MULTI-FUNCTIONAL INVERTERS FOR GRID-CONNECTED PHOTOVOLTAIC SYSTEMS

PhD. María Alejandra Mantilla Villalobos
Email: marialem@uis.edu.co
I. GISEL research group

II. Introduction to grid-connected PV systems

III. Multi-functional inverters

IV. Example: multi-functional inverter for grid-connected PV systems with load compensation functions under distorted and unbalanced grid voltages

V. Conclusions
ENERGY INTEGRATION LABORATORY

RENEWABLE ENERGY LABORATORY
INTRODUCTION

High penetration of renewable energy systems into the grid can lead to side-effects:
- Stability
- Reliability
- Power quality

Massive use of disturbing loads as non-linear systems and single-phase equipment can affect power quality in transmission and distribution systems.
INTRODUCTION
GRID-CONNECTED PV SYSTEMS
INTRODUCTION
GRID-CONNECTED PV SYSTEMS

The control system sets the system functionalities.
MULTI-FUNCTIONAL INVERTERS

GRID-CONNECTED PHOTOVOLTAIC INVERTER

Basic functions
- Maximum power point tracking
- Active power control
- Grid synchronization
- Islanding detection

Advanced functions
- Voltage regulation
- Voltage-active power control
- Fault Ride Through (FRT)
- Frequency and inertia support
- Static compensator
- Active power filtering
MULTI-FUNCTIONAL INVERTERS

- Provides voltage regulation capability by changes of reactive power
- Compensation of reactive power

**MODES OF REACTIVE POWER CONTROL FUNCTIONS**

- Constant power factor mode
- Constant reactive power mode
- Voltage-reactive power mode
- Active power-reactive power mode

MULTI-FUNCTIONAL INVERTERS

- Provides a voltage regulation capability by changes of active power.

Example: Voltage-active power mode

Voltage limit for DER continuous operation

MULTI-FUNCTIONAL INVERTERS

Fault Ride Through (FRT)

During temporary voltage disturbances according to the characteristic curve determined by the grid code (GC), the PV system shall be capable to ride-through and:

- Shall maintain synchronism with the grid.
- Shall continue to exchange current with the grid.
- Shall neither cease to energize nor trip.

The PV system may have the capability of dynamic voltage support during low-voltage ride-through (LVRT) and high-voltage ride-through (HVRT).

Maximum current and reactive current injection could be requested in order to support the voltage recovery.
MULTI-FUNCTIONAL INVERTERS

Frequency and inertia support

- Emulate the behavior of synchronous generator in order to improve frequency response of the system.
- The system can participate in frequency regulation during positive frequency excursion, by reducing the active power output of PV.
- For the PV system to participate in frequency regulation during negative frequency excursion, some reserve should be kept by de-loading or some other techniques should be considered as the ones that use energy storage devices.
- The concept of grid forming photovoltaic synchronous generator (PVSG) has been proposed in recent works.


PV-STATCOM: the PV inverter can be controlled as a static compensator and can provide different grid support functions.

- In the night time, the entire inverter capacity is used for operation as STATCOM.
- The system can provide voltage regulation capability during night and day.
- It includes LVRT capabilities. During a critical system disturbance in the daytime, the inverter discontinues its real power generation function temporarily (for about a few seconds), and releases its entire inverter capacity for STATCOM operation.
- Improves the power transmission capacity in the network at low irradiance or at night.

Inclusion of load compensations functions in distribution systems as:

- Harmonic mitigation
- Power factor correction
- Load balancing
EXAMPLE

MULTI-FUNCTIONAL INVERTER FOR GRID-CONNECTED PV SYSTEMS WITH LOAD COMPENSATION FUNCTIONS UNDER DISTORTED AND UNBALANCED GRID VOLTAGES

EXAMPLE
MULTI-FUNCTIONAL INVERTER FOR GRID-CONNECTED PV SYSTEMS WITH LOAD COMPENSATION FUNCTIONS UNDER DISTORTED AND UNBALANCED GRID VOLTAGES

Proposed reference signal generation algorithm:

\[ i_{\text{ref}}(t) = i_{\text{PV}}(t) + i_{\text{Pdc}}(t) + i_{\text{APF}}(t) \]

\[ i_{\text{PV}}(t) = \begin{cases} \frac{P_{\text{PV}}}{3(u_{\text{m}})^2} \left( u_{\text{m}}^+ + u_{\text{m}}^- \right) & \text{if } u_{\text{m}}^+ + u_{\text{m}}^- > 0 \\ \frac{P_{\text{PV}}}{3(u_{\text{n}})^2} \left( u_{\text{n}}^+ + u_{\text{n}}^- \right) & \text{if } u_{\text{n}}^+ + u_{\text{n}}^- < 0 \end{cases} \]

\[ i_{\text{APF}}(t) = i_{\text{L}}(t) - i_{\text{c}}^+(t) \]

\[ i_{\text{L}}(t) = \begin{cases} \frac{P_{\text{load}}}{3(u_{\text{m}})^2} \left( u_{\text{m}}^+ + u_{\text{m}}^- \right) & \text{if } u_{\text{m}}^+ + u_{\text{m}}^- > 0 \\ \frac{P_{\text{load}}}{3(u_{\text{n}})^2} \left( u_{\text{n}}^+ + u_{\text{n}}^- \right) & \text{if } u_{\text{n}}^+ + u_{\text{n}}^- < 0 \end{cases} \]
EXAMPLE
MULTI-FUNCTIONAL INVERTER FOR GRID-CONNECTED PV SYSTEMS WITH LOAD COMPENSATION FUNCTIONS UNDER DISTORTED AND UNBALANCED GRID VOLTAGES

Experimental prototype at UIS:
EXPERIMENTAL RESULTS

PCC voltages:

Fundamental positive sequence component of the PCC voltaje:

Load currents:

Grid currents:

PF correction:
CONCLUSIONS

- The inclusion of new and advanced control functionalities to grid connected photovoltaic systems plays a vital role in modern power systems. These functionalities are focused on: mitigation of grid stability and reliability problems due to the high penetration of renewable energy systems, and power quality improvement.

- Reactive power support, active power limitation, voltage regulation, and advanced capabilities under grid faults (ride-through capabilities) are some of the actual requirements for grid-connected PV systems in some countries.

- The concept of virtual synchronous generator has evolved. Recent works propose to include advanced functionalities to the PV system to emulate the behavior of a synchronous generator in order to provide frequency support functionality and other grid supporting functions.

- Active power filtering functions as harmonic mitigation, power factor correction, and load balancing can be incorporated to PV inverters. These functionalities aim to improve power quality by reducing electric disturbances produced mainly by non-linear loads, the wide use of single-phase equipment, among others.
¡THANK YOU!
¡GRACIAS!

Contact:
María Alejandra Mantilla Villalobos
Email: marialem@uis.edu.co