's resonant frequency. The resonant frequency in case (1) is 1.3kHz and that of case (2) is 0.8kHz. Due to this, the resonance phenomenon may not be occurred since the grid frequency is 50Hz. Simulation results in case (2) by using LC-filter as shown in Fig. 4, where system has no resonance phenomenon. However, the resonance phenomenon strongly depends on the system parameters and configurations.

It is noted that the transfer function of LC-filter before and after changing structure has no change in expression, but in capacitance value.

### 2.2 LCL-Filter

Similar to the LC-filter case, there are two cases depend on number of operating inverters. In case (2), the LCL-filter structure is changed to be similar to ladder filter, as shown in Fig. 5, and its frequency response is illustrated in Fig. 6, where the resonant frequency in case (1) is 3.8kHz and in case (2) are 3.8kHz and 7.3kHz. The simulation results are shown in Fig. 7, where the resonance phenomenon is occurred due to the change in LCL-filter structure.

The transfer function of LCL-filter before and after changing structure can be obtained as shown in (1) and (2), respectively:

$$G_{LCL}(s)=\frac{1}{L_iL_gCs^3+\left(L_i+L_g\right)s} \tag{1}$$

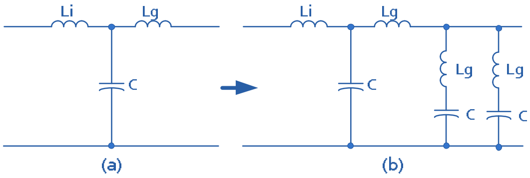

Fig.5 The change in LCL-filter's per-phase structure

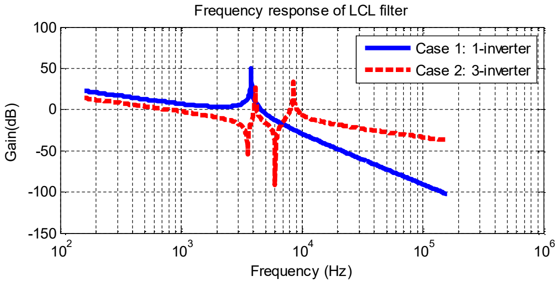

Fig. 6 LCL-filter's frequency responses

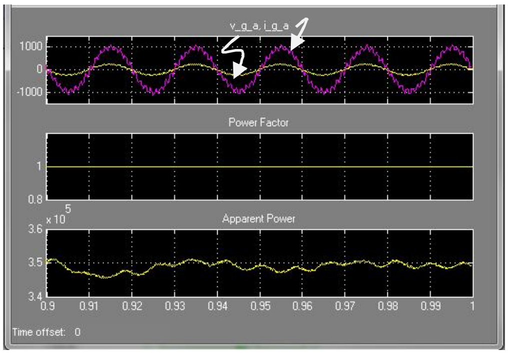

Fig. 7 Simulation results of case (2) using LCL-filter

$$G'_{LCL}(s)=\frac{\left(L_g^3C^2+L_g^2C^3\right)s^4+2L_g\left(L_gC+2C^2\right)s^2+L_g+3C}{\left(L_iL_g^3C^2+L_iL_g^2C^3+L_g^3C^3\right)s^5+2L_g\left[\left(L_gC+2C^2\right)L_i+L_gC^2+C^3\right]s^3+\left[\left(L_g+3C\right)L_i+L_gC+2C^2\right]s} \tag{2}$$

Table 1. System parameters

| | |
|---|---|
| Rated power | 350[kW] |
| Grid voltage | 290[V] |
| MV transformer | 290[V]/20[kV] |
| LC-filter inductance | 65[μH] |
| LC-filter capacitance | 200[μF] |
| LCL-filter inductances | 65[μH]/10[μH] |
| LCL-filter capacitance | 200[μF] |
| Switching frequency | 3[kHz] |
| Grid frequency | 50[Hz] |

## 3. Conclusion

This paper was focused on investigating the low pass output filter structure of three-phase high power inverters system in paralleling connection. Paralleling inverters can increase the output power, but it brings drawbacks in current protection, circuitry complexity and current sharing. When designing filter for paralleling inverters, one has to be aware of proper placement of the capacitor since the non-ideal properties of the capacitor. In other words the desired ripple cancellation and resonant protection cannot be obtained. Simulation results are shown to verify the analysis. Furthermore, due to the connection in parallel, system may face with leakage current problem caused by parasitic capacitance between the PV module and ground.

## References

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