Smart grids integration in ENEL Distribuzione distribution network

A. Cerretti, ENEL
ENEL Distribuzione SPA
Infrastructure & Network
Operation & Maintenance

Symposium
“SMART GRIDS: UN CAMBIO DI PARADIGMA PER LE RETI DI DISTRIBUZIONE DELL'ENERGIA ELETTRICA”

COLLEGIO DEGLI INGEGNERI DELLA PROVINCIA DI VENEZIA

ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI VENEZIA

2015-11-11 Venice

Enel Distribuzione

Outlines

- Impact of DER on transmission and distribution systems
- Evolution of the Standards: the EU level (CLC); the national level (CEI)
- Uncontrolled islanding detailed analysis
- Use of Interface Protection System (IPS) according to CEI 0-21 with a real-time Hardware In the Loop (HIL) simulation
- Effects of P/f operate times

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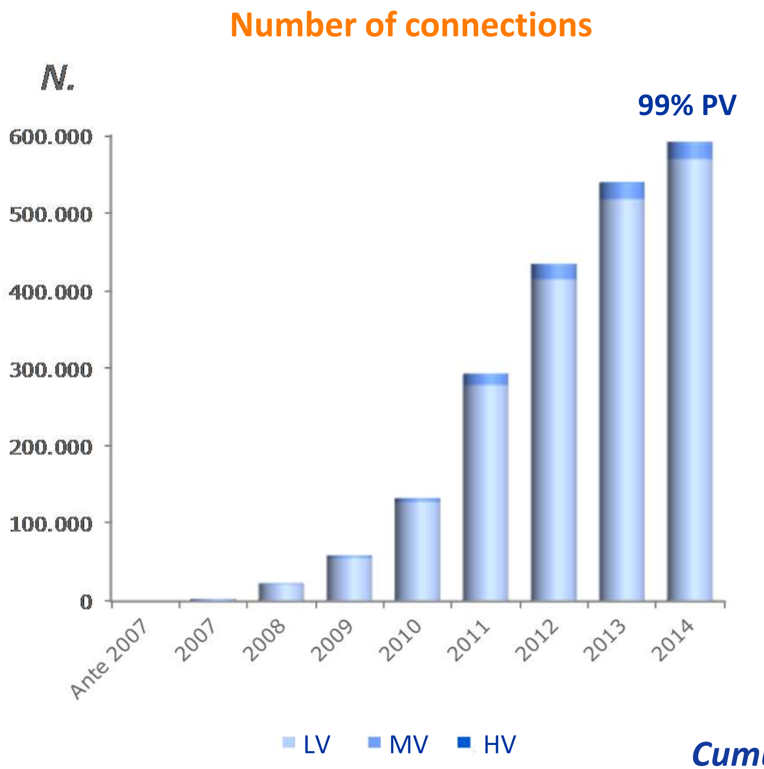
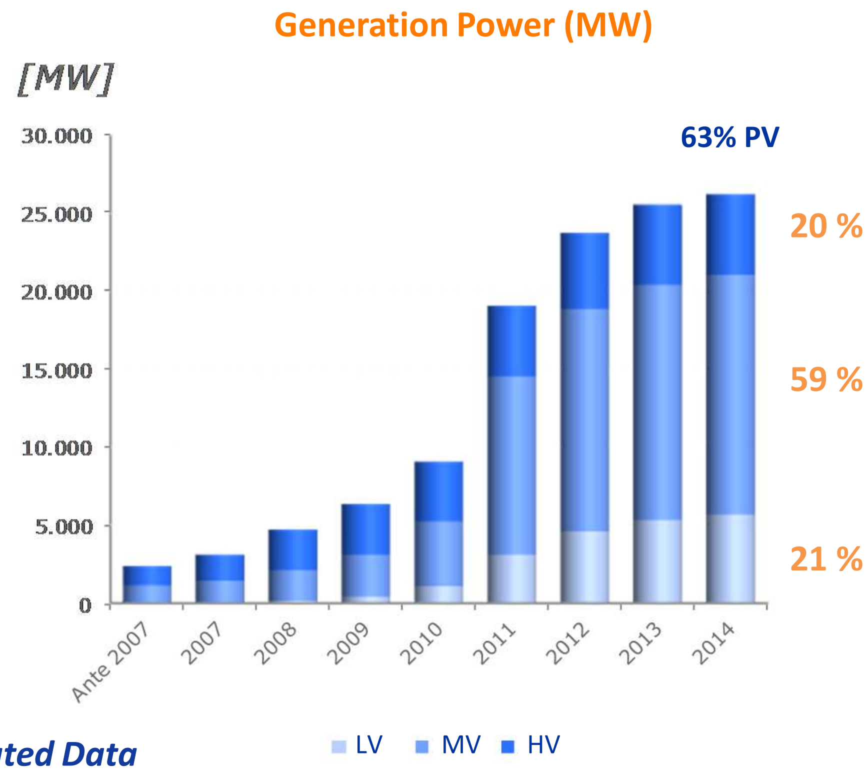
ENEL Distribuzione: GENERAL FIGURES

- ENEL Distribuzione network includes:
    - more than 350.000 km of MV lines
    - more than 780.000 km of LV lines
    - 2.100 HV/MV substation, 100% all remote controlled
    - more than 448.000 Secondary Stations (SS), out of which ~150.000 are part of the automation system currently in operation

- Starting from 2008, the number (and total rated power) of Dispersed Generators (DGs) connected to ENEL network has dramatically increased

Integration of renewables
Distributed Generation (DG) connections to distribution networks



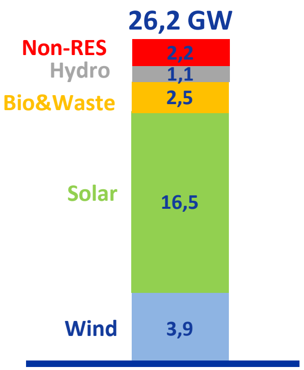


Cumulated Data

End 2014
~ 600.000 Prosumers
More than 26 GW installed capacity

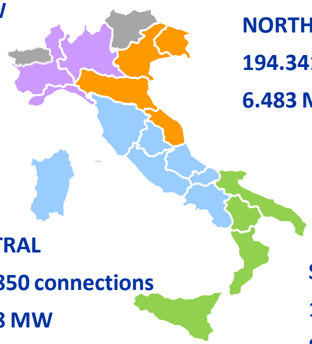
Integration of renewables
Distributed Generation (DG) connections to distribution networks

End 2014 situation – Number of connections and Total Installed Power (per year and cumulative)



DGS as 2014

NORTH-WEST
137.865 connections
5.551 MW



NORTH-EAST
194.341 connections
6.483 MW

CENTRAL
149.850 connections
6.178 MW

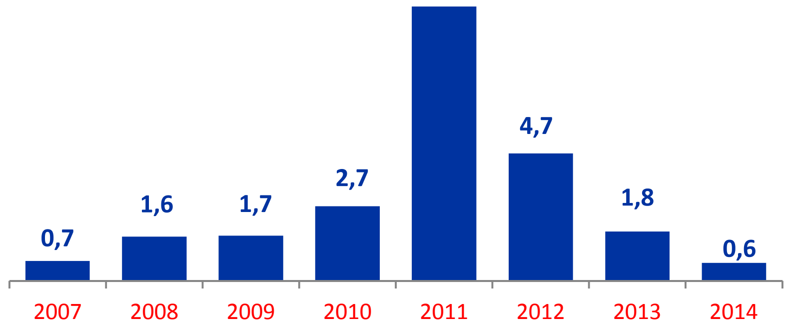
SOUTH
109.911 connections
8.028 MW

ITALY

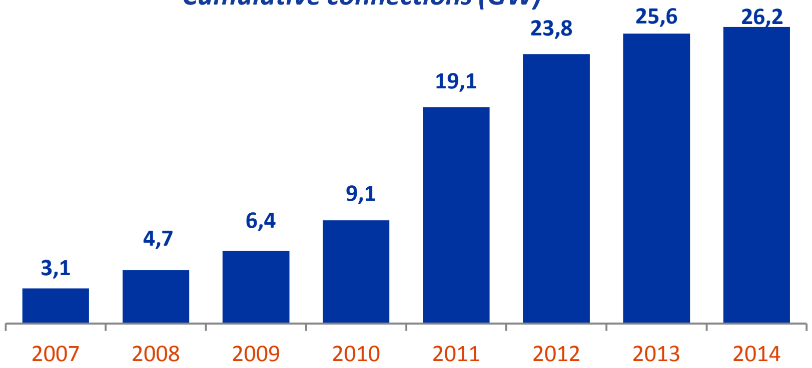
591.967 connections

26.240 MW

Connections per year (GW)

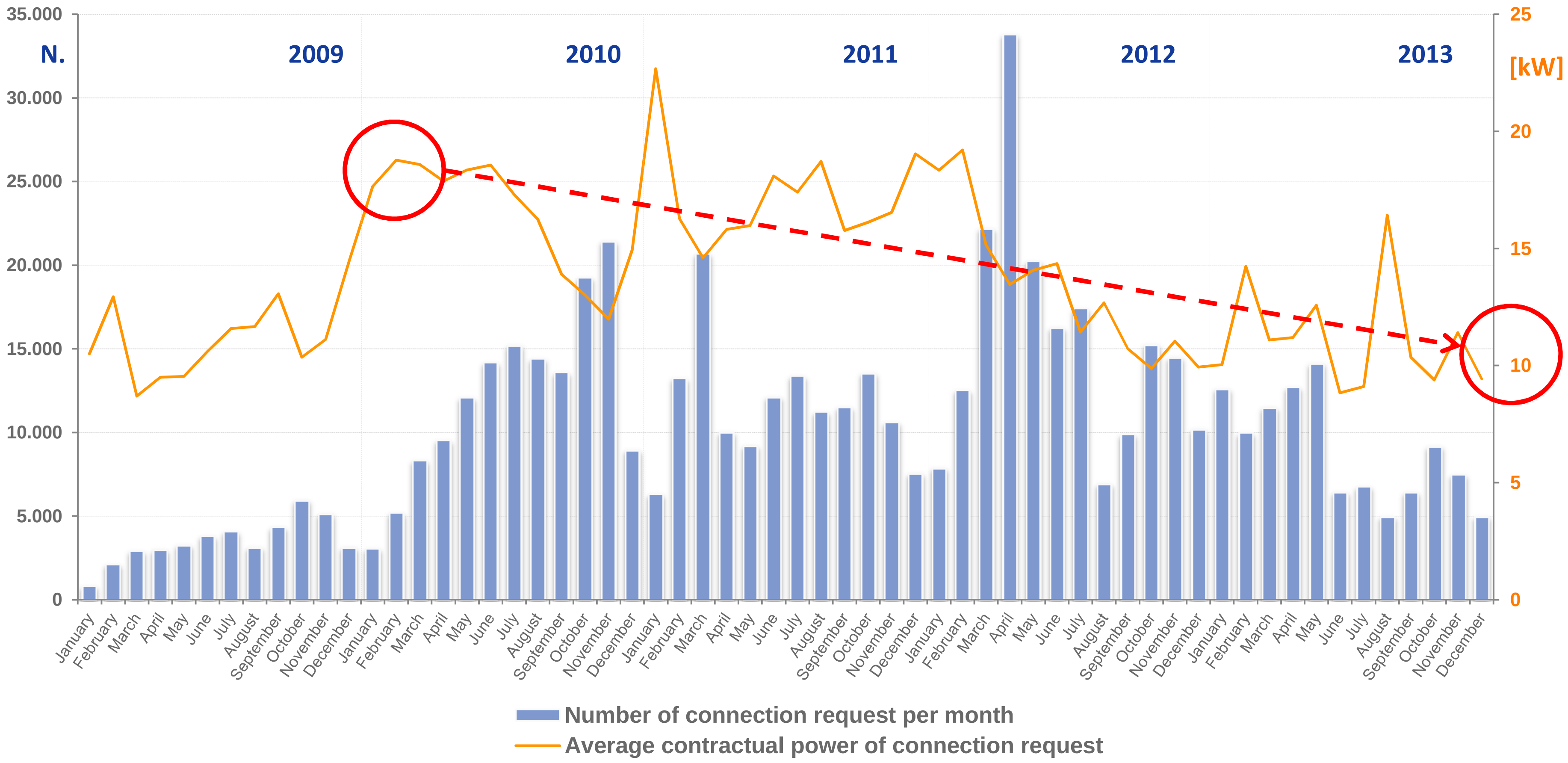


Cumulative connections (GW)



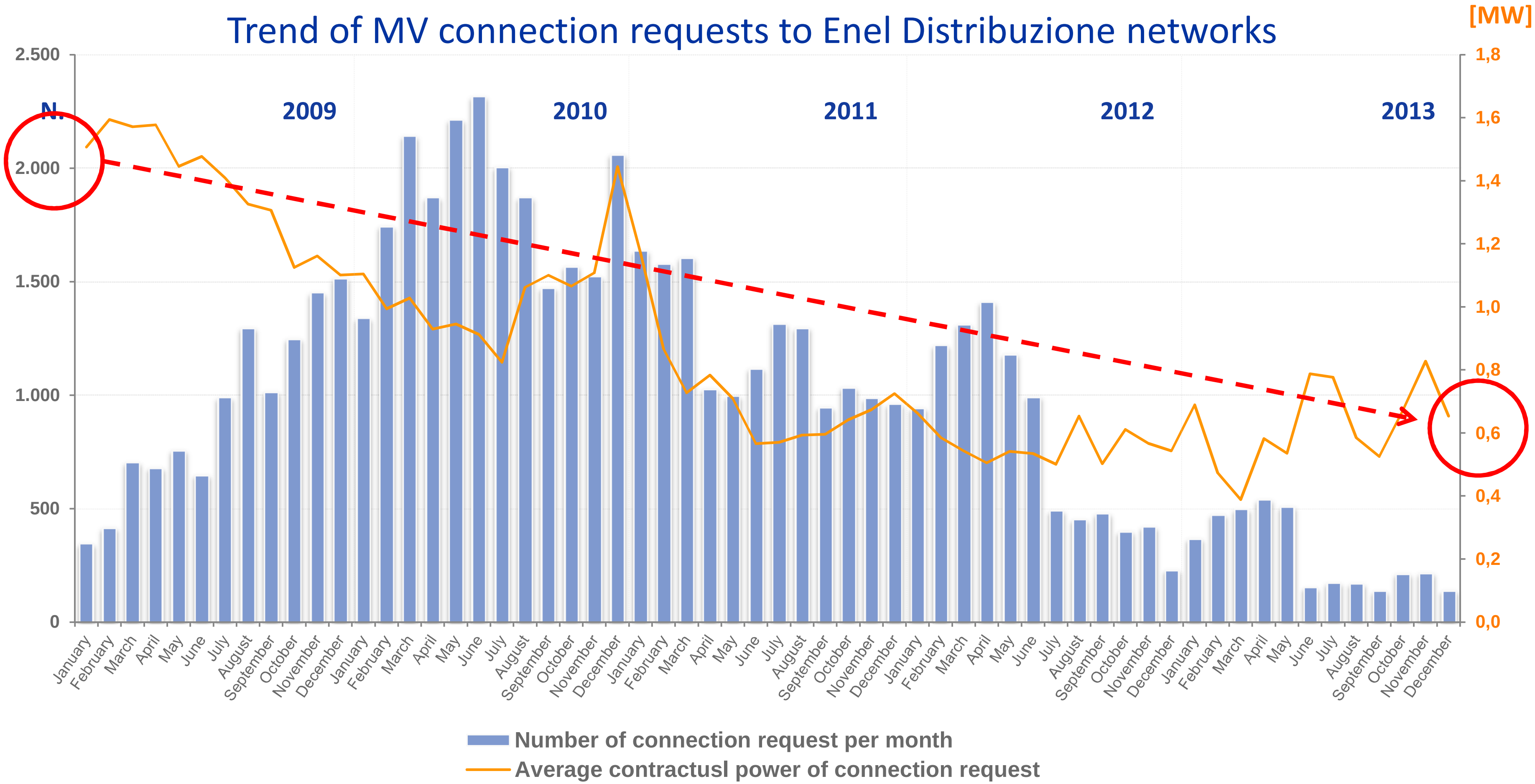
Integration of renewables
Distributed Generation (DG) connections to distribution networks

Trend of LV connection requests to Enel Distribuzione networks



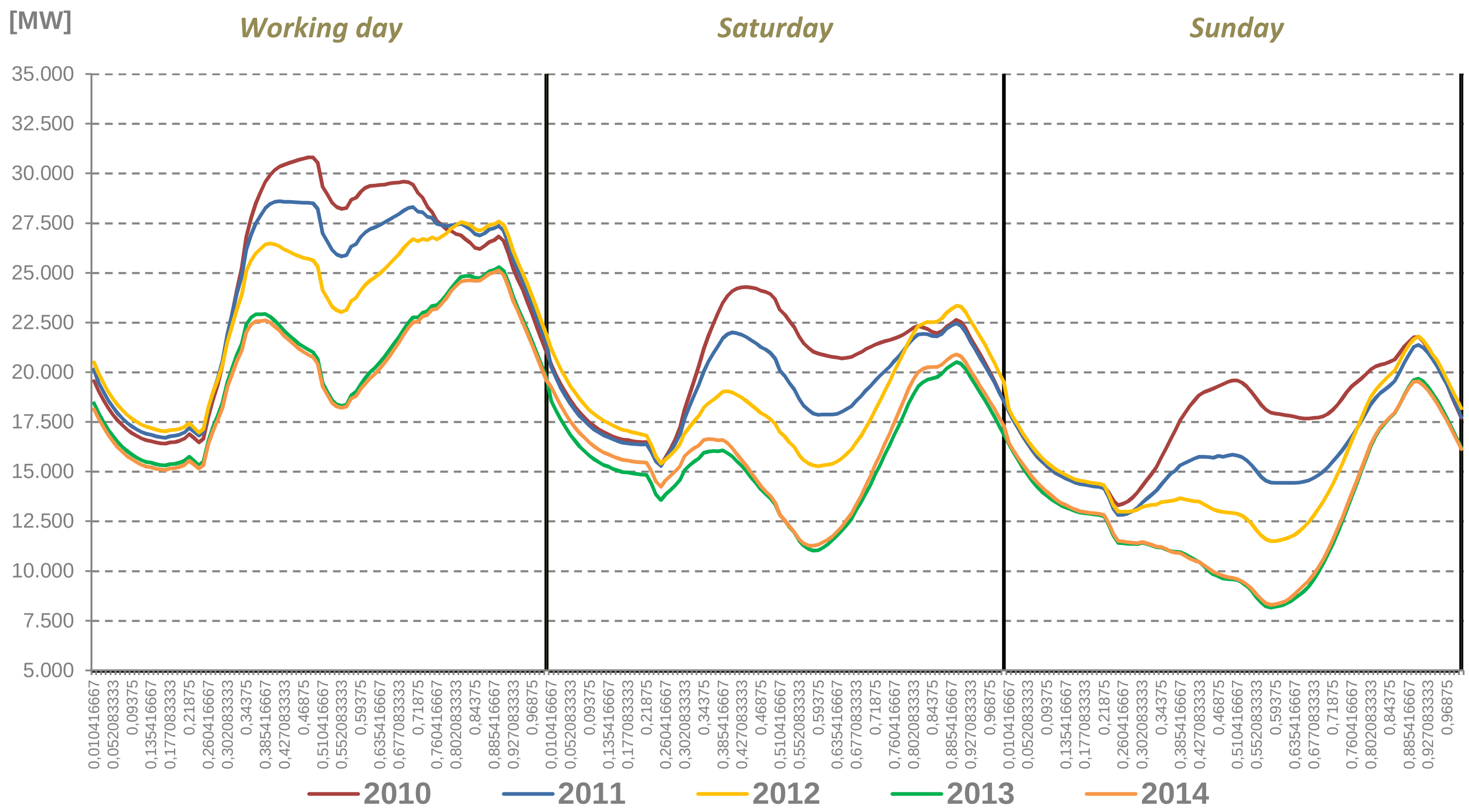
Integration of renewables
Distributed Generation (DG) connections to distribution networks

Trend of MV connection requests to Enel Distribuzione networks



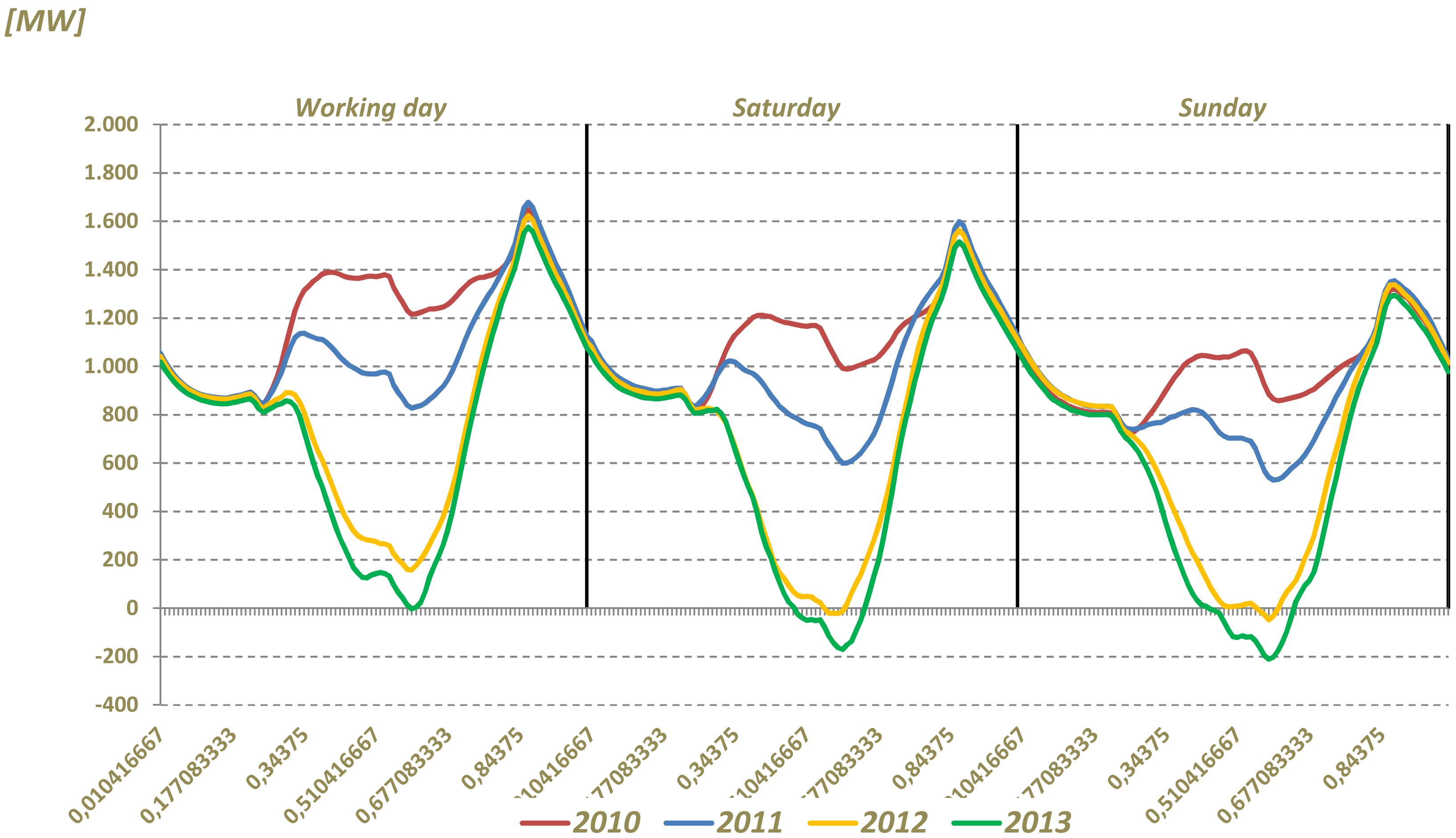
Effect of DG on Electric System

Active Power Flows from TSO network → ENEL DISTRIBUZIONE network – Giugno 2014, Italy



Effect of DG on Electric System

Active Power Flows from TSO network → ENEL DISTRIBUZIONE network – Region Puglia, South-estern part of Italy

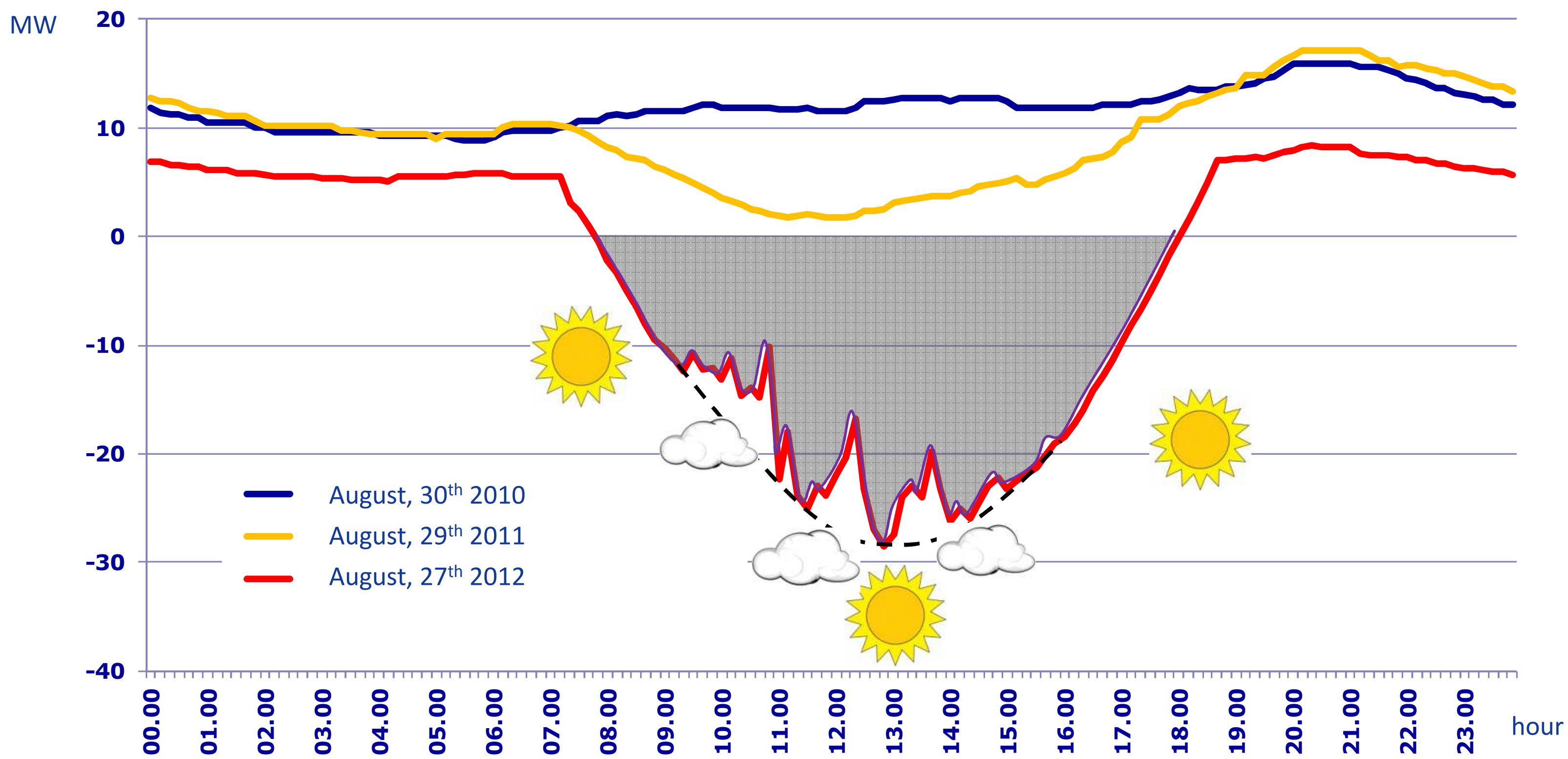


USE: Public
ENEL DISTRIBUZIONE

Effect of DG on Electric System

Load profile of a HV/MV substation day vs. night

HV/MV Transformation Station "Ginosa" - Puglia

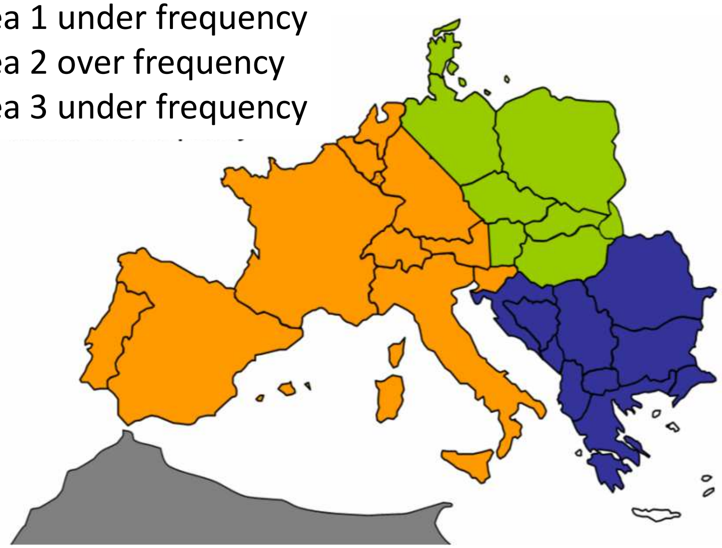


DG dispatching will be key to address future challenges through Smart Grids technologies

Impact of DER on transmission system

FREQUENCY ISSUES: effect of massive DER disconnection

- Area 1 under frequency
- Area 2 over frequency
- Area 3 under frequency



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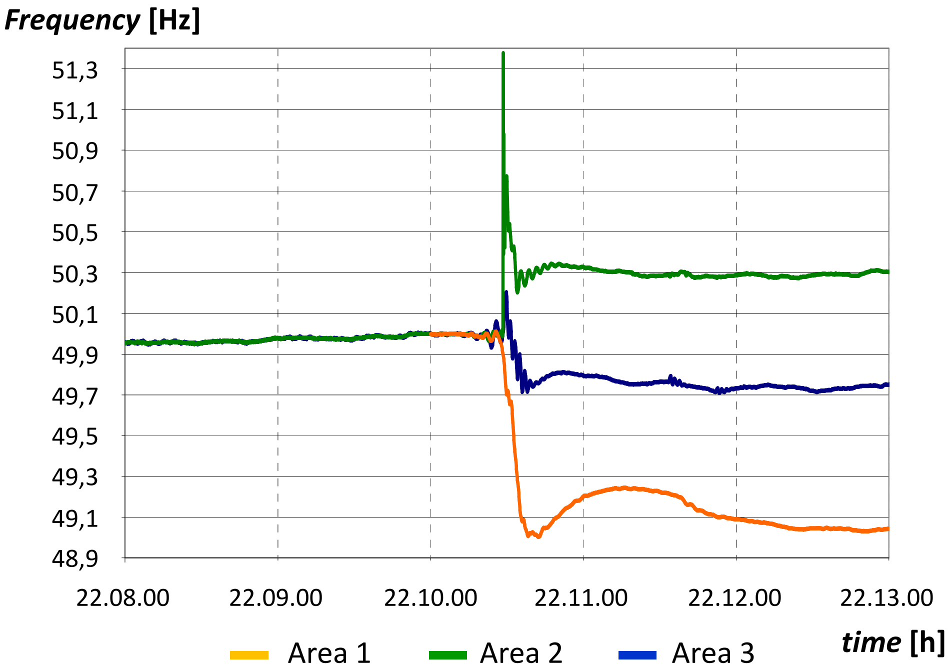
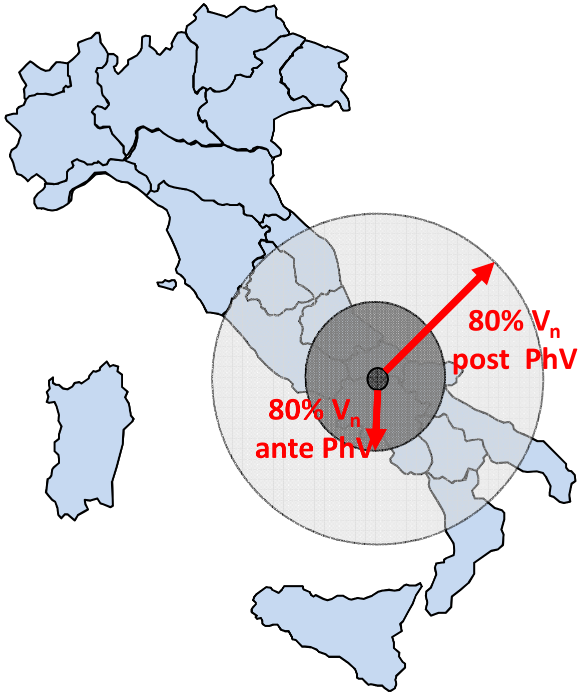
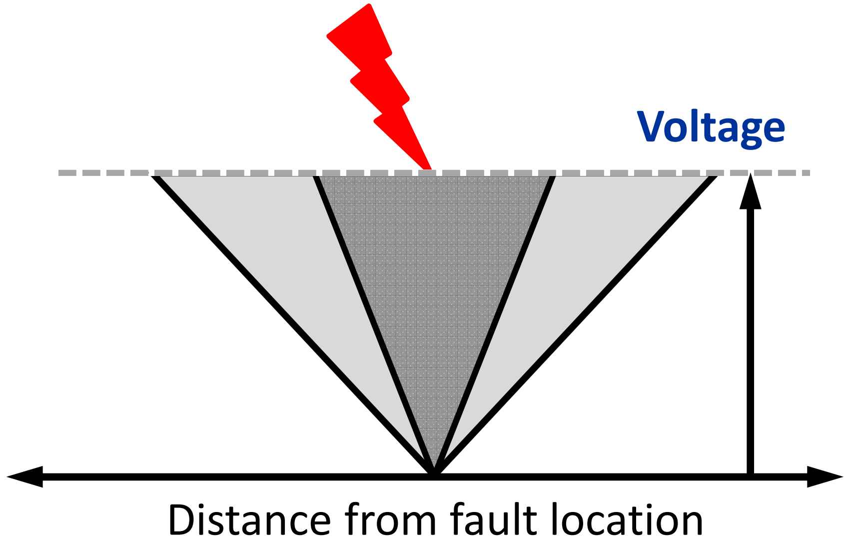


Impact of DER on transmission system

TSOs VOLTAGE ISSUES: Effects of a short circuit in the 380 kV network

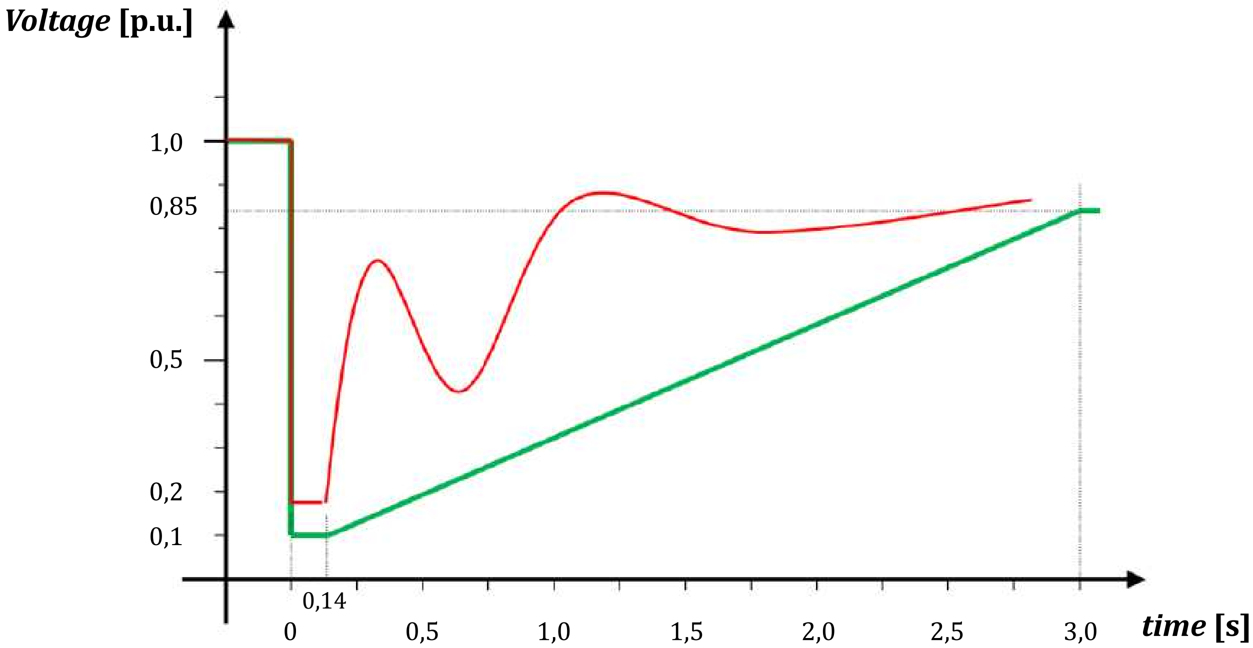




Hypothesis: DER uniformly distributed

Impact of DER on transmission system

IMMUNITY TO UNDERVOLTAGES (LVRT): Effects of a short circuit located on the 380 kV transmission network



Red curve: recovery voltage after a short circuit

Green curve: voltage/time profile of the LVRT curve

Impact of DER on distribution system

VOLTAGE ISSUES

- The presence of DG along the MV lines could increase the voltage at the POC much beyond the levels allowed from EN 50160 Standard.

- In order to comply with the above limits even when there are huge DG units:
  - GD units must be cut off from the network (by 59.S2 setting of the IPRs) when voltage levels are higher than 120% Un for more than 0,2 s;
  - GD units must be cut off from the network within 3 s (by 59.S1 setting of the IPRs) when the average level of measured voltage over a time period of 10 min in moving average mode exceeds 110% Un;
  - in addition to the cut-off function, **<u>TO AVOID DG DISCONNECTION</u>**, when voltage levels are close to the 110% Un, the DER GUs must contribute to limiting the voltage value at the POC by injecting/absorbing reactive power (possibly also reducing active power on LV network), according to different control laws.

Impact of DER on distribution system

VOLTAGE ISSUES

- Voltage regulation may be implemented:
  - automatically, according to cos φ = f(P) curve;
  - automatically, according to Q = f(V) curve;
  - by external command by the DSO.

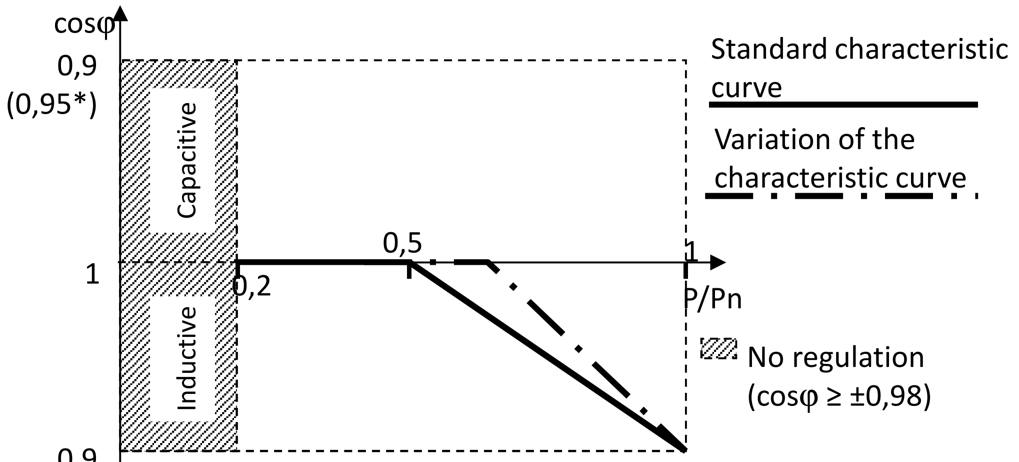
- In the first two laws, a simplified control strategy is adopted:
  - each generator operates without coordination with other generators or network devices (local voltage control);
  - when a particular voltage threshold is reached (e.g. 1.08 Vn), DER Gus are controlled to absorb reactive power;
  - if this action is not enough it is also possible to curtail the injection of DER GUs active power.

- In the third law, the control actions of each DG unit will be coordinated at a centralized level

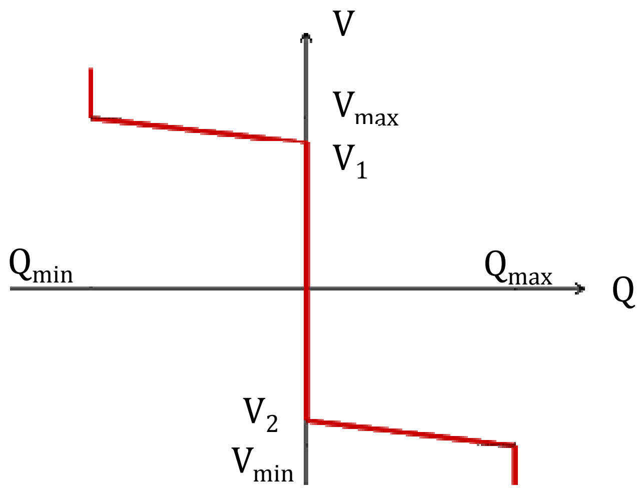
Impact of DER on distribution system

VOLTAGE ISSUES

- This method encompasses two conditions:
  - a normal operating situation, where no control action is required
  - a situation where voltage thresholds (V1 and V2) are violated:
    - DG operates at a variable PF injecting/absorbing reactive power from the network according to the local voltage, if voltage limits are reached;
    - DG operates at a variable PF, injecting/absorbing reactive power, according to the injection of DG active power



(*) cosφ_max depends on the total installed power (0,95 before 6kW, 0,90 after 6kW)



possible voltage control laws

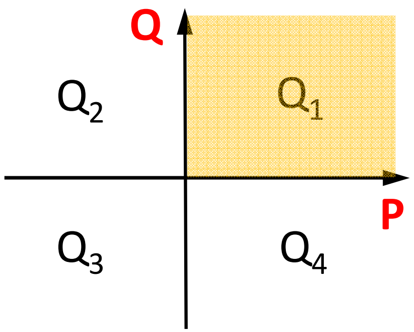
Impact of DER on distribution system
ACTIVE LOSSES INCREASE ISSUES

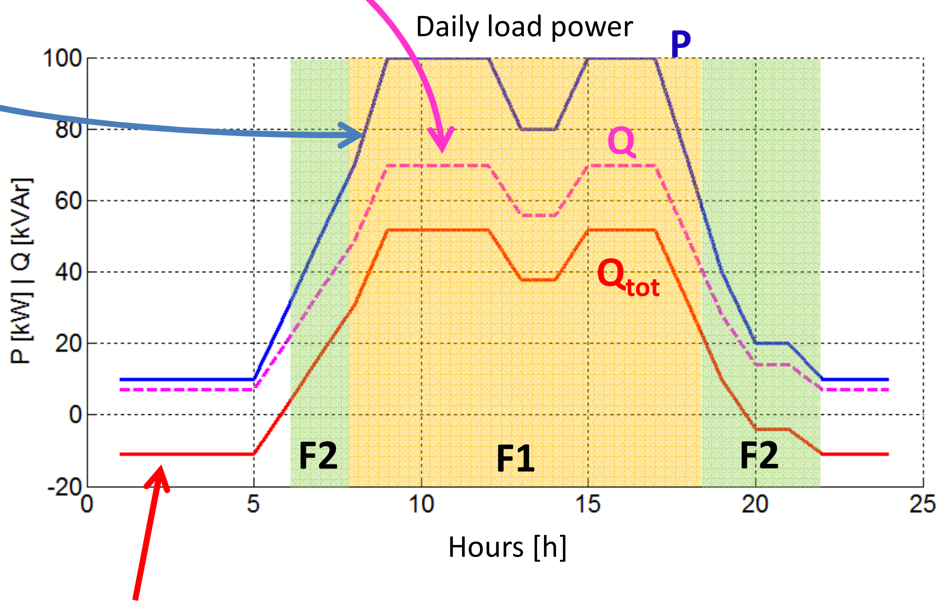
Active losses increase issue in distribution networks due to the combination of DER units and constraint of having a fixed power factor (average calculated - $\cos\varphi_{mean}$) at the **P**oint **O**f **C**onnection

Case 1) : Passive User $\cos\varphi_{mean}$ 100 kW plant

$$\cos\varphi_{\mathbf{mean\_F1}} = \cos\left[atan\left(\frac{E_{r\,Q1}}{E_{a\,Q1}}\right)\right]$$

Calculated only for positive Q_1 and during the F1 hours



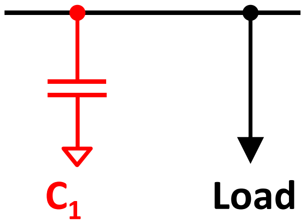


Total Reactive Power – with fixed capacitor bank

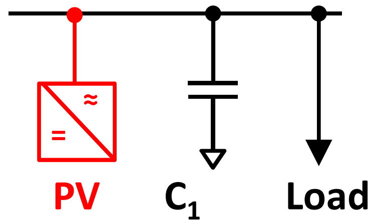
Impact of DER on distribution system

ACTIVE LOSSES INCREASE ISSUES

Step 1)
Passive user with capacitor bank in order to have $\cos\varphi_{mean}$ = 0.9 lagging

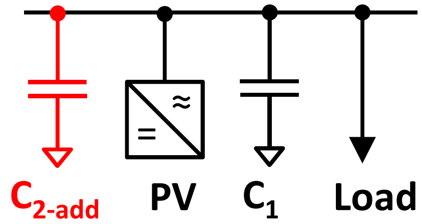


Step 2)
User instals local generation ($P_{G\,max} = P_{L\,max}$)



$\cos\varphi_{mean} \sim 0$

Step 3)
User instals an additional capacitor bank



$\cos\varphi_{mean}$ = 0.9
if PV generates, is highly leading during night

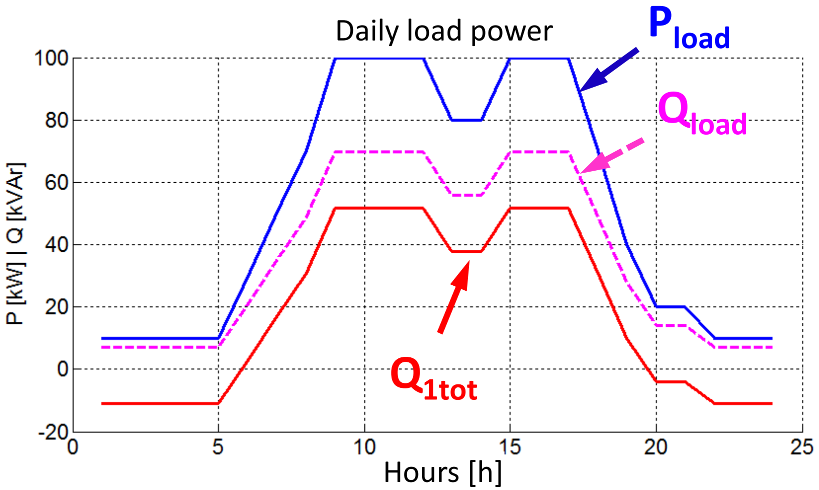
The additional capacitor bank C2 reduces the reactive power flow during the F1 hours (when PV generates), while the other hours of the day the reactive power flow of step 3 is higher in value than in step 1, and also with opposite sign (Q from user's plant to distribution network).

Investigation on network losses between step 2 and 3

Impact of DER on distribution system
ACTIVE LOSSES INCREASE ISSUES

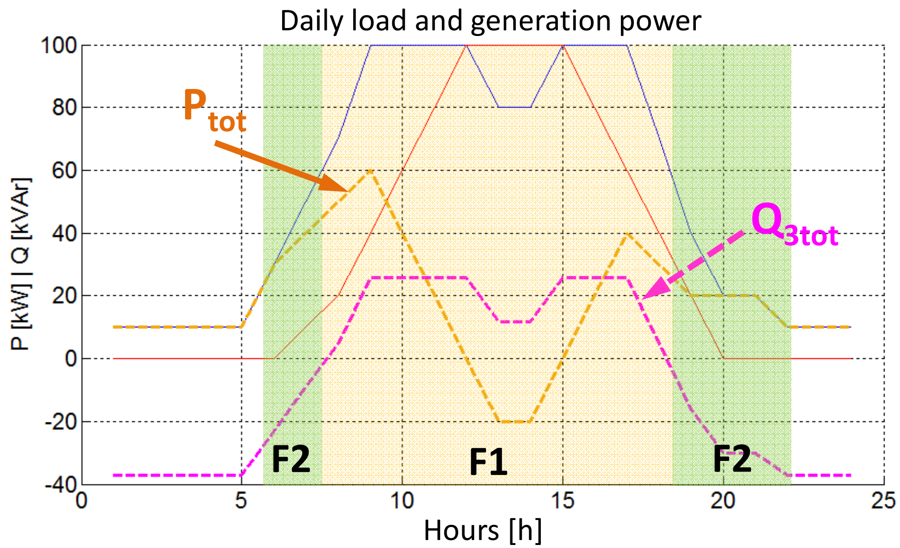
Step1)

P_load
Q_load (cosφ $_{mF1}$ = 0,82)
Q_1tot (additional capacitor bank to obtain cosφ $_{mF1}$ = 0,9)



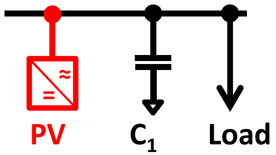
Step 3)

Case 1) with generation has:
P_tot = P_load - P_gen
cosφ $_{mF1}$ = 0,4885
cosφ $_{mF2}$ = 0, 9986
Q_3tot (need of additional capacitor bank to obtain cosφ $_{mF1}$ = 0,9)
During F1 hours, cosφ is leading !



Impact of DER on distribution system
ACTIVE LOSSES INCREASE ISSUES

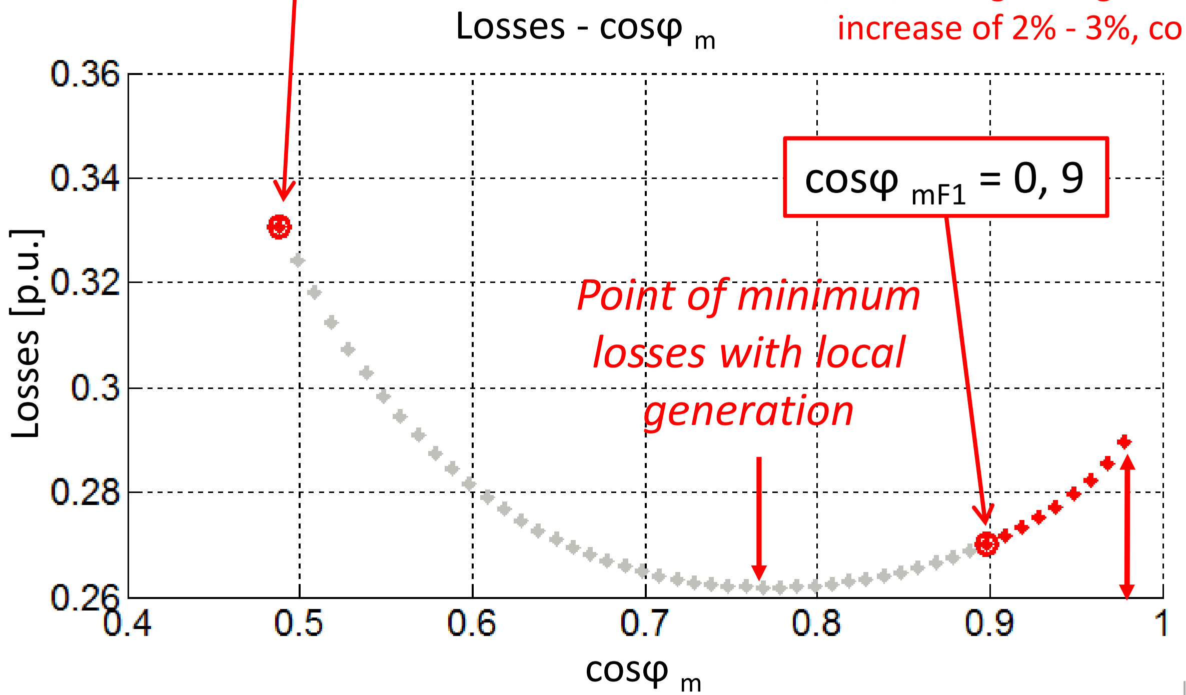
Step 3: losses behavior function of cosφ $_{mean}$ in presence of generation

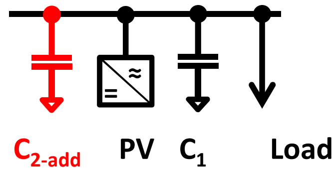


cosφ $_{mF1}$ = 0,4885
cosφ $_{mF2}$ = 0, 9986

Losses are referred to those of case 1
(cosφ $_{mF1}$ = 0,9 without generation)

In the example, losses may decrease down to 26% of case 1, but, asking for high fixed values of cosφ$_m$, may increase of 2% - 3%, completely useless





Useless losses due to the rule of fixed cos φ$_m$ with local generation

Impact of DER on distribution system
ACTIVE LOSSES INCREASE ISSUES

Case 2) : $\cos\varphi_m$ related losses evaluation according to generation variation during the year

a) Load and Generation power curves as in Case 1 (Step 3), i.e. $P_{G\,max} = P_{L\,max}$;
b) Load power curves as in Case 1 (Step 1), but with double active power generation, i.e. $P_{G\,max} = 2 \cdot P_{L\,max}$;

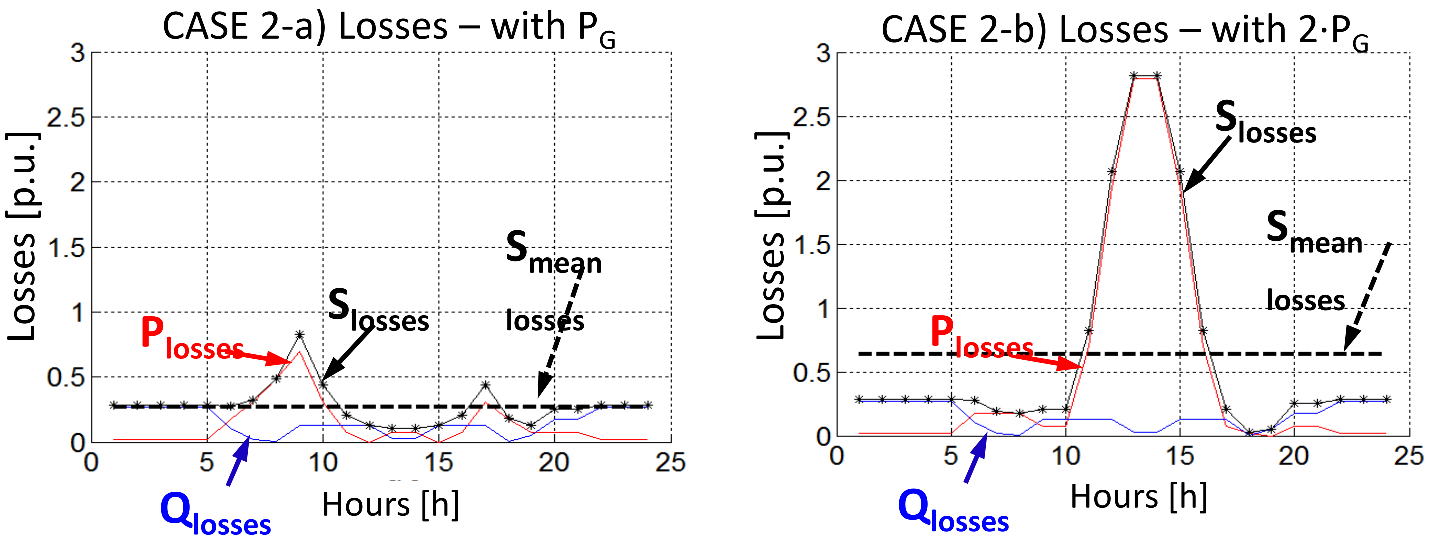
The $\cos\varphi_{mean}$ is lower in condition a), therefor the capacitor bank is designed for this situation.

Condition b) implies a further over sized reactive power flow, therefore an important increase of useless losses.

Impact of DER on distribution system
ACTIVE LOSSES INCREASE ISSUES

Enel Distribuzione

Daily losses Daily losses (in p.u. refered to Case 1-step 1) during condition a) and b) during condition a) and b)

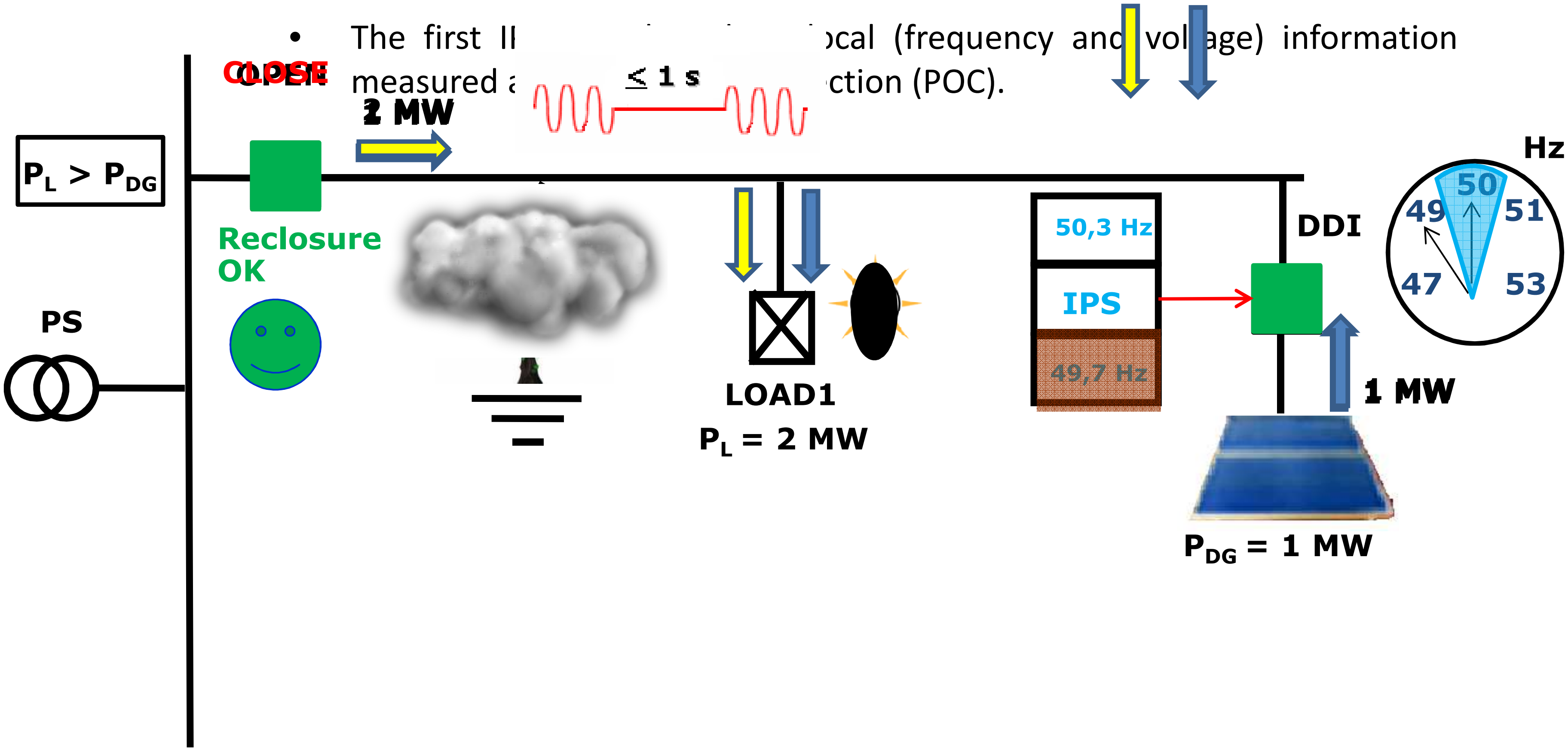


P_{losses} : losses associated to active power
Q_{losses} : losses associated to ractive power
S_{losses} : losses associated to current module

The losses mean value is increased due the presence of generation
Note: the curves of generation and load power influence the losses behavior

Impact of DER on distribution system

UNCONTROLLED ISLANDING: behavior and limits of IPRs based on local information. **NO UNCONTROLLED ISLANDING !**



Impact of DER on distribution system

UNCONTROLLED ISLANDING: behavior and limits of IPRs based on local information

- The increasing DER penetration, up to values similar to loads, in combination with new requirements for DER GUs, will lead to a higher possibility of local balance for line trip. This will leave voltage/frequency very close to the nominal values, causing unwanted islanding.

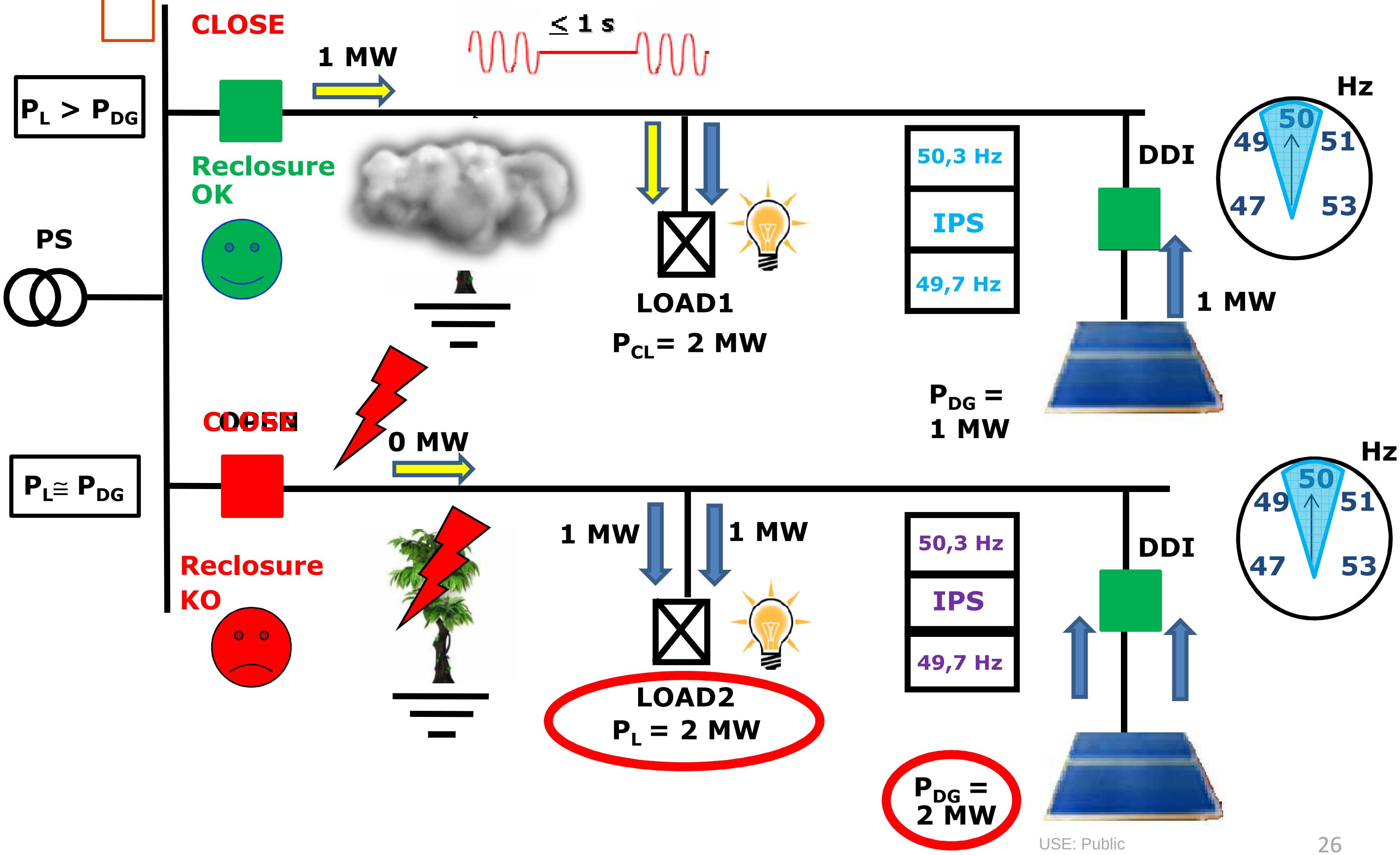
- During the islanding operation a portion of the distribution network (which is isolated from the main system) is energized by the DER GPs connected.

- If the production and consumption within the island find an equilibrium point, the islanding operation can become permanent, whilst in case of significant unbalance between load and generation, the island usually collapses (after a temporary islanding transient).

- In this case a Non Detective Zone (NDZ) appears; it indicates the limited reliability of the IPRs in case of islanding.

Impact of DER on distribution system

UNCONTROLLED ISLANDING: behavior and limits of IPRs based on local information. **UNCONTROLLED ISLANDING !**



Impact of DER on distribution system

UNCONTROLLED ISLANDING: behavior and limits of IPRs based on local information.

Uncontrolled islanding issues:

- Islanding operation is considered as an unwanted event for the points listed below.
  - Power quality: DSO is not able to maintain the power quality in the island according to the standards. The fault levels may be too low, so the overcurrent protections won't operate the way they are designed.
  - Safety 1: in case of intentional or accidental islanding, the utility personnel may be unaware that the portion of the network is still energized by DG.
  - Safety 2: in case of intentional or accidental islanding, no correctly coordinated protection system against overcurrents and earth faults is present on the island (fire hazards, admissible touch and step voltage, etc).
  - Automatic reclosing bad operation 1: DER GUs may sustain fault current during fast autoreclosure open time preventing possible self arc extinction.

Impact of DER on distribution system

UNCONTROLLED ISLANDING: behavior and limits of IPRs based on local information

- **Uncontrolled islanding issues:**
  - Automatic reclosing bad operation 2: automatic reclosing may cause damages to equipment (DSOs CBs and/or switches performing reclosing actions, rotating generators and prime movers) during out of phase (counterphase) reconnection between island and the rest of the system. On DSOs networks synchro-check devices and single phase reclosing operations are not adopted.
  - Failure of MV network automation: generators sustain voltage in the feeder, therefore network automation is not able to select the faulted section of a MV feeder.

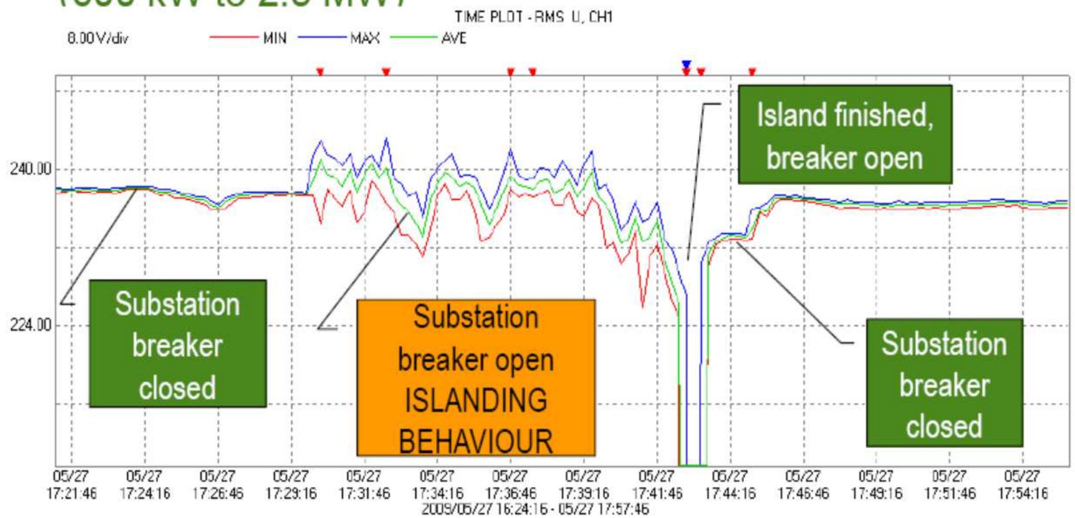
Impact of DER on distribution system

Uncontrolled island happened in Spain caused by PV inverters

FAILURE OF ANTI-ISLANDING PROTECTIONS IN LARGE PV PLANTS

IBERDROLA

- In both cases long duration islands have been reproduced (600 kW to 2.5 MW)



13 minutes island (intentionally finished, so it could be longer)

2 PV plants, 3 inverter manufacturers, 2.5 MW.

Pg. 2

CIRED 8 - 11 June | PRAGUE 2009

Recent measurements
fj.pazos@iberdrola.es

UNCONTROLLED ISLANDING: capability of PV inverters to sustain the island

Impact of DER on distribution system

Uncontrolled island happened in Spain caused by PV inverters

Enel Distribuzione

Field tests in Iberdrola

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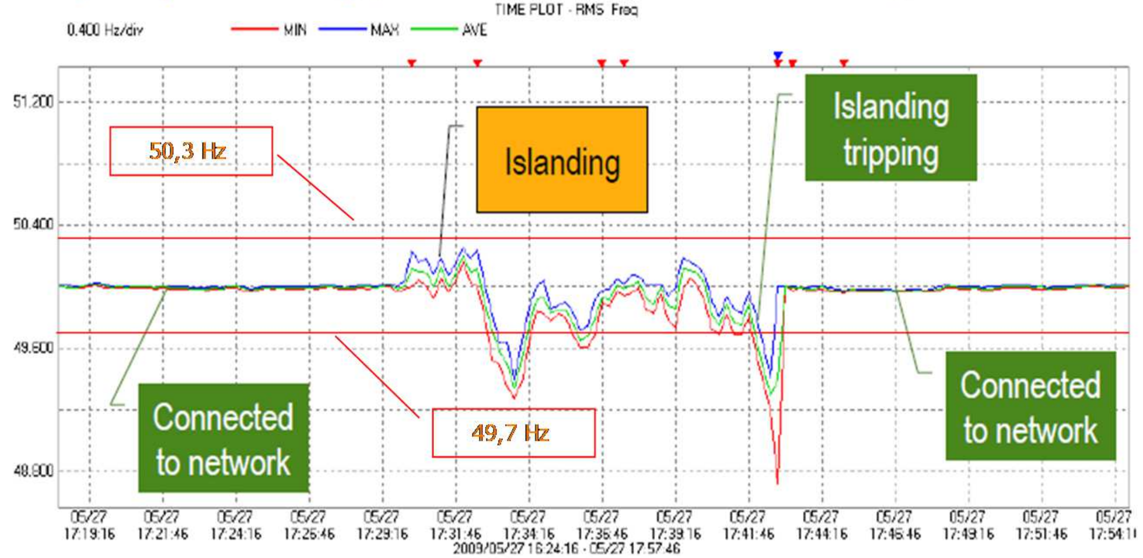
Islanding tests

- Islanding behaviour is more unstable than connected to network, but voltage, distortion, unbalance magnitudes remain within normal limits.
  - 2.5 MW islanding during 13 minutes *(intentionally tripped, could be longer)*

With “narrow frequency window” uncontrolled islanding would be avoided.

Frequency: fluctuating (difference between max. and min. values), but within limits



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UNCONTROLLED ISLANDING: capability of PV inverters to sustain the island

Outlines

- Impact of DER on transmission and distribution systems
- Evolution of the Standards: the EU level (CLC); the national level (CEI)
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- Use of Interface Protection System (IPS) according to CEI 0-21 with a real-time Hardware In the Loop (HIL) simulation
- Effects of P/f operate times

New requirements for DER operation

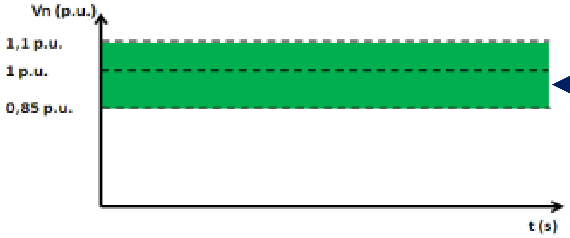
Mainly defined from TSOs for security of the electric transmission system. With reference to Italy included in:

- RfG Grid Code (from ENTSOE); approved from EC, it's implementation it's up to National TSOs;

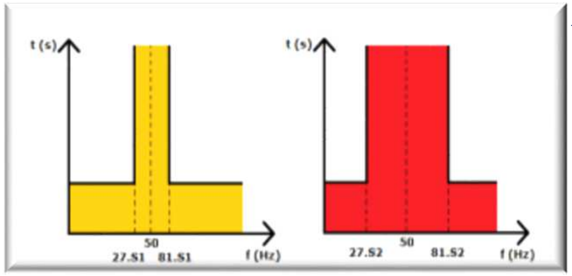
- Annex A70 to Italian Grid Code (introduces most of RfG requirements on new DER generators and also requires most important ones, in agreement with national Regulator, though a wide retrofit plan already completed, on existing GUs MV connected over 50 kW and on course, below 50 kW);

- Italian Standards CEI 0-16 and 0-21, EN 50438, TS 50549-1 & 2 (besides RfG/A70 requirements, also DSOs needs are considered, mainly voltage related issues)

New requirements for DER operation



Voltage normal operating range (GU capability) (TSOs)
85% ÷ 110% Vn permanently at Point of Connection



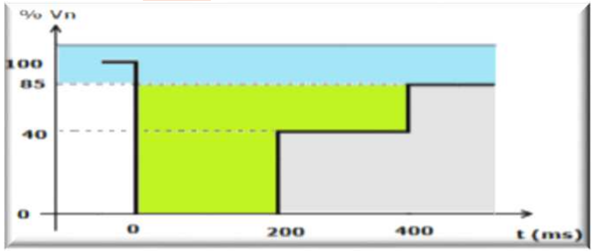
Frequency normal operating range (GUs capability) (TSOs)
47,5 Hz ÷ 51,5 Hz permanently (static GUs)

Two alternative frequency window regulations on IPR (DSOs, Italian solution):

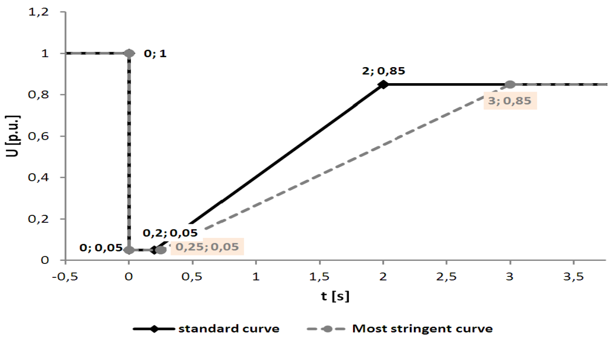
- High sensitivity setting: 49,7 ÷ 50,3 Hz (49,8 ÷ 50,2 Hz), operating time 100 ms (faults on distribution)
- Low sensitivity setting: 47,5 Hz, 4 s ÷ 51,5 Hz, 1 s (perturbancies on trasmission)

Limited Frequency Sensitive Mode-Overfrequency (TSOs)
For all generators, possibility of local activation/deactivation.

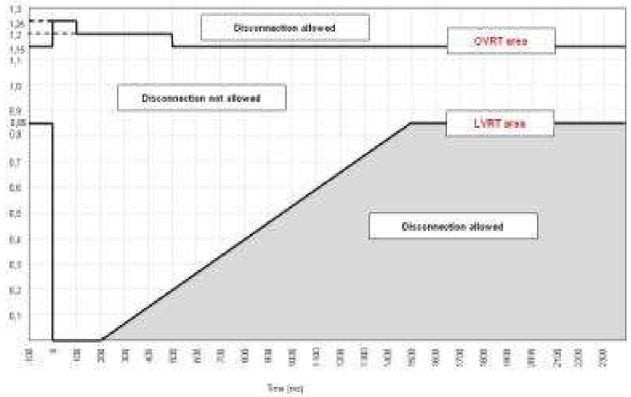
New requirements for DER operation

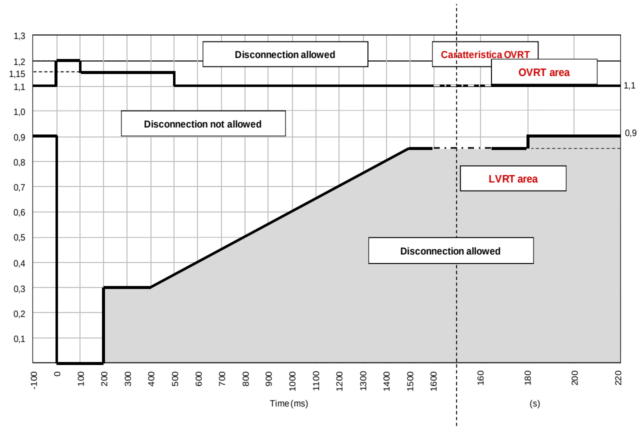


Low Voltage Fault Ride Through capability (TSOs)
Italian profile for LV connected inverters over 6 kVA plant rated power



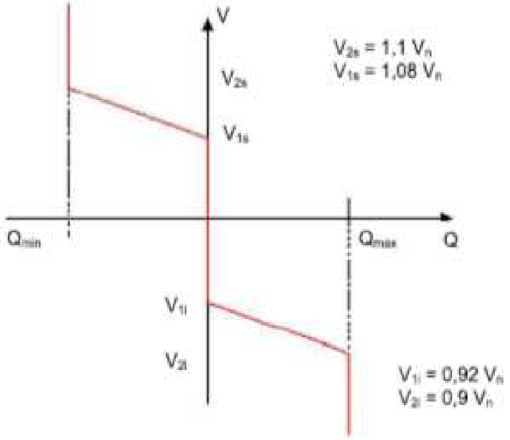
Low Voltage Fault Ride Through capability (TSOs)
For inverter based generators, according to TS-50549-2 and to Italian Standard CEI 0-16 (MV connected)





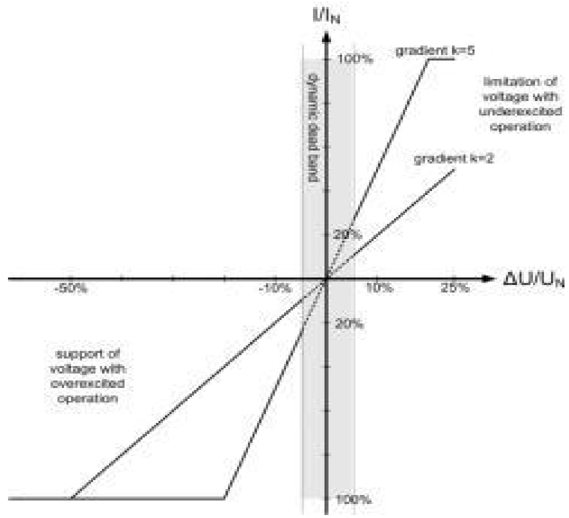
Low Voltage Fault Ride Through capability (TSOs)
For wind turbines, according to TS-50549-2 and to Italian Standard CEI 0-16 (MV connected)

New requirements for DER operation



Reactive power/voltage droop (DSOs)
One of different Q(V) functions according to Italian Standards

Voltage support during faults and voltage steps (TSOs)
Not yet considered in Italian Standards, neither in simulations (full power test bed and HIL one)



Synthetic inertia (TSOs)
Not yet considered in Italian Standards, neither in simulations (full power test bed and HIL one), being not even clearly defined

The six features, combined together, result in an important increase of uncontrolled island operation of parts of distribution networks

Main new elements in latest RfG version

Article 3
Scope of application

1. The connection requirements set out in this Regulation shall apply to new power generating modules which are considered significant in accordance with Article 5, unless otherwise provided.

   The relevant system operator shall refuse to allow the connection of a power generating module which does not comply with the requirements set out in this Regulation and which is not covered by a derogation granted by the regulatory authority, or other authority where applicable in a Member State pursuant to Article 60. The relevant system operator shall communicate such refusal, by means of a reasoned statement in writing, to the power generating facility owner and, unless specified otherwise by the regulatory authority, to the regulatory authority.

2. This Regulation shall not apply to:

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(a) power generating modules connected to the transmission system and distribution systems, or to parts of the transmission system~~,~~ or distribution systems, of ~~a~~islands of Member ~~State~~States of which the systems are not operated synchronously with either the Continental Europe, Great Britain, Nordic, Ireland and Northern Ireland or Baltic synchronous area;

(b) power generating modules that were installed to provide back-up power and operate in parallel with the system for less than five minutes per calendar month while the system is in normal system state. Parallel operation during maintenance or commissioning tests of that power generating module shall not count towards the five minute limit;

(c) power generating modules that do not have a permanent connection point and are used by the system operators to temporarily provide power when normal system capacity is partly or completely unavailable;

(d) storage devices except for pump-storage power generating modules in accordance with paragraph 2 of Article 6.

RfG, article 3.2.(d):
how are battery based storages to be considered?

From electric system point of view, for sure they are generators, despite what is written in RfG !

Main new elements in latest RfG version

Article 11
Stakeholder involvement

The Agency, in close cooperation with the ENTSO for Electricity, shall organise stakeholder involvement regarding the requirements for grid connection of power generating facilities, and other aspects of the implementation of this Regulation. This shall include regular meetings with stakeholders to identify problems and propose improvements notably related to the requirements for grid connection of power generating facilities.

RfG, article 11:
How to deal the implementation of RfG (EC Regulation) at National level, expecially where proper TCs in charge of defining Generating Units/Generating Plants requirements are existing?

In Italy, what will be the future role of CT 316, appointed from National Regulator AEEGSI, to define this?

Have all the stakeholders to be considered of the same level, despite DSO are in charge of construction, operation and maintenace of the largest part of the electric system and that, to distribution networks, a relevant percentage of total generation is present (more than 26 GW in Italy, close to 50% of total power peak demand) ?

Outlines

- Impact of DER on transmission and distribution systems
- Evolution of the Standards: the EU level (CLC); the national level (CEI)
- Uncontrolled islanding detailed analysis:
  in cooperation with: Università degli studi di Padova
- Use of Interface Protection System (IPS) according to CEI 0-21 with a real-time Hardware In the Loop (HIL) simulation
- Effects of P/f operate times

Uncontrolled islanding detailed analysis

As a consequence of a Regulation Order of Italian National Regulator (AEEG), in 2013 ENEL started a detailed study on:

- Islanding possibility sustained from DER at MV and/or LV level;
- Effects on islanding of new requirements for DER operation;
- Consequence of islanding (damages to appliances, generators, CBs and/or switch disconnectors, both MV and LV, absence of a coordinate protection system on islands, both for apparatus/plants and human safety, etc.
- Evaluation of islanding probability;
- Definition and effectiveness evaluation of possible countermeasures

End of the main part of the study at beginning 2014. A dedicated workshop to show the results of the study was organized and held held in ENEL premises, Rome, 14th April 2014.

Further analysis have been perfomed after the workshop and are still on course.

Uncontrolled islanding detailed analysis

STUDY SET UP

1. set up of proper consultancy contracts from **ENEL** to define a correct, up to date and complete PhV inverter model to be used for simulations;

2. involvement of main Manufacturers to have data about MV and LV CBs/switch disconnectors, generators, prime movers, mainly their capabilities to face counterphase reclosing operation. In case of generators, all the models for voltage/frequency regulators, were supplied and inserted in the simulation models together with new inverters models. Manufacturers produced a list of relevant parameters to be obtained from the simulations necessary to assess the capability to withstand conterphase reclosing operations;

3. involvement of **National Regulator** as an **OBSERVER**, to assess the neutrality of the study.

Uncontrolled islanding detailed analysis

Agenda of the ENEL Workshop on UNCONTROLLED ISLANDING 2014.04.14

Uncontrolled islanding

13.30	Introduction – Dr. Eng F. Amadei
14.00	Evolution of Standards and of RER requirements general framework. Impacts on the operation of electric distribution networks – Dr. Eng. A. Cerretti
14.30	Main results of the study performed from ENEL/CESI – Dr. Eng. E. De Berardinis
15.00	Main results of the study performed from University of Padua – Proff. Mattavelli & Turri
16.30	Lesson Learned e future trends – Dr. Eng. F. Amadei/ Dr. Eng. A. Cerretti
17.30	Q & A.

Unintentional islanding
Rome, 14th Aprril 2014

USE: Enel Distribuzione 2

New results from:

proceedings of islanding detailed analysis with full power and HIL test beds

evolution of the Standards and Grid Codes

From the Workshop held in 2015-04-14, other/new items/issues have been or still have to be investigated. In particular:

1. Real Interface Protection Systems behavior and consistency assessment with analytical calculated NDZs adopting different test-beds (full power & HIL);

2. Effect on overall system of different frequency measurements: starting from TC8X WG03 Document for Comments: NWIP on Power frequency measurement (TC8X/Sec/0129/DC). Measurement and testing requirements for local-power regulating and protection functions (HIL test bed);

3. Still on course to be properly investigated in detail:
   a) Identification and/or definition of other additional passive and/or active anti-islanding methods (no tests);
   b) Selection among those above of more expected reliable and robust anti-islanding methods to be tested (full power and HIL test beds);
   c) Real time models design and assessment by means of full power and HIL test beds (also a CIGRE C4-C& CIRED JWG is operating on inverter based generators modeling, but it's activity is mainly focused on phasors models to be used in simulations for TSOs needs);

New results from:

proceedings of islanding detailed analysis with full power and HIL test beds

evolution of the Standards and Grid Codes

d) Study of Anti-islanding Methods behavior in sperimental setup, using real Interface Protection System (in cooperation with the protection Manufacturer) in full power, but mainly HIL test beds;

e) Analysis in single and multi inverter cases (till three inverter), through HIL test beds;

4. Entry into force of the new RfG (Requirements for Generators), approved from EC.

a) Requirements of type A and Type B generators (different from regulations stated by Italian Standard CEI 0-21 and CEI 016), regarding Voltage Ride Througth (FRT) capability and Limited Frequency Sensitive Mode (LFSM) for over and under frequency. Impact on the unintentional islanding issue ? Also rated power of type A and B are not according Italian National Standards

b) Storages, except for hydro pump storages, are not considered as generators, as they are from electric system dynamic behavior perspective. No specific regulations or requirements? Storage connection impact on the network stability? Negative load?

New results from:
proceedings of islanding detailed analysis with full power and HIL test beds
evolution of the Standards and Grid Codes

c) The network code is a EC «law» stating Generators requirements for grid connection.

   i. A Technical Standard is a sufficient condition to assure the state of art compliance, but it is not mandatory (not necessary)

   ii. A law, instead, is both sufficient and necessary. What about possible consequences involving National Standards, if and where existing, asking for more ? For instance, would it be possible to consider EESS as generators and ask them for proper compliance tests/capabilities and/or to require type A generators to have Q(V) & LVRT ?

More detail in The Network Codes, backup slides

Outlines

Enel Distribuzione

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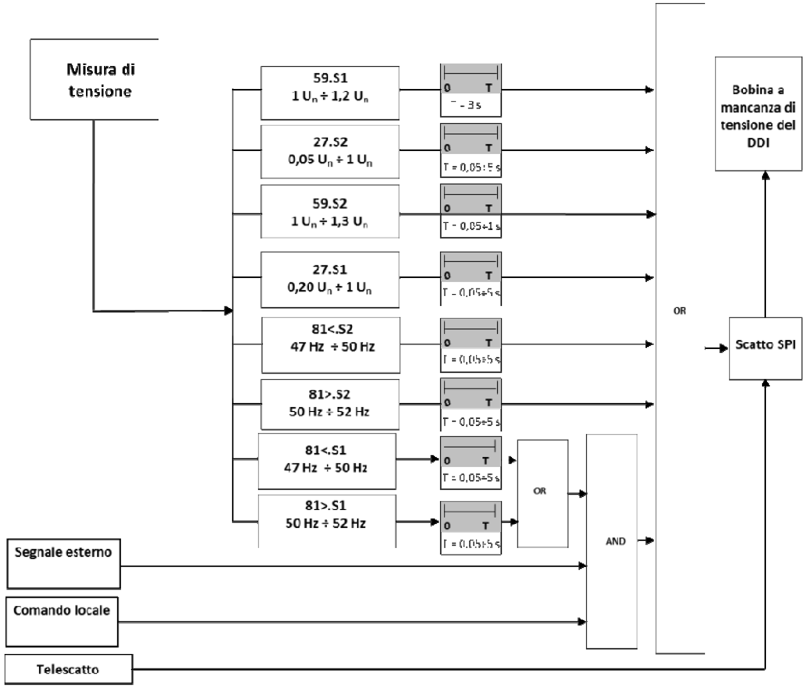
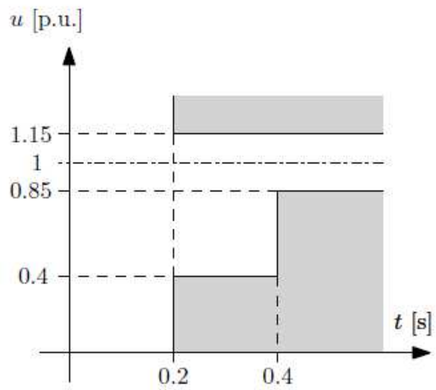
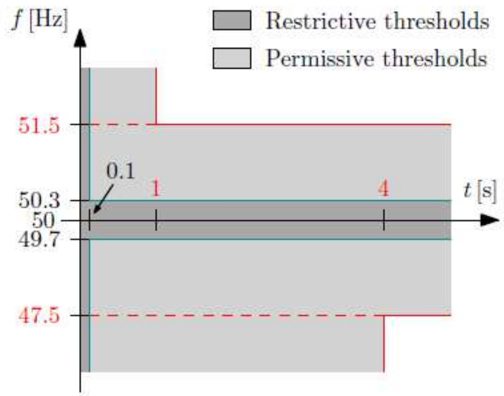
  In cooperation with: Università degli studi di Padova
- Effects of P/f operate times

CEI 021 Requirements

IPS scheme, Regulations ans Setting for different combined protection functions







Protection	Reset Ratio (Dropout ratio)	Reset Time (Dropout time)
27	1,03-1,05	0,04 s
59	0,95-0,97	0,04 s
81<	1,002	0,04 s
81>	0,998	0,04 s

Overshoot time 0,03 s

CEI 021 Requirements

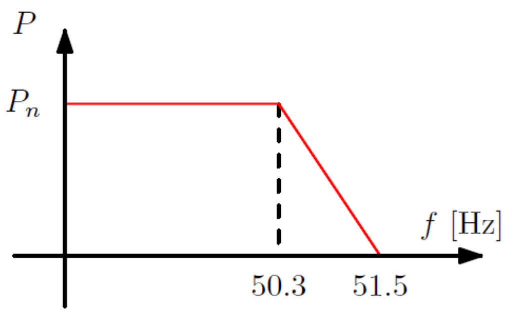
IPS Regulations ans Setting adopted in the tests

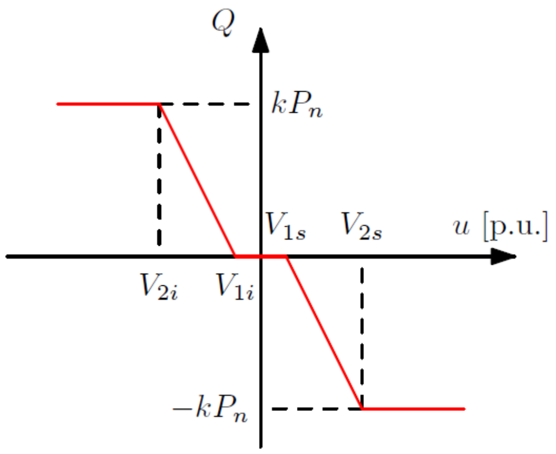
Protection function	regulation	operate time
OVR 2 (59 S2)	1.15 p.u.	200 ms
UVR 1 (27 S1)	0.85 p.u.	400 ms
UVR 2 (27 S2)	0.4 p.u.	200 ms
OFR 2 (Wide frequency window, according to Rfg), 81 > S1	51.5 Hz	1 s
UFR 2 (Wide frequency window, according to Rfg), 81 < S1	47.5 Hz	4 s
OVR 1 (59 S1)	1.10 p.u.	within 603 ms
OFR 1 (Narrow frequency window), 81 > S2	50,5 Hz	100 ms
UFR 2 (Wide frequency window), 81 < S2	49.5 Hz	100 ms

Thresholds in yellow landscape have not been adopted during tests

CEI 021 Requirements

P/f and Q/V considered for the tests





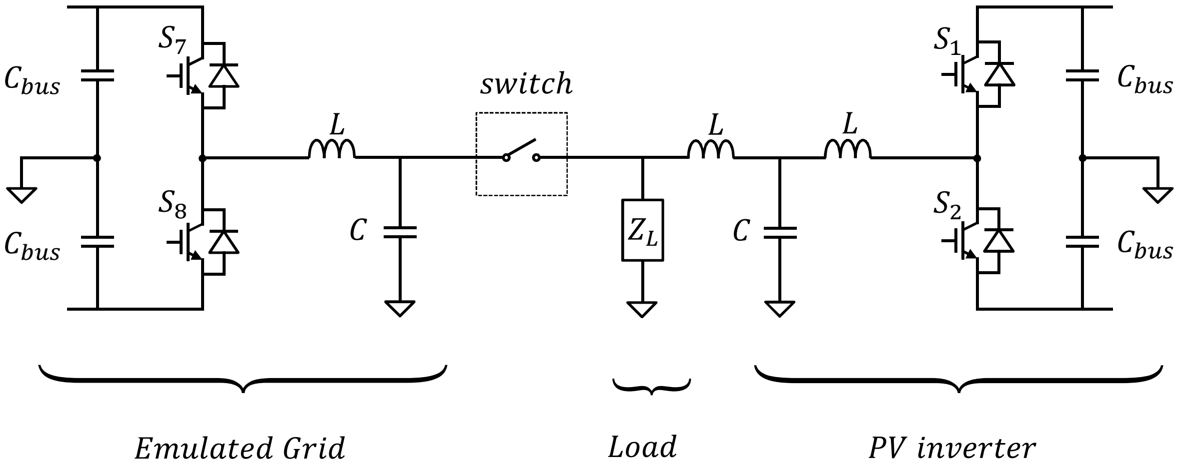
Regulation of Q(V)

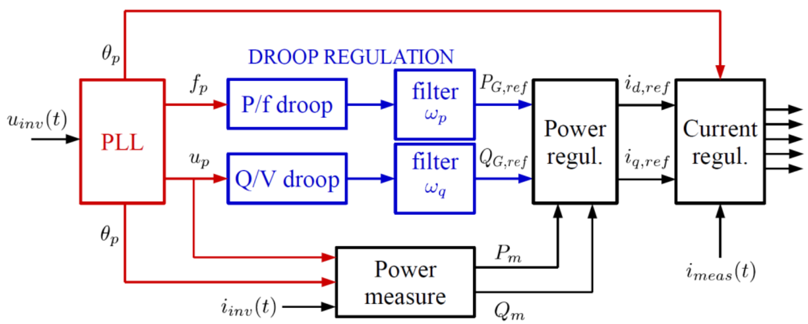
k = 0.48
V_{2i} = 0.9
V_{1i} = 0.95
V_{1s} = 1.05
V_{2s} = 1.1

P(f) and/or Q(V) may be either without intentional delay ("as fast as technically feasible", i.e. some tens of ms, as well as with different intentional delays or even with other combinations

Experimental prototype used for comparison

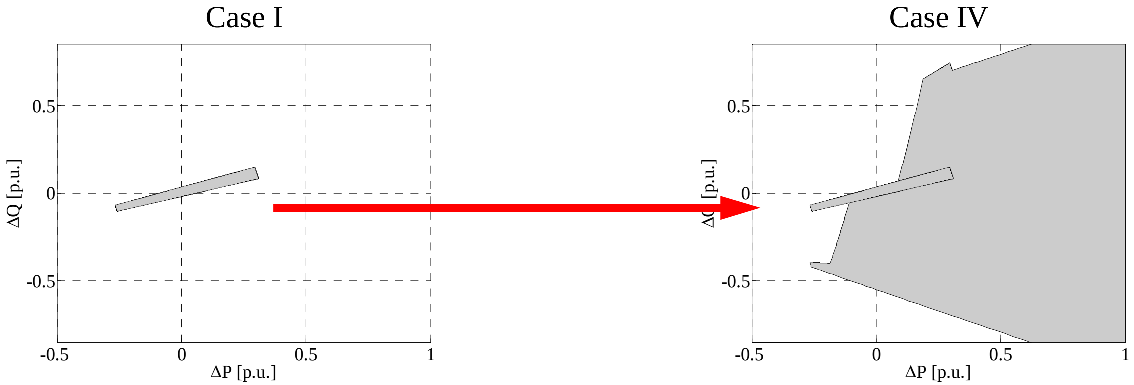
Experimental Setup – Single-phase representation of the three-phase 15kVA lab-scale prototype. Real interface protection system is going to be included in the experimental setup for future analysis and works.





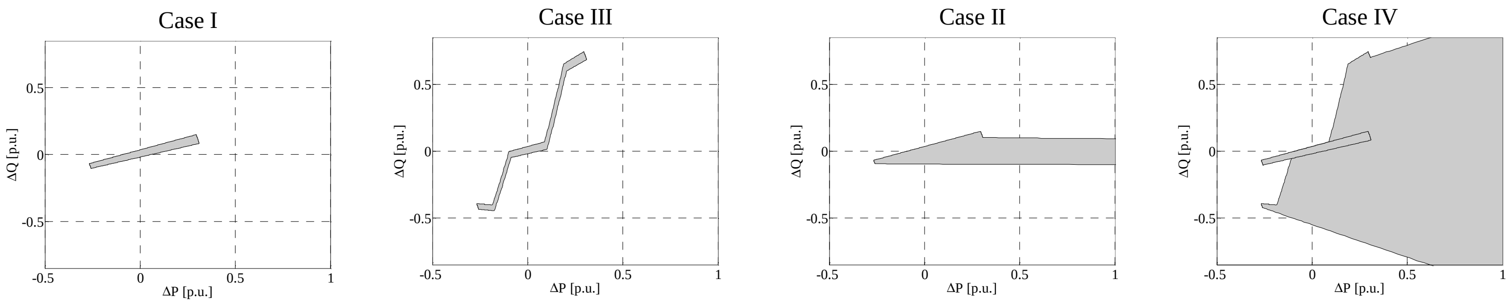
DSP control

Analytical results: NDZ enlargement due to *P/f* & *Q/V* droops (steady state analysis)



No DROOP activated.
Situation BEFORE “Smart Grids”
Limited NDZ

Both DROOP (P(f) & Q(V)) activated.
Situation AFTERE “Smart Grids”
Dramatic NDZ enlargement



P_G constant
Q_G constant

P_G constant
Q/V droop regulation

P/f droop regulation
Q_G constant

P/f droop regulation
Q/V droop regulation

Many other combinations of DROOPS, as well as methods to implement DROOPS, have been examined and analyzed with the described HIL. Besides “steady state” behavior, also intentional delays both in P(f) and Q(V) have been examined

Experimental results: confirmation of NDZ enlargement analytically evaluated

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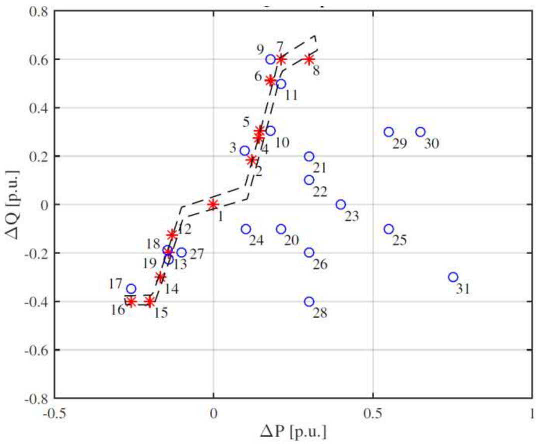
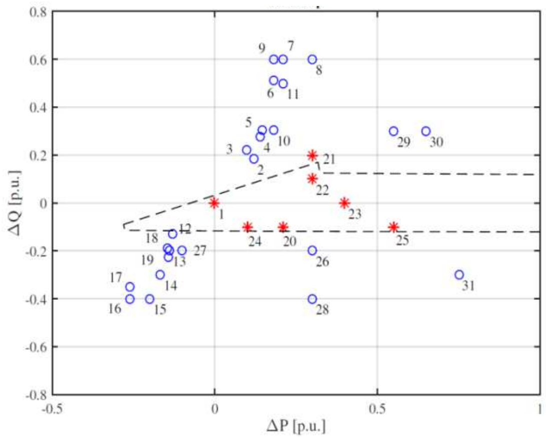
Case II



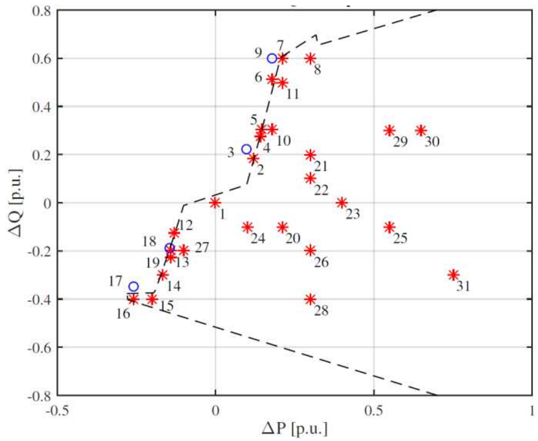
P_G constant
Q/V droop regulation

Case III



P/f droop regulation
Q_G constant

Case IV

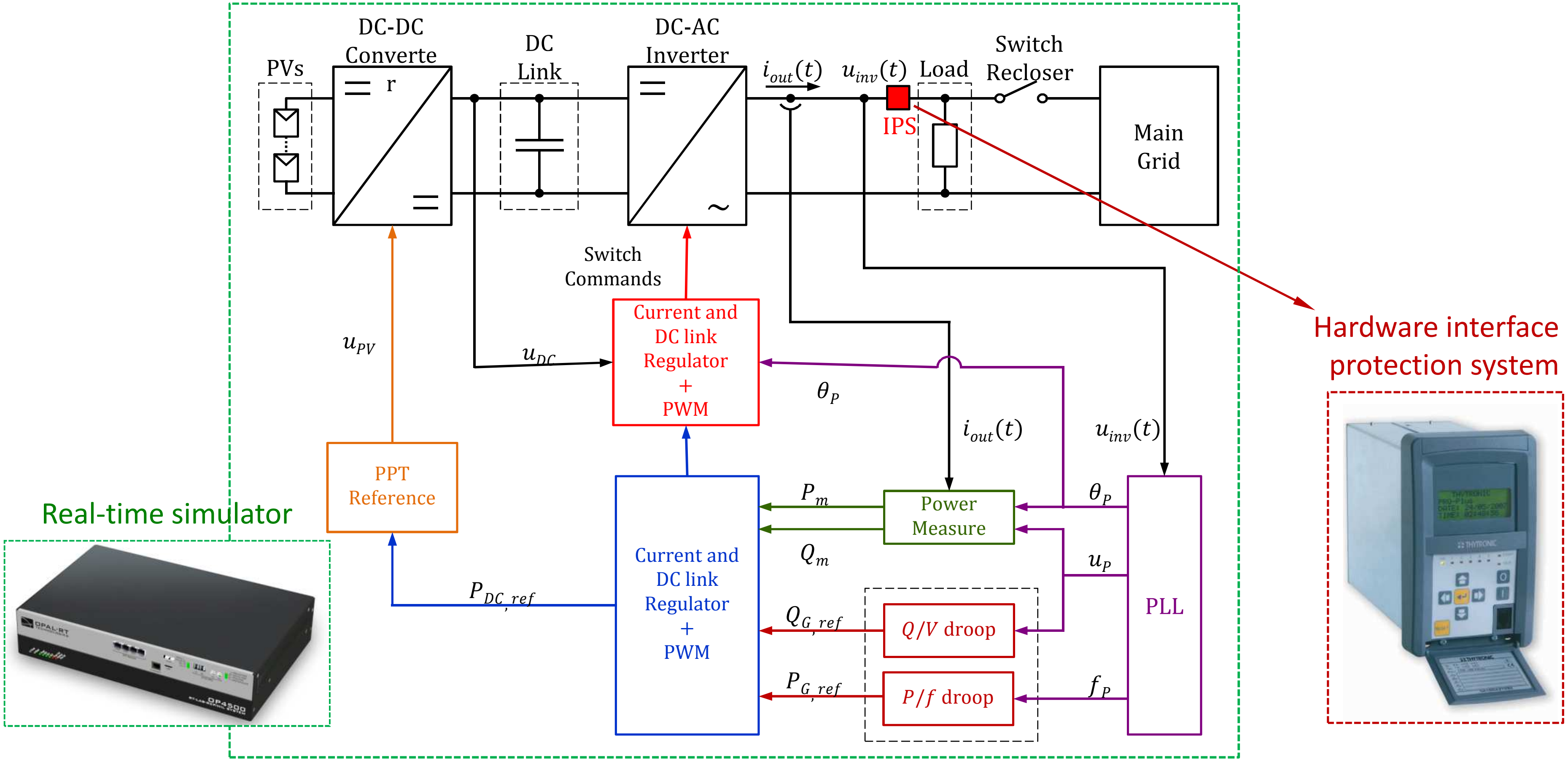


P/f droop regulation
Q/V droop regulation

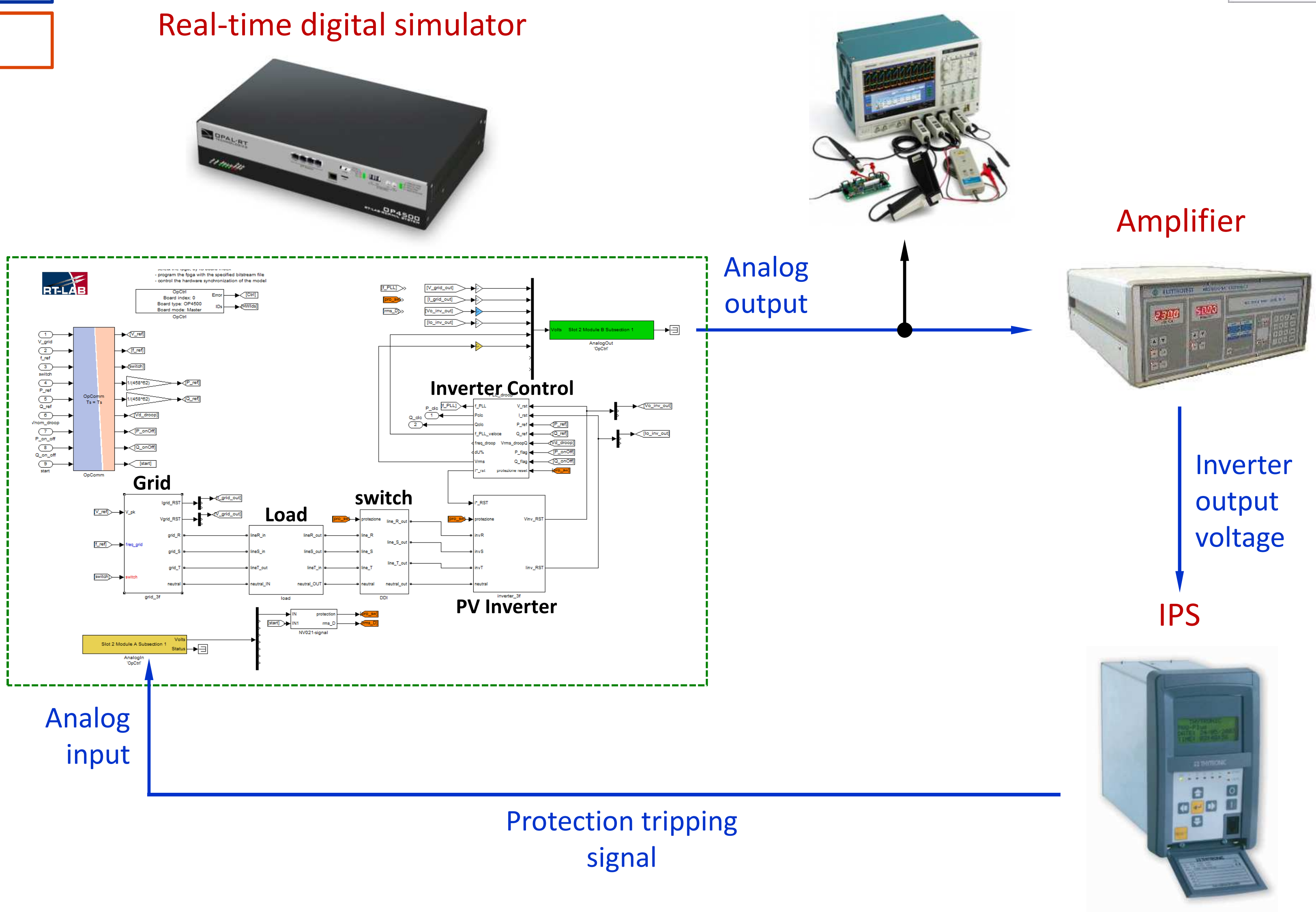
○ Tests with islanded operation out of protection thresholds * Tests with islanded operation within protection thresholds

Analysis for IPS behavior purposes

For real-time HIL simulations it has been adopted a typical scheme of photovoltaic inverter as the test case, modeling the power electronics components and control system



SimPowerSystem – HIL setup 1 - General



SimPowerSystem – HIL setup 2
P/f & Q/V control loops operate times 1

Enel
Distribuzione

2. With regard to the limited frequency sensitive mode — overfrequency (LFSM-O), the following shall apply, as determined by the relevant TSO for its control area in coordination with the TSOs of the same synchronous area to ensure minimal impacts on neighbouring areas:

(a) the power generating module shall be capable of activating the provision of active power frequency response according to figure 1 at a frequency threshold and droop settings specified by the relevant TSO~~, in coordination with the TSOs of the same synchronous area, and taking into account the potential for compliance on an aggregate level while limiting cross-border impact and maintaining the same level of operational security in all system states. Where compliance is to be met on an aggregate level, those requirements shall be~~

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~~submitted for approval by the relevant TSO to the regulatory authority concerned~~;

(b) instead of the capability referred to in paragraph (a), the relevant TSO may choose to allow within its control area automatic disconnection and reconnection of power generating modules of Type A at randomised frequencies, ideally uniformly distributed, above a frequency threshold, as determined by the relevant TSO where it is able to demonstrate to the relevant regulatory authority, and with the cooperation of power generating module owners, that this has a limited cross-border impact and maintains the same level of operational security in all system states;

~~(b)~~(c) the frequency threshold shall be between 50.2 Hz and 50.5 Hz inclusive;

~~(c)~~(d) the droop settings shall be between 2 % and 12 %;

~~(d)~~(e) the power generating module shall be capable of activating a power frequency response with an initial delay that is as short as possible. If that delay is greater than two seconds, the power generating facility owner shall justify the delay, providing technical evidence to the relevant TSO;

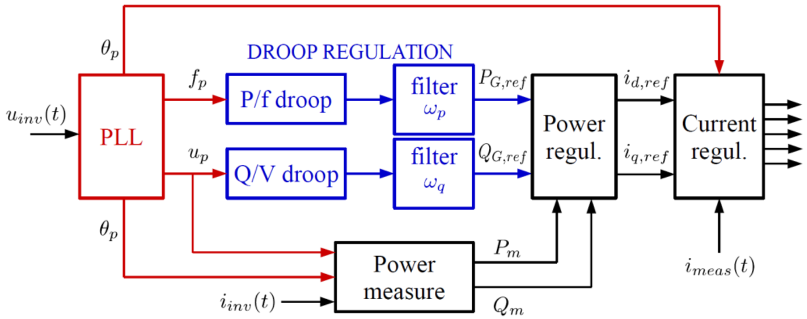
From latest available version of RfG

SimPowerSystem – HIL setup 3
P/f & Q/V control loops operate times 2

Most of the simulations have been performed assuming typical reaction times of the whole PV inverters control loops:

- ***Tp*** = 800ms. Time settling, i.e. time necessary to allow ***Pmeas*** (generated active power) to become equal to ***Pref*** ("target" active power to be generated in the specific test conditions) after a sudden change of ***Pref*** from 10% to 100%;
- ***Tq*** = 2500ms. Time settling, i.e. time necessary to allow ***Qmeas*** (exchanged reactive power) to become equal to ***Qref*** ("target" reactive power to be exchanged in the specific test conditions) after a sudden change of ***Qref*** from 10% to 100%.

These settling times are obtained with NO INTENTIONAL DELAY for the first activation of both *P/f* & *Q/V* (*f* & *V* measurements are performed in ~ 100 ms). In case an intentional delay is inserted, this acts just one time before the first activation on ***Pref*** and/or ***Qref***.



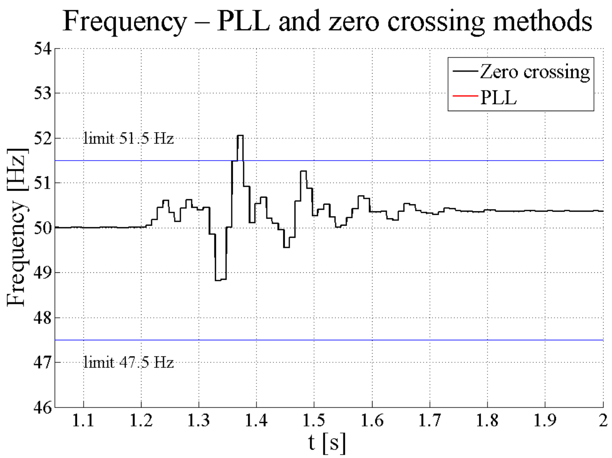
Reduced settling times to *P/f* control loops have been also simulated, as well as different ways to implement intentional delays in *Q/V*.

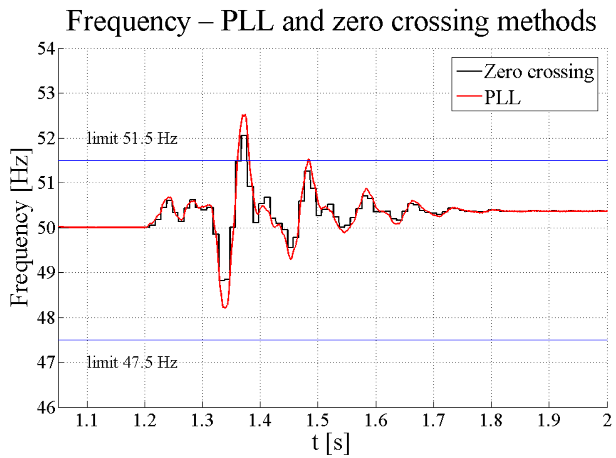
SimPowerSystem – HIL setup 4
Frequency measurements: zero crossing and PLL (1)

Different frequency measurements methods have been hypothesized:

- PLL internal of the PV inverter (as shown in the following scope traces), typical for P/f droop regulator (~ 12 kHz is the value assumed in the present studies);
- Post-elaboration (to simulate typical frequency measurement for IPS protection systems) of the instantaneous voltage (sampled at 1 Msample/sec from oscilloscope, properly filtered concerning high frequencies)) using:
  - o Zero crossing of the measured/calculated voltage value (method typical of protection relays)
  - o PLL with a fast dynamic response (bandwidth of the order of 100 Hz)

Islanding TEST with ΔP=-0,08 and ΔQ=-0,06



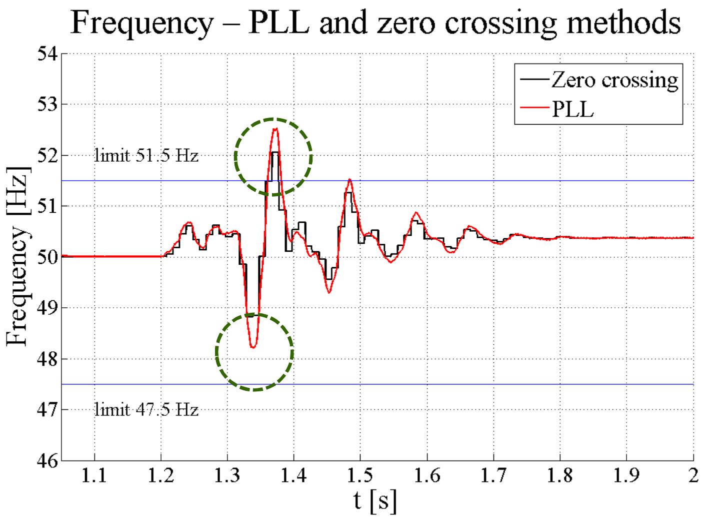


Note: tipically protection sampling rate concerning analog signals is in the range 1,2 kHz- 2 kHz) (see backup slide on **typical frequency measurement methods of protection relays***)*

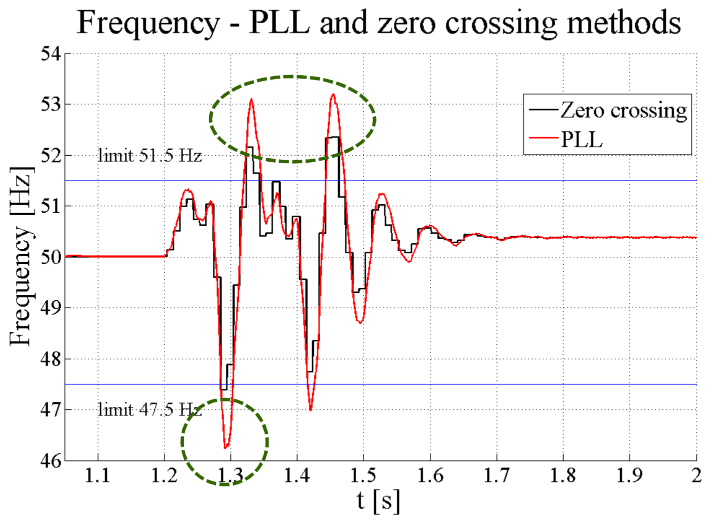
SimPowerSystem – HIL setup 5

Frequency measurements: zero crossing and PLL (2)

Islanding TEST
ΔP=-0,08 and ΔQ=-0,06



Islanding TEST
(ΔP=-0,08; ΔQ=-0,1)



- Little mismatches between frequency measurements are possible between zero crossing method and PLL, despite a minimum initial P and Q mismatch (therefore a relatively “slow” dynamic system reaction during the transient
- PLL frequency output (for internal inverter control) is due to its own dynamic and features of the hyphotized model
- The different behavior depends on the frequency sudden change (instantaneous for zero crossing, of course depending on sampling rate frequency and zero crossing calculation and filtering, and with dynamic for PLL).
- **More important deviation between the two methods may take place for high ΔP-ΔQ imbalances or for a very fast time response of droop characteristic, with a not coordinated whole electric system behavior**

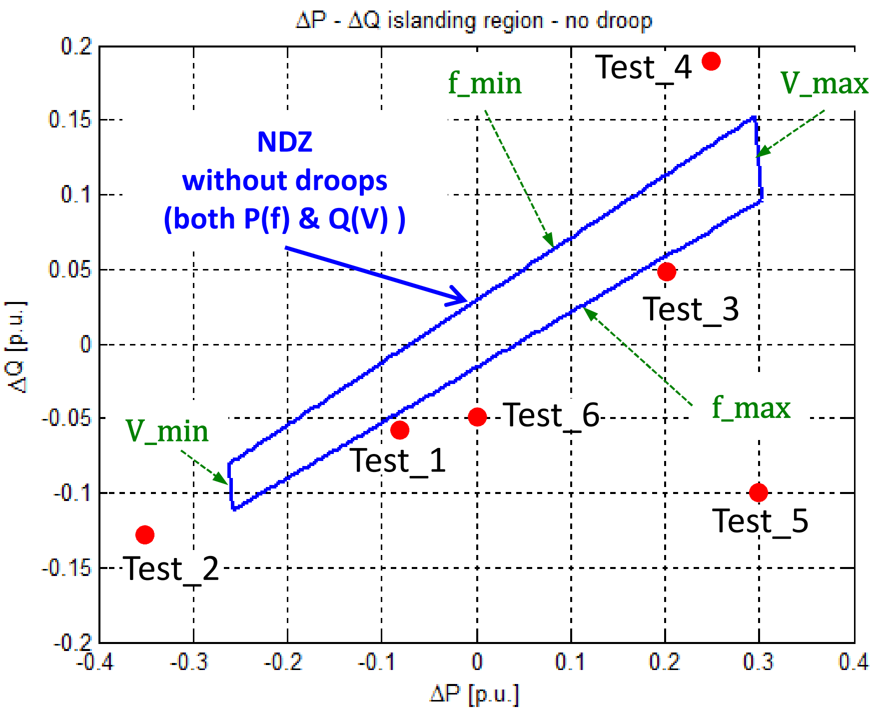
TEST HIL

- Tests were performed to understand the P/f - Q/V regulations influence on the size of islanding NDZ and to test the protection performance in islanding transients

TEST	ΔP	ΔQ
Test_1	-0,08	-0,06
Test_2	-0,35	-0,13
Test_3	0,2	0,05
Test_4	0,25	0,19
Test_5	0,3	-0,1
Test_6	0	-0,05

$$\Delta P = (P_{G\ (Inverter)} - P_N) / P_N$$
$$\Delta Q = (Q_{G\ (Inverter)}{}^{*} - Q_N) / P_N$$

$$P_{N\ (Load)} = 4560\ W$$
$$Q_{N\ (Load)} = 1960\ VAr^{*}$$



*Q_N >0 inductive reactive power absorbed; Q_G >0 inductive reactive power produced (i.e. capacitor bank behavior)

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Effect of active power control loop reduced settling time

In this section some tests already shown previosly have been repeated with different settling times for P/f control loop (no change regarding Q/V settling time), i.e.:

$$\tau_P = 0{,}23\ s$$
$$\tau_Q = 2{,}5\ s$$
(previously $\tau_P = 0{,}8\ s,\ \ \tau_Q = 2{,}5\ s$)

- ***Tp:*** Active power control loop time settling, i.e. time necessary to allow ***Pmeas*** (generated active power) to become equal to ***Pref*** ("target" active power to be generated in the specific test conditions) after a sudden change of ***Pref*** from 10% to 100%;
- ***Tq:*** reactive power control loop time settling, i.e. time necessary to allow ***Qmeas*** (exchanged reactive power) to become equal to ***Qref*** ("target" reactive power to be exchanged in the specific test conditions) after a sudden change of ***Qref*** from 10% to 100%.

These settling times are obtained with NO INTENTIONAL DELAY for the first activation of both *P/f* & *Q/V* (*f* & *V* measurements are performed in ~ 100 ms). In case an intentional delay is inserted, this acts just one time before the first activation on ***Pref*** and/or ***Qref***.

Effect of active power control loop reduced settling time.

Comments

A shorter P/f control loop settling time (230 ms instead of 800 ms) maintaining a relatively slow Q/V control loop settling time increase system instanbility.

Advantages on reduction of «dynamic» NDZ are negligible, on the contrary both frequency and voltage present oscillations and instability, in most of the simulated situations very important.

It must be pointed out that, anyway, Tp = 230 ms IS NOT THE TECHNICAL LIMIT OF AN INVERTER BASED GENERATOR, it may be reduced even more than a further 50% and that f measurent is, anyway, performed in ~ 100 ms.

Conclusions (1)

- HIL systems are extremely flexible with respect to full power (HW) test beds. The degree of simulated system with respect to real part of the system may be changed according to points/aspects/behaviors to be evaluated deep in detail

- Consequently, once the model is properly and accurately defined, costs to check different situations and conditions of the system is much lower with respect to real full power test beds

- Critical points of HIL simulation systems are:
  - the accuracy of the model (level of details, consistency with real features/parameters/internal settings and regulation, algorithms of the simulated device/part of the system/etc). For a detailed and specific analysis, Manufacturers of the device included in the simulations should be involved;
  - Real Time simulators are based both on HW and SW. Costs may be relatively, especially if power amplifiers are needed (most of the situations);
  - The use of these system requires a proper training of personnel.

Conclusions (2)

- Phasors based simulation tools are easier to use, generally a dedicated HW is not required, and allows “long time” simulations. On the contrary, models, both included in internal libraries, and customized, have less details with respect to real time systems;

- Real Time Models and phasors models are used in different simulation tools (SW, HW, both), but are, generally, not aligned between the two simulation tools “families”. Many activity on proper model definition is on course (for instance CIGRE C4-C6/CIRED JWG on inverter based generator modeling, IEEE publications on WIND generators model, etc.). More detailed models should be defined first, i.e. for Real Time systems, whilst models for phasor simulation tools should be derived from these models, i.e. simplified but consistent with more detailed ones

- Concerning results of the present study (just a minor part of the whole study still on course), simulation results shown many not expected behaviors of the system, ranging from the extreme increase of uncontrolled islanding probability, to different behaviors of interoperating system components (protection, inverters controls, etc.) depending on different frequency measurement methods, on the heavy influence of load features in terms of P and Q absorption depending both on f and V variations, on *Tp* and *Tq* settling times and, finally on the way possible delays, both in *Tp* and in *Tq* are implemented in the inverter based generators

Conclusions (3)

- Critical points, left open both from CENELEC Standards and from RfG are:
  - Frequency measurement: no standardized method is defined in any Standard or Law or Grid Code or other doc, leading to a complete not – coordinates whole system behavior. Being Grid Codes defined, theoretically, to assure electric system security, this is a really a heavy lack in the Code. The topic, clearly, has to be studied first at system level, TC8 8 (X) or new System Committees, using correct dynamic simulations of the whole electric system (i.e. correct models of generators and their control systems per each involved technology , but also of loads !), then the results should be transmitted to Product TCs for implementation in the devices and the definition of compliance assessment procedures. Anyway, in all the studied cases, f measurents has been performed in ~ 100 ms;
  - Fast P/f control loop settling time (as require from RfG): increase system instability, both concerning frequency and voltages values. Advantages on reduction of «dynamic» NDZ are, on the contrary, negligible. It must be pointed out that, finally, that the minimum consider Tp = 230 ms IS NOT THE TECHNICAL LIMIT OF AN INVERTER BASED GENERATOR, it may be reduced even more than a further 50%;
  - Way to define and implement possible intentional delays in *P/f* and/or Q/V settling times, where time settling is to be intended as the time necessary to allow *Pmeas* (generated active power) or *Qmeas* (exchanged reactive power) to become equal to Pref ("target" active power to be generated in the specific test conditions) *Qref* ("target" reactive power to be exchanged in the specific test conditions) after a sudden change of Pref from 10% to 100%;

Conclusions (3)

- With the introduction of new requirements for generators, uncontrolled islanding become, more than a possibility, the expected behavior in case of CB opening without fault. Withe respect to situation BEFORE the new requiements, the uncontrolled islanding probability was dramatically increased. The static analisys shows an increase in NDZ, which is confirmed also from dynamic simuations performed both on full power tests beds and HIL test beds with real IPS. These uncontrolled islanding probability increase is obtained simply studying just some of new stabilizing requirements, some others have not been tested. In addition just one inverter based generator has been considered in the simulations;
- The transient is affected, in sequence:
  1. from initial ΔP & ΔQ in the part of the network «moving» towards «island» conditions;
  2. from load *P/(V-f)* & *Q/(V/f)* dynamic response;
  3. from frequency detection methods adopted from all the different devices/controls reacting to frequency variations in the electric systems;
  4. From the way *P/f* & *Q/V* control loops in inverter based generators are designed and from their settling times *Tp* & *Tq*;
  5. From how possible initial intentional (additional) activation delays on *P/f* & *Q/V* control loops are designed and their values;

Conclusions (4)

- The «status» of «influence factors» above is the following:
  1. Variable in time & space with no forecast possibility;
  2. Not at all defined at Standard level;
  3. Not at all defined at Standard level;
  4. Not at all defined at Standard level;
- With traditional protection relays/functions (some of them are, as pointed out above, are not even defined at Standard level), no guarantee of islanding detection is present. It's hard to find an «optimal» solution operating correctly in every possible conditions;
- Active methods still have to be investigated, but overall effect should be the same because affected AT LEAST from the same «influence» factors as traditional protection relays based LOSS OF MAIN systems (IPS);
- The only reliable anti-islanding system is confirmed to be transfer trip (see **Back Up 3, Slide 88 and followings**);
- Effect of uncontrolled islanding involving parts of MV networks in case of earth faults still have to be investigated with this new approach, but it's very likely the same results obtaoned from 2014 studies will be confirmed (LV generators could sustsain an MV uncontrolled islanding).

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Thank you for your attention

Enel Distribuzione

Typical frequency measurement methods of protection relays

Two main different basic techniques for frequency mesurements are currently adopted in frequency relays and similar (81, ROCOF, Automatic Load Shedding, etc.).

- Constant sampling frequency, usually relatively high (more than 1,5 kHz). In the range considered from ENTSOE, i.e. 47,5 Hz÷51,5 Hz, the error due to a constant sampling in presence of frequency variations is negligible;
- Frequency tracking, i.e. a constant number of samples per period, for instance 20÷30 samples. If the frequency varies, the sampling frequency will change accordingly, to maintain the same samples per period. These relays are commonly used for generating units able to have black start capabilities.

Both methods generally used zero-crossing techniques, may be on negative rate of change or on positive rate of change or on the average of both. Values among two samples in sequence are calculated through interpolation.

Typical frequency measurement methods of protection relays

Filtering techniques are as well adopted, for instance further zero-crossing within a certain time window before and after the zero crossing considered from the relay are not considered.

For relays whose nuisance intervention may have heavy negative consequences, such as Automatic Load Shedding relays, a relatively long operate time is required, to increase reliability of relay operation (frequency measurement may be of 100 ms or longer).

Before RfG in DSOs networks, a nuisance tripping was preferred to an uncontrolled islanding. In Italy, typically, a 3 periods (60 ms) based frequency measurement was the minimum one, adopted for aviation derivate gas turbines, with a maximum axis breaking torque of about 4 times nominal torque. A 5 periods (100 ms) based frequency measurement was the maximum one, adopted for hydro turbines (for instance Kaplan turbines), with no problem of breaking torque and of counter-phase reclosing.

Return to main presentation

BACK UP 2

THE NETWORK CODES

common rules for electricity markets, as defined in Regulation (EC) N° 714/2009

THE NETWORK CODES

From ENTSOE WEBSITE - 1

"Network codes are a set of rules drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), to facilitate the harmonisation, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market, and achieving the European Union's 20-20-20 energy objectives of:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency.

Representing European electricity transmission system operators, ENTSO-E was mandated by the European Commission (EC) to draft these rules for electricity, with sister association ENTSOG drafting the rules for gas. Under development since 2011, each code takes approximately 18 months to complete. Following ACER's recommendation,each code is submitted to the European Commission for approval through the Comitology process, to then be voted into EU law and implemented across Member States.

THE NETWORK CODES

From ENTSOE WEBSITE - 2

For technical legal reasons, it was decided in May 2014 that the regulation on capacity allocation and congestion management (CACM), would be labelled “binding guideline” instead of “network codes”. ……..

……………….

Changing the CACM label from “network code” to binding guideline will not materially change CACM’s content or affect its legal value. Many other codes should maintain their “network code” label.

In the interest of simplification, the term “network codes” refers, in this document, to all the common rules for electricity markets, as defined in Regulation (EC) N° 714/2009.

………..”

THE NETWORK CODES

Legal aspects - 1

Regulation:

A regulation is a legal act of the European Union that becomes immediately enforceable as law in all member states simultaneously.

Regulations can be distinguished from Directives which, at least in principle, need to be transposed into national law.

Regulations can be adopted by means of a variety of legislative procedures depending on their subject matter.

Regulations are in some sense equivalent to "Acts of Parliament", in the sense that what they say is law and they do not need to be mediated into national law by means of implementing measures. As such, Regulations constitute one of the most powerful forms of European Union law and a great deal of care should be required in their drafting and formulation.

When a Regulation comes into force, it overrides all national laws dealing with the same subject matter and subsequent national legislation must be consistent with and made in the light of the regulation. Member states are prohibited from obscuring the direct effect of regulations.

Binding Guideline:

A Binding Guidelines has, more or less, the same legal value as Regulation. EC, however, is even more free in the definition of possible amendments.

THE NETWORK CODES

Legal aspects - 2

Referring to Network Codes:

- Regulation:

The adoption process is legally detailed with involvement of ACER and ENTSO-E;
Amendments definition process: EC opens the process itself or by stakeholders request to EC directly - without ACER formal involvement - or to ACER – with ACER's involvement.

- Binding Guideline:

Adoption process is not as detailed and less formalised with respect to Regulation ones;
The Commission can draft rules itself and provides only consultation obligation with ENTSO-E and ACER – Therefore, this gives EC more flexibility;
The same procedure applies to amendments.

As a conclusion, a Guideline is as bidding as a Regulation, but there will be a big difference: once a Network Code is adopted: the involvement of the stakeholders under the "Guideline procedure" is limited and amendments will not follow Article 7 of the Regulation 714/2009

THE NETWORK CODES

Legal aspects - 3

Article 7

Amendments of network codes

1. Draft amendments to any network code adopted under Article 6 may be proposed to the Agency by persons who are likely to have an interest in that network code, including the ENTSO for Electricity, transmission system operators, system users and consumers. The Agency may also propose amendments on its own initiative.

2. The Agency shall consult all stakeholders in accordance with Article 10 of Regulation (EC) No 713/2009. Following that process, the Agency may make reasoned proposals for amendments to the Commission, explaining how such proposals are consistent with the objectives of the network codes set out in Article 6(2).

3. The Commission may adopt, taking account of the Agency's proposals, amendments to any network code adopted under Article 6. Those measures, designed to amend non-essential elements of this Regulation by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 23(2).

4. Consideration of proposed amendments under the procedure set out in Article 23(2) shall be limited to consideration of the aspects related to the proposed amendment. Those proposed amendments are without prejudice to other amendments which the Commission may propose.

THE NETWORK CODES

Update on NC Comitology Process - 1

RfG NC Regulation: adopted in June 2015 by Member States in Comitology. RfG is now through scrutiny from European Parliament and Council Publication is expected by the end of the year. It will have an important impact in the DSO.

DCC NC Regulation: Discussions between the EU and Member States are still going on within the Electricity Cross-Border Committee. Voted is foreseen in the next Electricity XB Committee (15-16 October 2015).

These two codes, especially RfG, have maximum impact on the evaluation dealt in the analysis shown in this presentation.

THE NETWORK CODES

Update on NC Comitology Process - 2

Enel Distribuzione

HVDC NC Regulation: was adopted in September 2015 by Member States in Comitology.

CACM Guideline: On 5 December 2014, the CACM guideline was adopted by Member States in Comitology and entered into force on 14 August 2015.

FCA NC Regulation: The text was discussed for the first time by European Member States in Comitology in July 2015 and the vote is tentatively scheduled for the Electricity XB Committee meeting on 29-30 October 2015.

Transmission System Operation Guideline: Discussions should start in the Electricity XB Committee meeting on 12-13 November 2015.

Emergency and Restoration NC Regulation: ACER delivered a positive opinion and recommended for NC for adoption to EC, along with a number a proposals for changes. The Commission is working on the NC to prepare it for the comitology.

Electricity Balancing Guideline: The Commission is also working on the Electricity Balancing Guideline after recommendation to adoption by ACER on 22 July 2015. EC will look into it after analysing replies to the Consultation on a new Energy Market Design. The comitology process is scheduled to start in May 2016. Vote is planned for end 2016, and entry into force 2017.

THE NETWORK CODES

Update on NC Comitology Process - 2

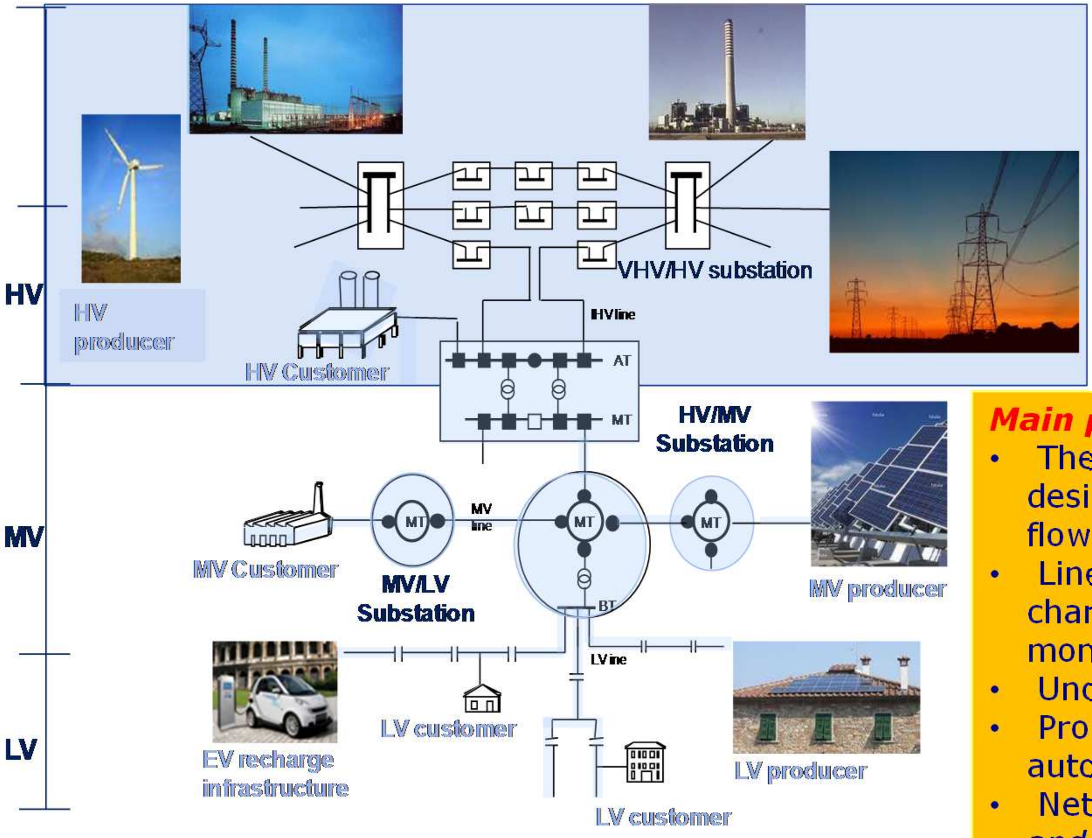
New results from:

proceedings of islanding detailed analysis with full power and HIL test beds

evolution of the Standards and Grid Codes

BACK UP 3
Enel Distribuzione IEC 61850 applications

Enel Distribuzione



Due to the incentive policies aimed to reduce the important problem of the pollution, a great number of distributed energy resource (DER) was connected to the distribution networks (MV & LV). The appearance of these DER has totally changed the historical conventions and caused the need of completely new network management strategies.

Main problems:

- The existing MV network was designed for mono-directional power flows.
- Line voltage profile: the DER presence changed the old convention of monotone decreasing profile.
- Uncertainty of power generated.
- Problems to protection, control and automation system.
- Network congestions.

… and more…

There is a limited capacity to integrate Distributed Energy Resources (DER).

Smart Grid
Functional and architectural developments

Enel Distribuzione

BROADBAND COMMUNICATION
(different latency times according to each single function)

Voltage Control
DER participation to MV network Voltage Control (thanks to reactive/active power reduction/increase)

Anti – Islanding
disconnection of DER in the event of unwanted islanding operation

Δf
Variation of DER Frequency Disconnection Range

Fast Fault Selection
New automatic MV fault selection and restoration procedures, exploiting communication between IEDs along MV feeder

Monitoring and Data Collection
Measurements at MV network level (both substation and customers): Active and Reactive Power, V, I (also towards TSO).

Storage Systems
Storage application at MV network level (ancillary services, voltage control, intermittent sources balancing, black start)

EV Recharging Infrastructure
also in conjunction with Storage device

SMART INFO
Demand Response strategies thanks to direct consumption information to the final LV Customer.

SMART GRIDS

REGULATORY FRAMEWORK
- **New connection criteria**
- **Dispatching rules**
- **Awards and Penalties**

Smart Grid
Functional and architectural developments

Enel Distribuzione

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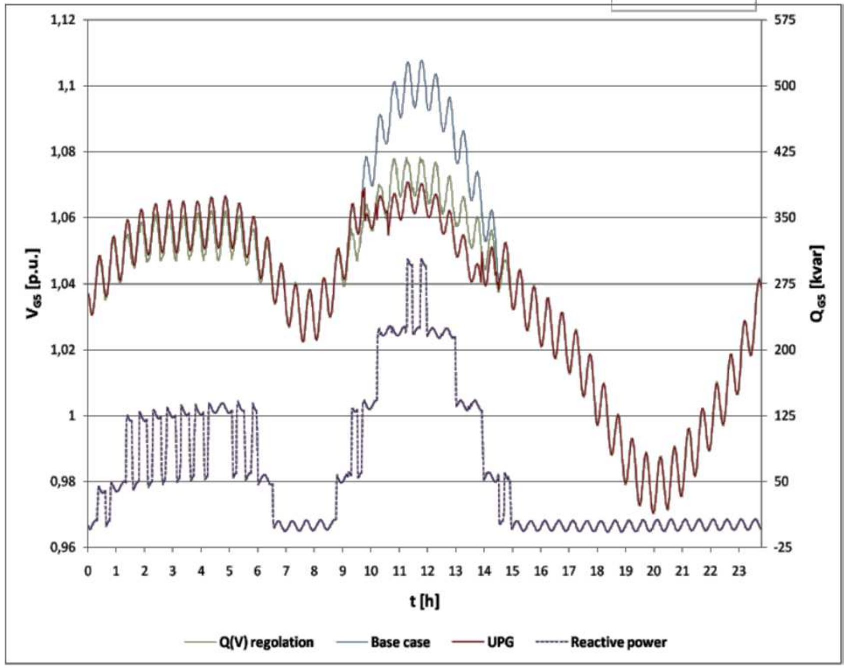
Voltage Control

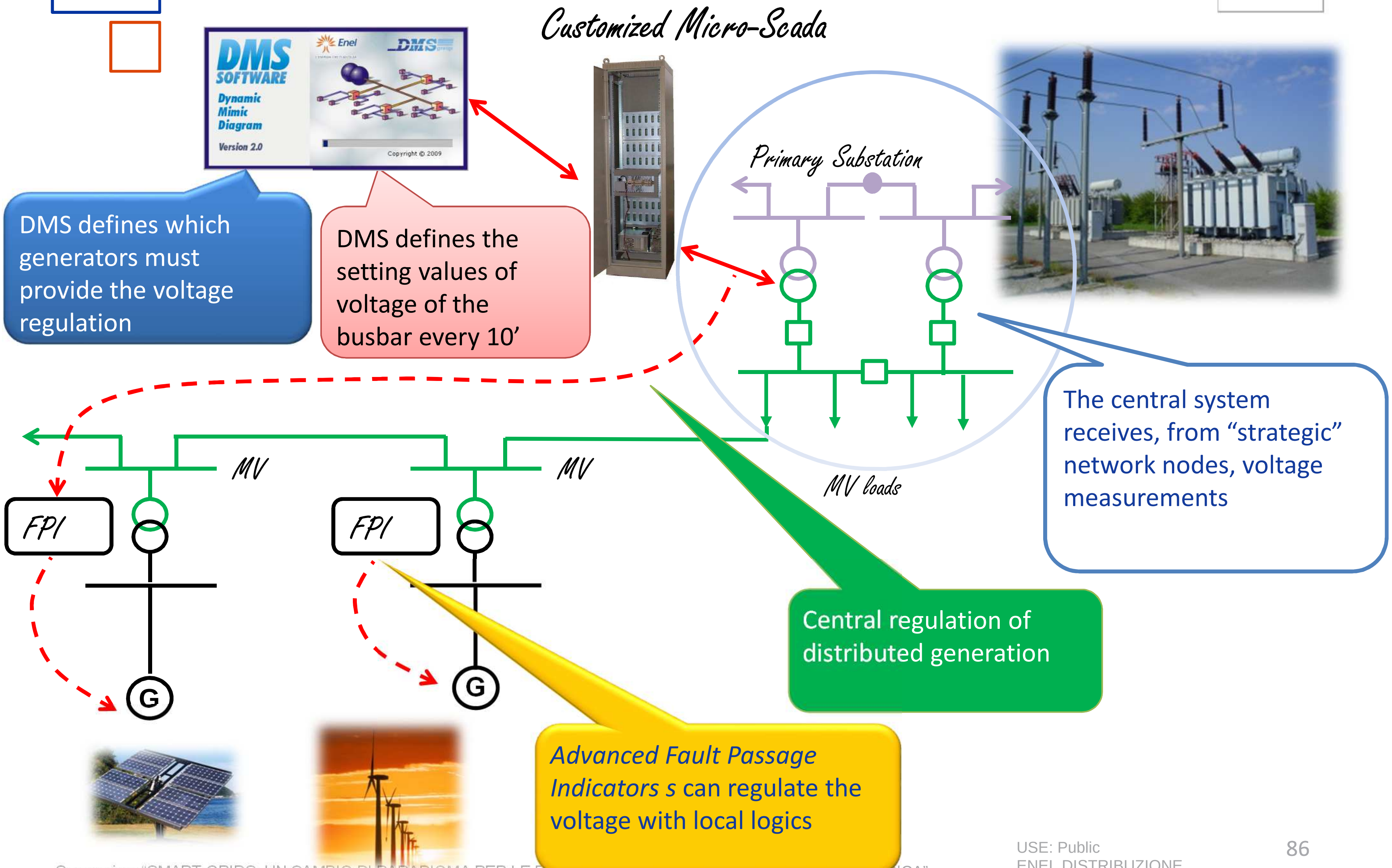
MV network hosting capacity is not usually limited by conductors capability, but by voltage increase caused by generators



The approach:

- Optimal voltage setting at bus bar level evaluated by **DMS**;
- In case of overvoltage due to a generator injection, the generator is asked by local algorithms to absorb reactive power at a specific cosϕ value (i.e. 0,95, according to generators capabilities);
- If needed, the Control Centre could:
  - ask another generator to “help”, modulating its own reactive power
  - ask the generators causing the overvoltage also an active power production curtailment

Voltage Control



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Functional and architectural developments

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Anti Islanding + Δf

Interface Protection Relay (IPR)

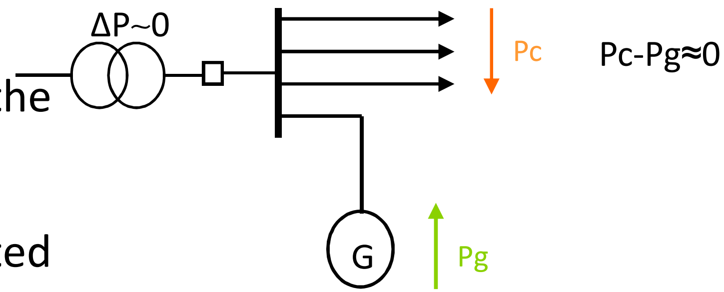
The interface protection aims to disconnect the generators from the network to avoid:

- the supply of the network from the customer when the network is down.
- in case of fault on the MV or LV line where the client is connected, the Customer could supply energy to the fault;
- in case of automatic or manual reclosing of network breaker, the generator could provide power with phase discordance with the network.

In absence of faults, if the generated power is close to the loads power, a balance condition may be present and the IPR doesn't detect voltage and/or frequency changes over the regulated tresholds and it doesn't act.

This may happen at different levels:

- HV/MV station MV busbar (no P-Q flows through the HV/MV TR);
- at the beginning of a MV feeder;
- on a section of a MV feeder, able to be originated from automation system or on remote/manual action on CBs/switch disconnectors along the MV feeder.

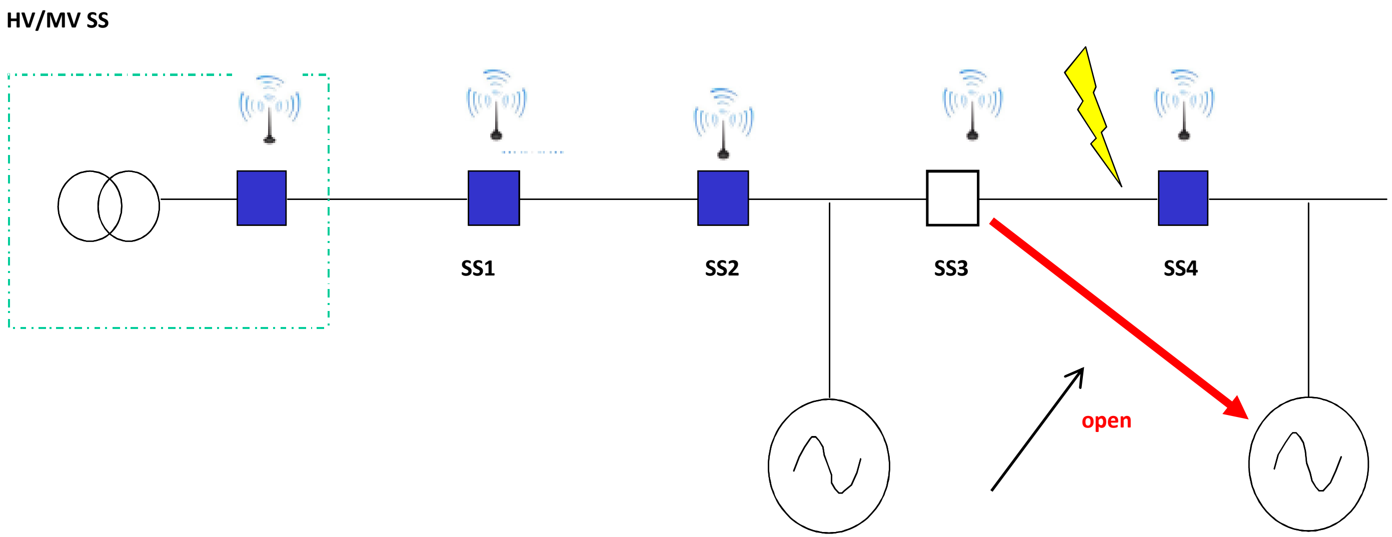


Anti Islanding + Δf

Interface Protection Relay (IPR)

Remote Control System of Enel monitors every network section. Potential situation of "uncontrolled" islanding will be avoided from sending explicit commands of remote disconnection to all generators of "island" network section, according to annex A.70 of the Italian Grid code (from Terna, the italian TSO).

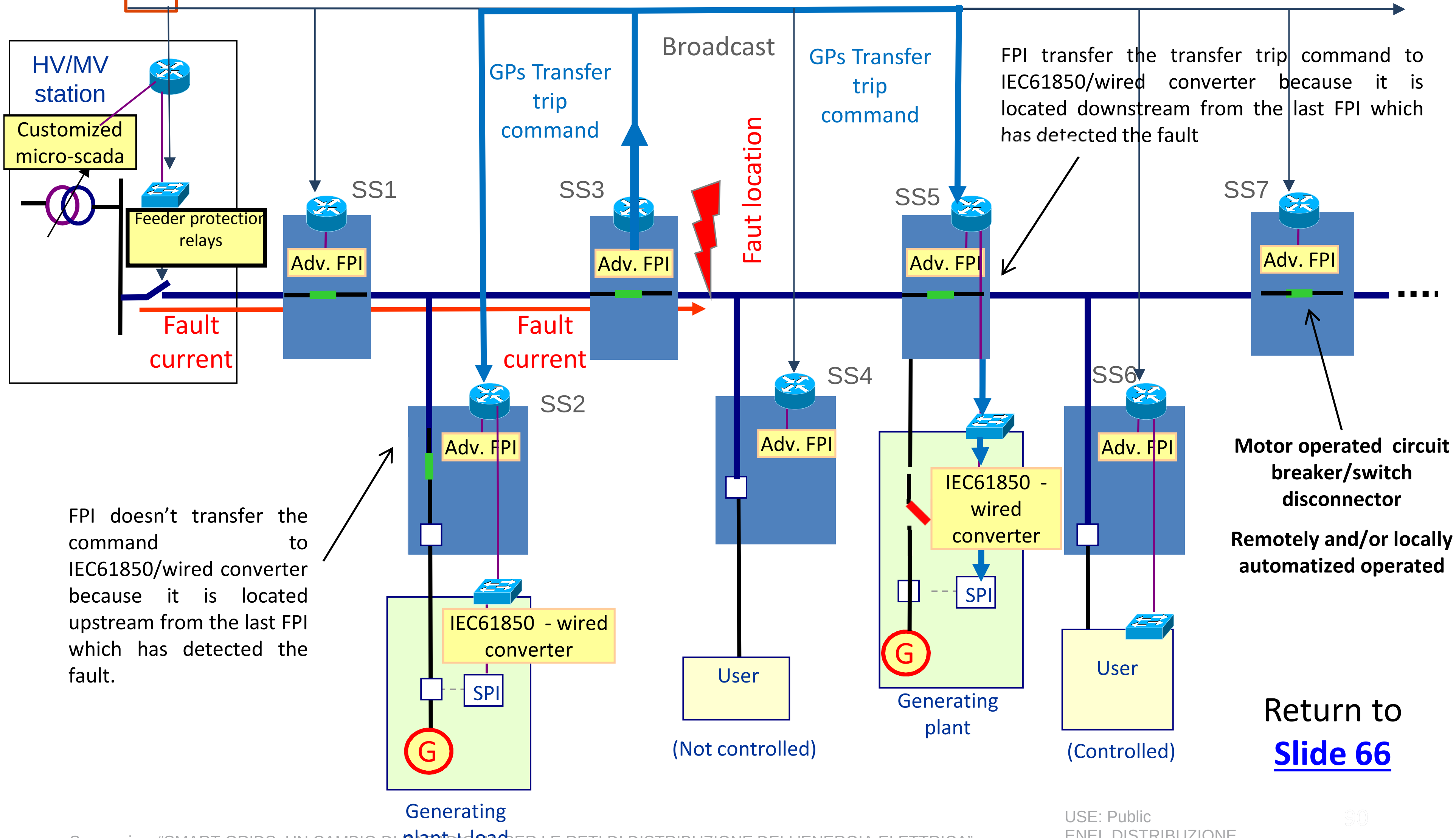
Enabling more sensitive thresholds (narrower frequency windows, i.e. 49,8 Hz/50,2 Hz instead of 47,5 Hz/51,5 Hz) using another proper signal from the Distributor will also be tested as part of the preventive actions to be implemented for the specific hazard.



This operation ensures no island

Anti Islanding + Δf

MV automatic fault location and isolation procedures.
Example of anti-islanding solution through transfer



Return to Slide 66

Smart Grid
Functional and architectural developments

Enel Distribuzione

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(different latency times according to each single function)

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SMART GRIDS

REGULATORY FRAMEWORK
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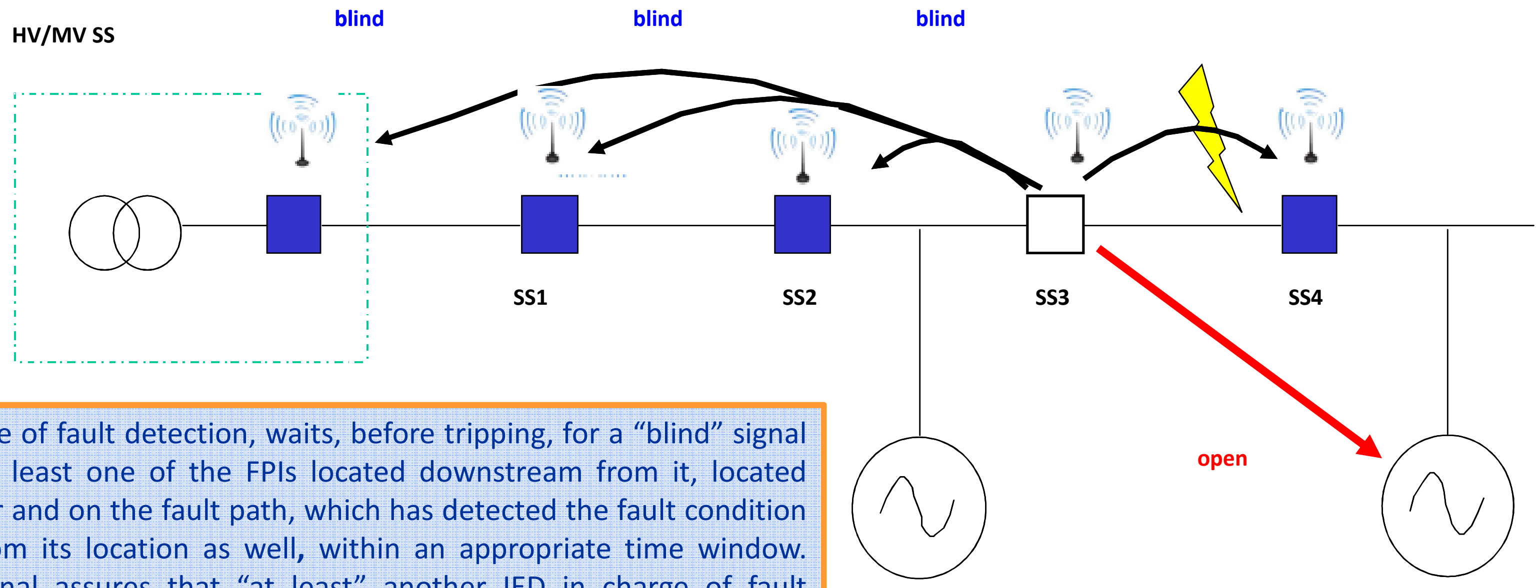
- **Dispatching rules**
- **Awards and Penalties**

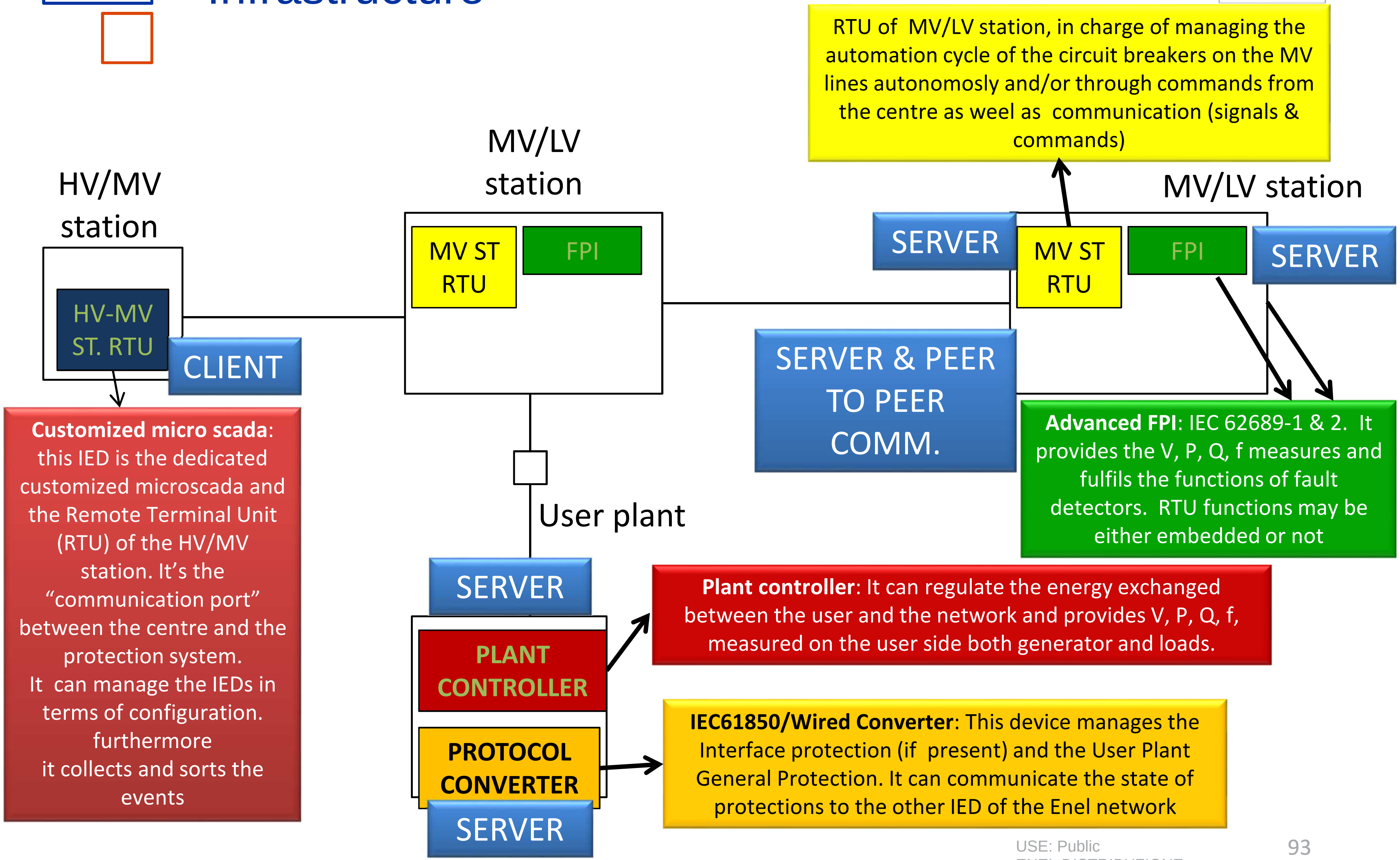
MV automatic fault location and isolation procedures

CEI 0-16 is foreseen, if the MV networks allows it, an intentional delay time of MV feeder protection relay delay ranging from 170 ms up to 250 ms (short circuits and similar faults, as cross- country ones) to improve protection selective coordination among DSOs and MV Customers. This delay could allow several advantages. An improved MV protection relay is used for each automatized feeder at HV/MV substation level both to the Distributor or to the user



The relay, in case of fault detection, waits, before tripping, for a “blind” signal coming from at least one of the FPIs located downstream from it, located along the feeder and on the fault path, which has detected the fault condition downstream from its location as well, within an appropriate time window. This “blind” signal assures that “at least” another IED in charge of fault clearing or detection along the feeder is going to cause a CB/switch disconnector opening clearing the fault

Intelligent Electronic Devices (IED) in Enel Infrastructure



Intelligent Electronic Devices (IED) in Enel Infrastructure

Enel decided to adopt IEC 61850 standard for each kind of communication (Commands, controls etc.) between all network devices (including user's devices like plant controller) in trial solutions. Main Standards considered as references:

IEC 61850-7-4

IEC 61850-7-420

IEC 61850-90-7

All IEDs data models and profiles have been defined adopting IED 61850-XX release 1. Many new logical nodes have been defined, as well as the concept of "extended electric station".

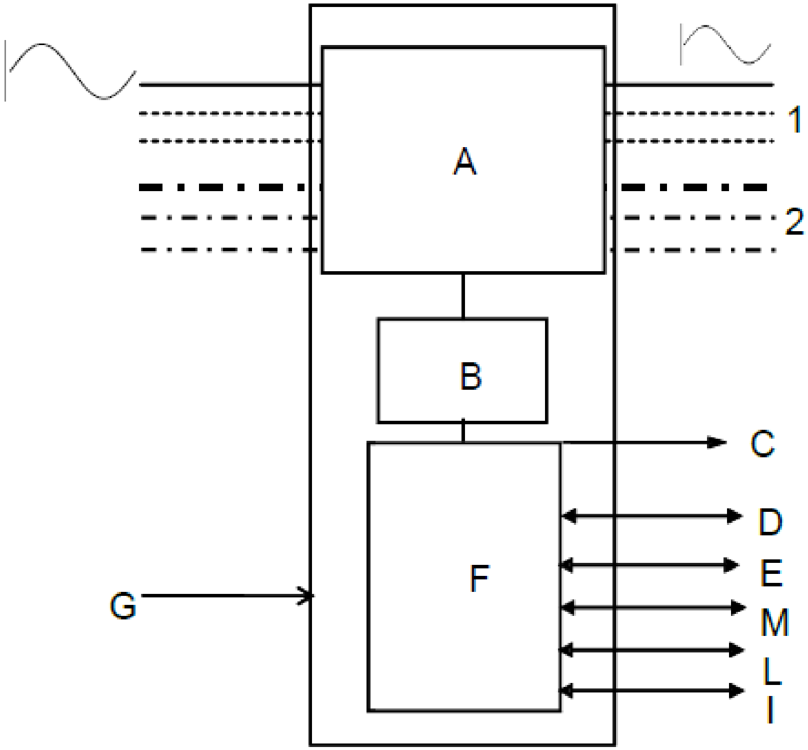
For FPI, instead, an IEC TC inside TC38 (WG46) was set up. The family standard IEC 62689 will be defined by this WG.

Part 1 & 2 will be approved from IEC by end of present year (already approved from IEC, voting process at CENELEC still on course), part 3 (data model & profile) was defined for about 50% through the action of IEC JAHG 51 (in cooperation between TC57 WG17 & TC38 WG46). IEC 61850-90-6 will be the deliverable TC 57 side.

IEC 61850 release 2 was adopted, included UML use case methodology.

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

– 24 – IEC CDV 62689-1 © IEC 2014



Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

Key:

[1]: feeder 1

[2]: feeders 2, 3,…,n

[A]: Current sensors (and voltage sensors, optional, depending on additional functions). 1 or 3 phases may be monitored, as well as more than one feeder . Sensors may be both independent components from FPI's electronics, thus respecting specific standards (for instance IEC 61869-2, IEC 60044-7, IEC 61869-4, etc), and a fully integrated elements of the FPI (not compliant to any specific standards and/or separately testable)

[B]: Transmission of signals between sensors and electronics. Up to Manufacturer

[C]: Local Indication (lamps, led, flags, output relays, etc). These indications are mandatory for stand alone applications (FPIs non inserted in a network control system), optional in case of FPIs inserted in a network automation system and/or for smart grids application

[D]: Remote indication communications and/or commands (bi-directional communication, directly or through other apparatus), optional for standard applications, mandatory for network automation system and/or for smart grids application. These signals/commands may be transmitted/received both through analogue, digital and/or communication inputs/outputs for remote communication/commands (hard wired and/or wireless)

[E]: Possible connections to field apparatus (hard wired)

[F]: Electronics for signals conditioning and indication about the passage of a fault downstream the FPI installation point

[G]: Power Supply:

- self supply from the current signal
- power supply from a non rechargeable battery
- Power supply from AC mains (a suitable backup is recommended)
- power supply from a Dc supply

Recommend supply from proper energy station (rechargeable battery or power DC supply) in case of network automation / smart grid applications

[I]: (Ethernet) Interface (copper or optical fiber) to router for communication through IEC 61850 protocol to SCADA or other FPI (IEDs) outside the Distribution Station; physical interface

[L]: (Ethernet) Interface (copper or optical fiber) to router for communication through IEC 61850 protocol to apparatus internally Prosumer's plant (inverters, generators control systems, etc.); physical interface

[M]: (Ethernet) Interface (copper or optical fiber) to router for communication through IEC 61850 protocol to other FPI (IEDs) in the same DS; physical interface

[I], [L] and [M] may also be different data flows using a single physical interface

Current sensor(s) may detect fault current passages without any need of galvanic connection to the phase(s) (for instance in case of cable type current sensors or of magnetic field sensor).

If IEC 61850 communication is present, [D] could be removed, unless compatibility with older solutions is necessary

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

Table 1 – FPI's classes to be used for data model and profile definitions and testing

Classification Code: element 1 Fault Detection capability and algorithms	Classification Code: element 2 Communication capability	Classification Code: element 3 Power supply
F1**C**/**NC**:overcurrent detection (phase to earth fault on solid earthed systems), non directional, fault detection **C**onfirmation through voltage absence detection needed/**N**o **C**onfirmation through voltage absence needed for fault detection	T1: no intra/extra-substation communication directly managed from FPI	P1: self powered. The FPI doesn't have any terminal to connect any external power supply (no power port) neither any internal battery.
F2C/NC:phase to earth fault detection (except on solid earthed systems), non directional, fault detection Confirmation through voltage absence detection needed/No Confirmation through voltage absence needed for fault detection	T2: no extra-substation communication directly managed from FPI	P2: internal power supply (batteries, solar cells, etc, no power port)
....	T3: Client/server communication	....
....	...	....
etc.	etc.	etc.

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

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....	T3: Client/server communication	....
....	...	....
etc.	etc.	etc.

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

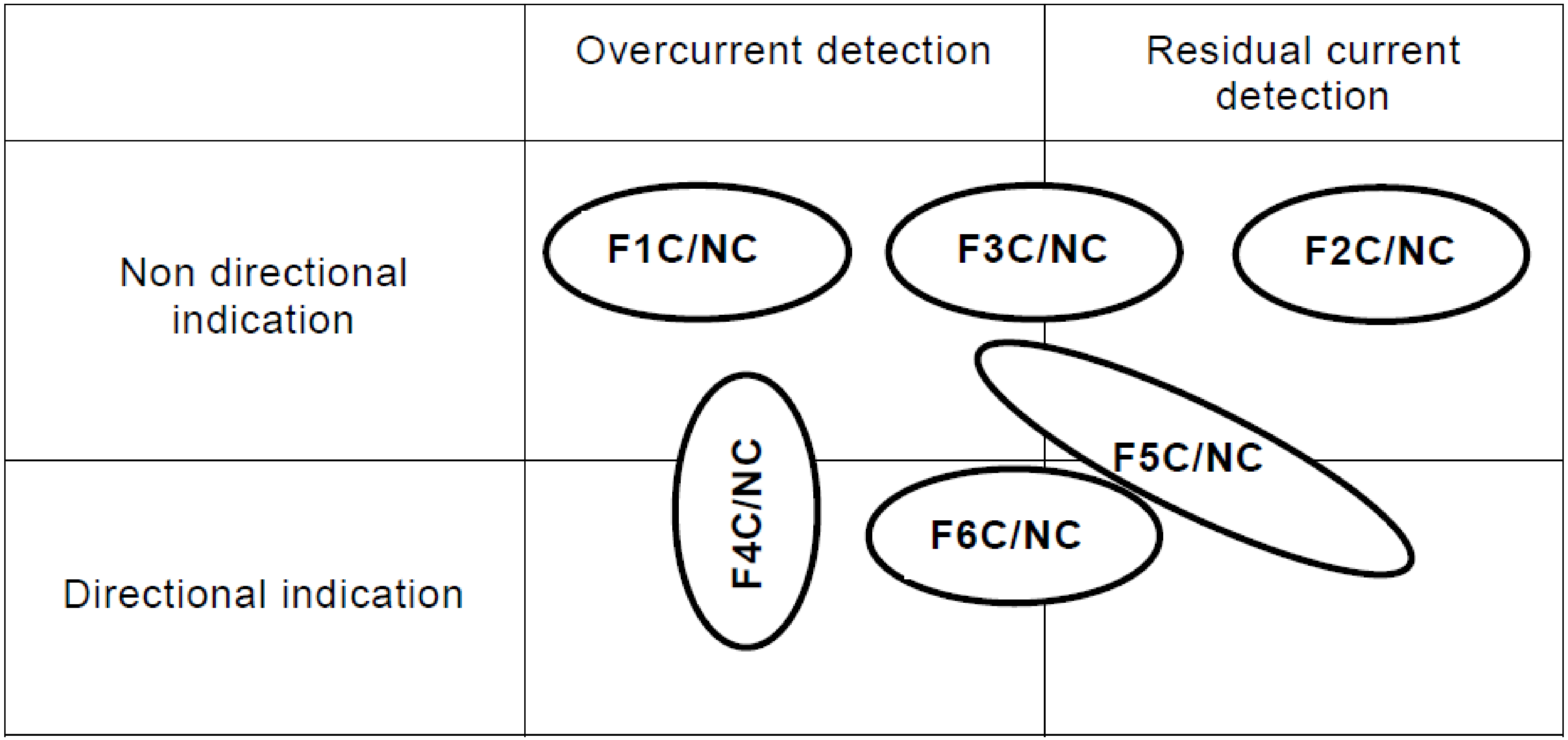
In addition, the same with the aim of properly define data model and profile (see IEC 62689-3: "Current and voltage sensors or detectors, to be used for fault passage indication purposes. Part 3: Data Model and profiles, digital interface, communication protocols"), a further additional classification level is needed (see subclause 8.4.4), to describe possible additional optional functionalities for FPIs/DSUs.

Examples:

- F2C-T1-P1-1: is an FPI able to detect only phase to earth faults, without directional detection functions, with need of fault confirmation through voltage absence detection, without possibility of remote communication (only local indications through lamps, flags, etc), self powered. It is a FPI for local indication of fault detection, with no additional optional feature (basic level FPI);
- F1NC-T2-P3-3: is a FPI able to detect only overcurrents, without directional detection functions, without any need of fault confirmation through voltage absence detection, with possibility of communication only with SCADA system not directly managed from the FPI (managed through other IEDs, for instance a RTU + modem, etc), with external power supply with/without backup capability. It is a FPI for remote indication of fault detection, with most of possible additional optional features, such as FPI internal status and alarms, distribution substation monitoring (e.g. measurements, alarms, etc.) and voltage and current measurements for operation purposes (advanced level FPI);
- F5C-T3-P3-4: is a DSU able to perform non directional detection both of phase to earth faults and overcurrents, plus directional detection of phase to earth faults, with need of fault confirmation through voltage absence detection, with local indications through lamps, flags, etc and with possibility of remote communication only with SCADA (Extra-substation communication) directly managed from FPI(for example through modems directly controlled from the DSU itself), with external power supply with/without backup capability. It is a DSU fully integrated in network operation system (SCADA), with some additional optional features, such as DSU internal status and alarms, distribution substation monitoring (e.g. measurements, alarms, etc.), voltage and current measurements for operation purposes, embedded algorithms for MV network automation (based on local measurements and/or signals from field apparatus, for instance disconnector/circuit breaker position control (basic level DSU);
- F6NC-T4-P3-6: is a DSU able to perform directional detection both of phase to earth faults and overcurrents, without any need of fault confirmation through voltage absence detection, with possible local indications through lamps, flags, etc and with possibility of remote communication direct communication (bi-directional) both with SCADA and among all IEDs (for instance through IEC 61850), with external power supply with/without backup capability. It is a DSU fully integrated in network operation system (SCADA), with most of possible additional optional features. such as DSU internal status and alarms, distribution substation monitoring (e.g. measurements, alarms, etc.), voltage and current measurements for operation purposes, Volt/VAR control, DER monitoring and control (WATT control), embedded algorithms for MV network automation (based on local measurements and/or signals from field apparatus, for instance disconnector/circuit breaker position control), transfer trip signals transmission, with the purpose to send other IEDs information able to cause DER disconnection (advanced level DSU).

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

Table 2 – FPI's fault detection capability classes to be used for data model and profile definition and testing



Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

Table 3 – Communication capability to be used for data model and profile definition and testing

No intra/extra-substation communication directly managed from FPI	T1
No extra-substation communication directly managed from FPI/DSU	T2
Communication DSU- SCADA (Client-Server)	T3
Communication DSUs- SCADA (Client-Server) and peer to peer communication	T4

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

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Table 4 – Power supply class

Self powered. No terminal to connect any external power supply (no power port) neither any internal battery	P1
Internal power supply (batteries, solar cells, etc, no power port)	P2
External power supply with/without backup capability	P3
Combination of P1, P2 and P3	P4

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

Table 5 –additional optional features classes (not strictly related to pure fault detection)

FPI/DSU profile / Function	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
FPI/DSU internal status and alarms ○ internal fault; ○ lack of auxiliary source ○ auxiliary controls ○ others.		X	X	X	X	X
Distribution substation monitoring (e.g. measurements, alarms, etc.)		X	X	X	X	X
Voltage and current measurements for operation purposes			X	X	X	X
Embedded algorithms for MV network automation (based on local measurements and/or signals from field apparatus, for instance disconnector/circuit breaker position control)				X	X	X
Volt/VAR control					X	X
DER monitoring and control (WATT control)					X	X
Transfer trip signals transmission, with the purpose to send other IEDs information able to cause DER disconnection					X	X

Intelligent Electronic Devices (IED) in Enel Infrastructure: the FPI

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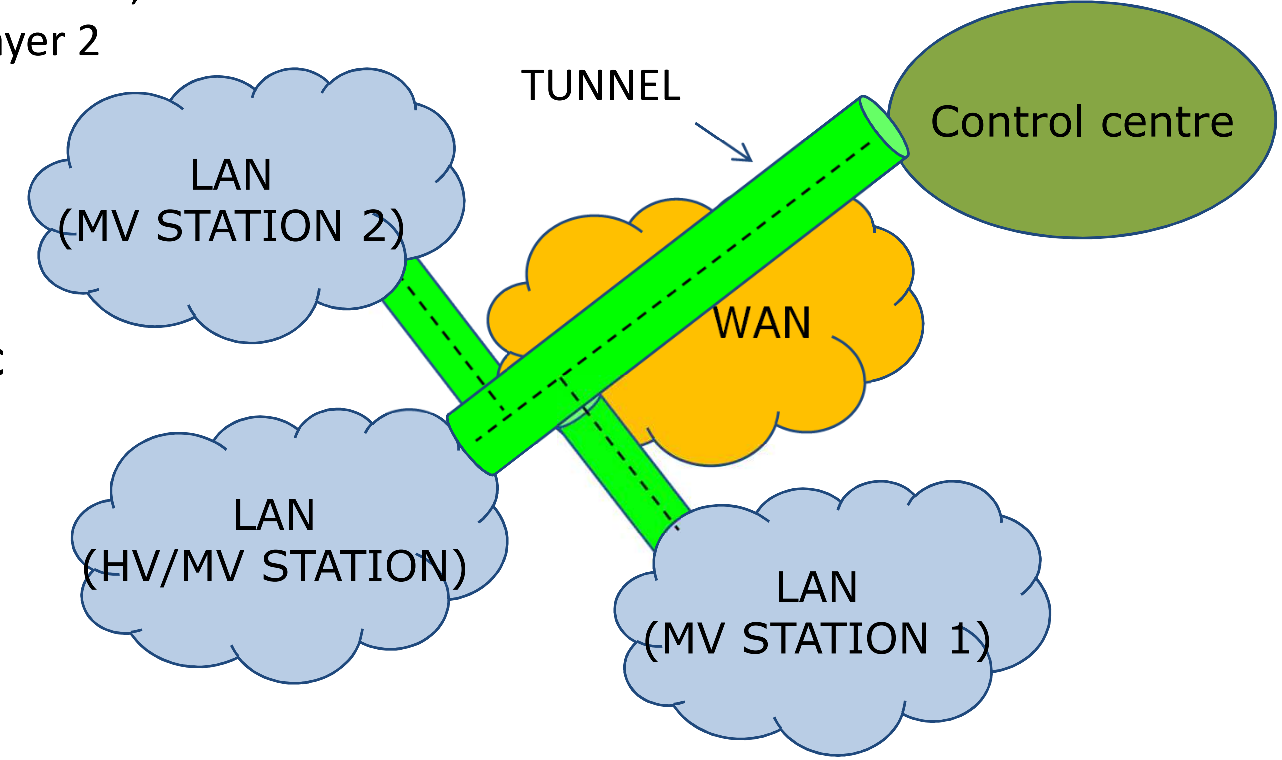
Logic selectivity signals (transmission/reception of locking signals, cumulative for all fault detection thresholds or separately for each fault detection threshold implemented in the DSU), with the purpose to inhibit the transmission of fault detection signals to other IEDs and/or the start of any internal algorithms related to actions consequent to fault detection (for instance MV network automation, transfer trip signal transmission to DER, etc)						X
	• FPIs for local indication of fault detection. Minimum level • FPIs for remote indication of fault detection. Minimum level	• FPIs for local indication of fault detection Intermediate level • FPIs for remote indication of fault detection. Intermediate level	• FPIs for remote indication of fault detection. Advanced level.	• DSUs fully integrated in network operation system (SCADA). Basic level	• DSUs fully integrated in network operation system (SCADA). Intermediate level	• DSUs fully integrated in network operation system (SCADA). Advanced level

GOOSE Messages Applications

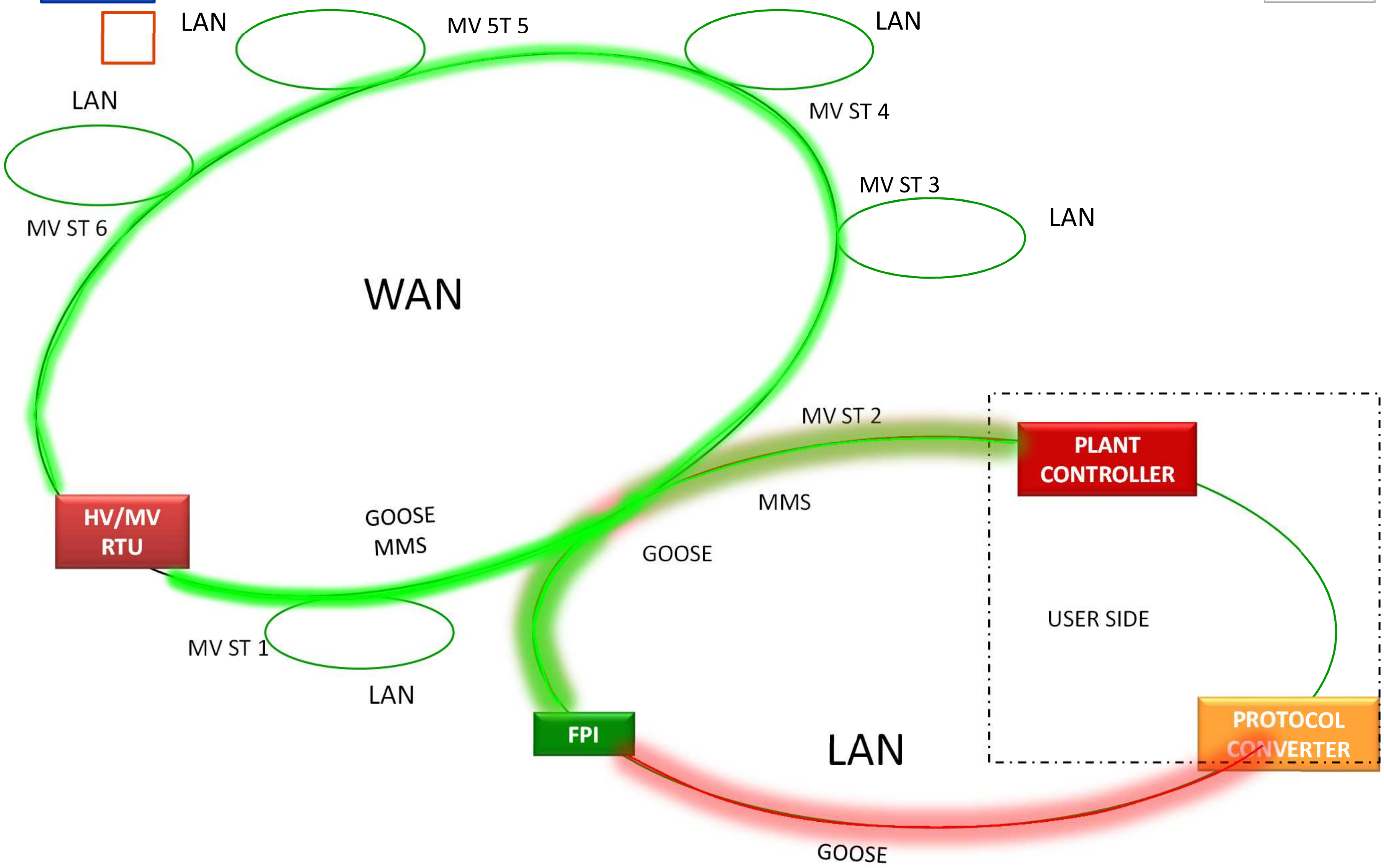
Enel uses GOOSE messages to obtain a correct operating of many of the previous functionality.

Enel has developed a communication infrastructure with WAN and LAN network using the “Tunnelling” method, based on VLAN ID. The kind of traffic is multicast messages on Ethernet layer 2

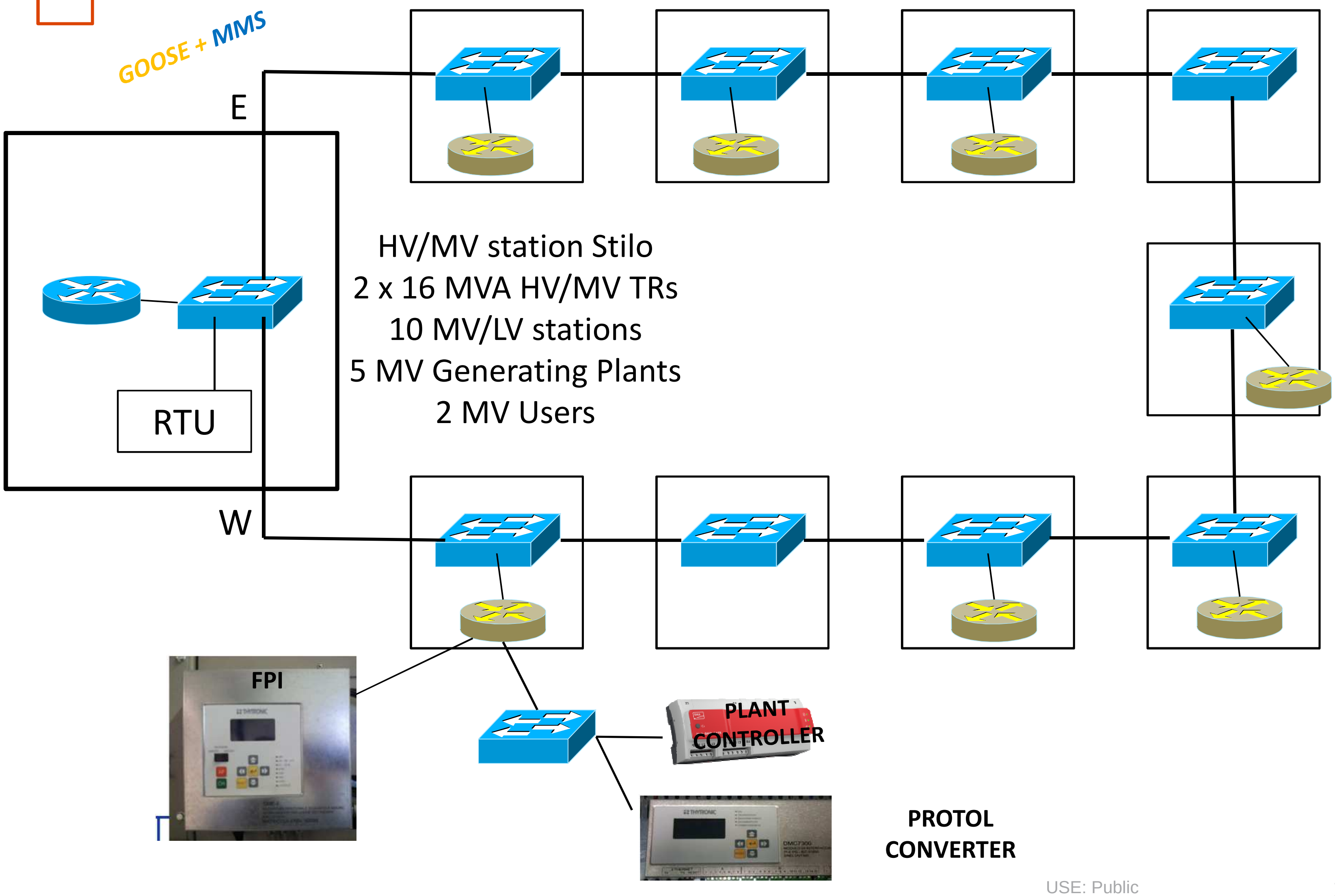
EXTENDED ELECTRIC STATION CONCEPT



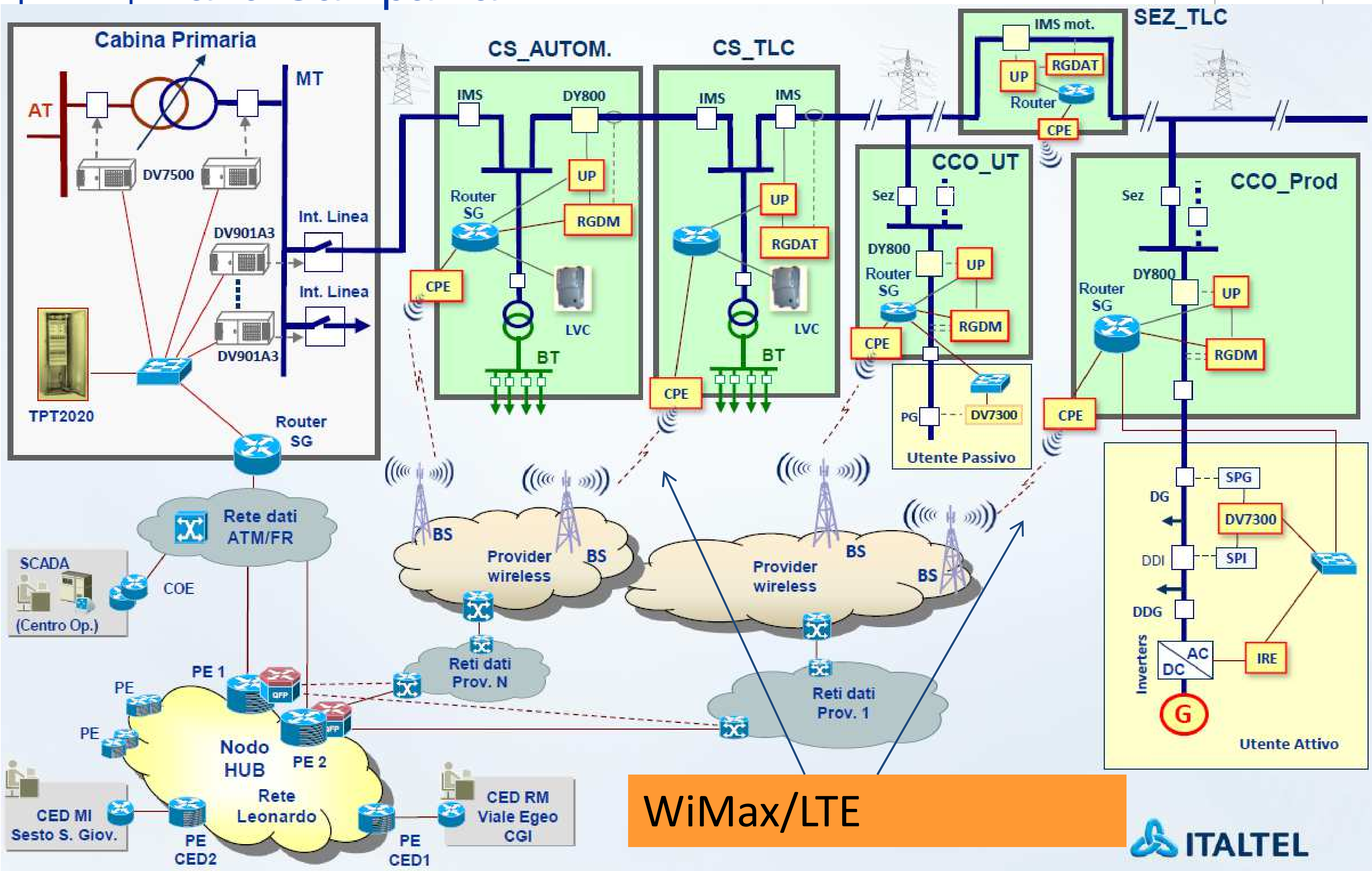
General Communication Network Scheme



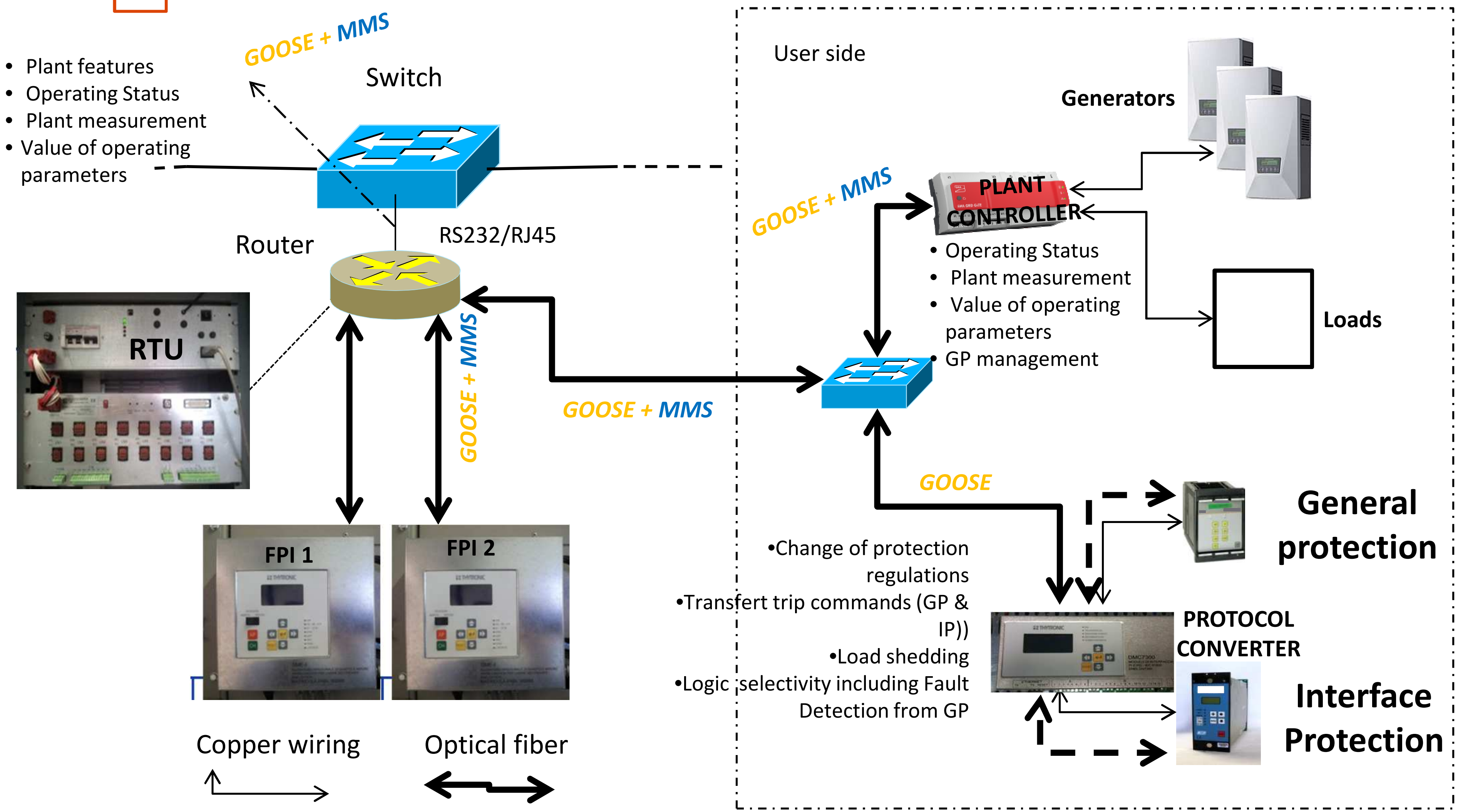
WAN - Optical Fiber solution - Calabria



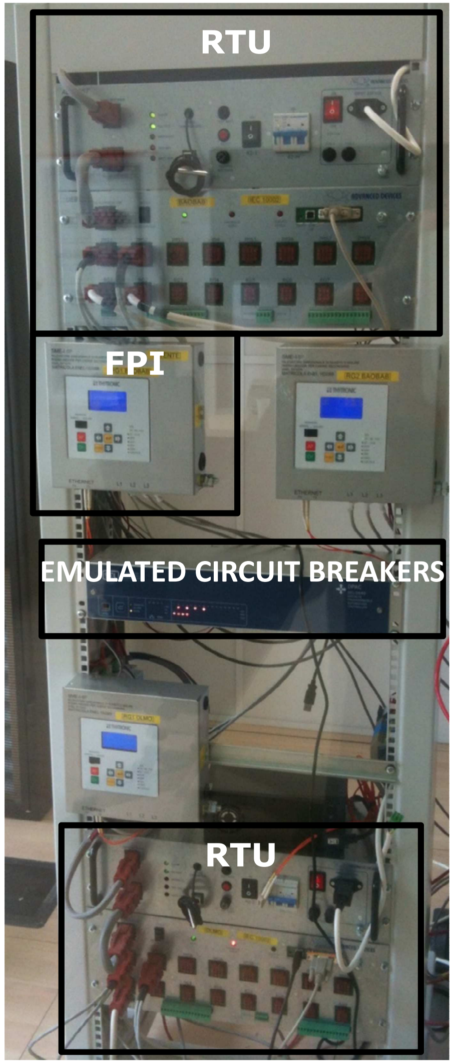
WAN - Optical Fiber solution – Sicilia, Puglia and Campania

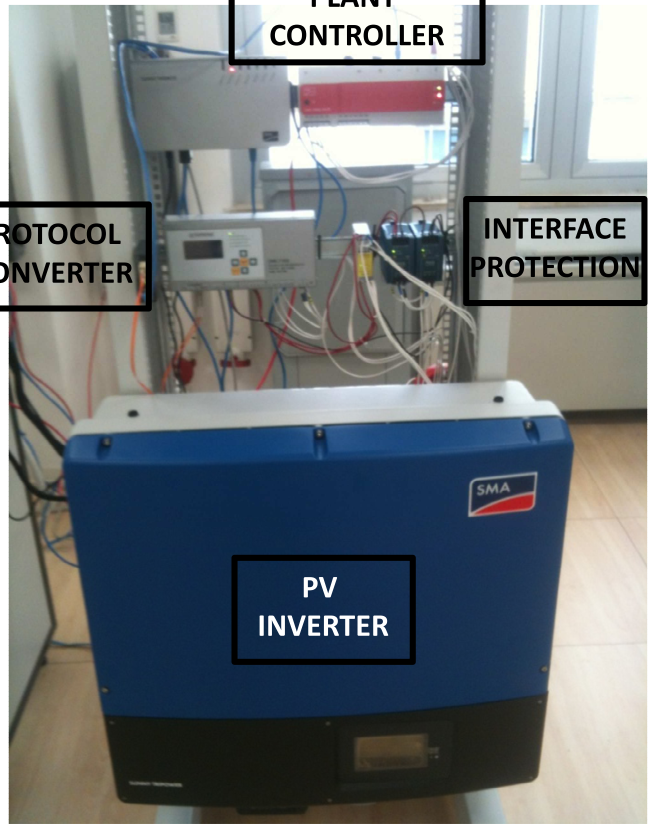


Optical Fiber Solution
Details of MV station (DSO & User)



What is Smart Grid Lab ?





What is Smart Grid Lab ?

L'EVOLUZIONE DELLA SMART GRID NON SI FERMA A EXPO: ALLO SMART GRID LAB DI ENEL DISTRIBUZIONE A MILANO SI TESTANO LE ULTIME INNOVAZIONI PER LE RETI INTELLIGENTI, TECNOLOGIA CHIAVE PER AMPLIARE SEMPRE DI PIÙ LA GENERAZIONE DA FONTI GREEN.

Nella smart city di Expo Milano 2015, Enel ha realizzato il primo spazio urbano full electric, installando una rete di distribuzione intelligente, la Smart Grid, capace di controllare e amministrare l'energia, ottimizzando l'uso di quella prodotta dagli impianti fotovoltaici installati nei diversi Padiglioni, di compensare la domanda, di monitorare gli apparati (dai LED per l'illuminazione pubblica, alle colonnine di ricarica per i veicoli elettrici), di isolare guasti su segmenti circoscritti della rete e di intervenire da remoto. Il tutto mantenendo costante l'equilibrio necessario a distribuire correttamente l'energia agli utenti finali.