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Event Driven Network Services for Smart Grids

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Presentation Outline

- TeamWare profile
- Smart grid scenario
- Low Voltage Network Services for Smart Grids
- Technical overview of an applied research for Voltage/Reactive Power distributed control solution on LV grid

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About TeamWare

- A highly evolved engineering company (SME) specialized in the design and production of electronic equipments and systems for electrical grid monitoring and control.

- Three business areas:
  - Products & Systems
  - Engineering Services
  - Research
- 40 employees

Located in Milan, Italy, since 1988

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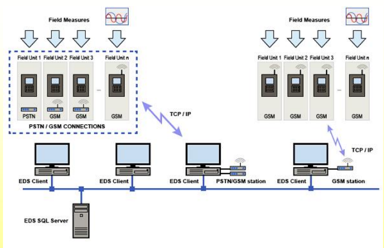
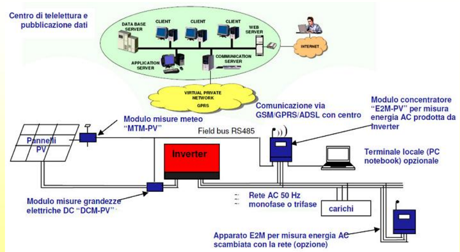
TeamWare Products Portfolio

Class A PQ &
Metering Instruments

Substation Automation
Equipments

Wireless sensors
network (Zigbee)





Automatic
reading
systems
(cloud based)

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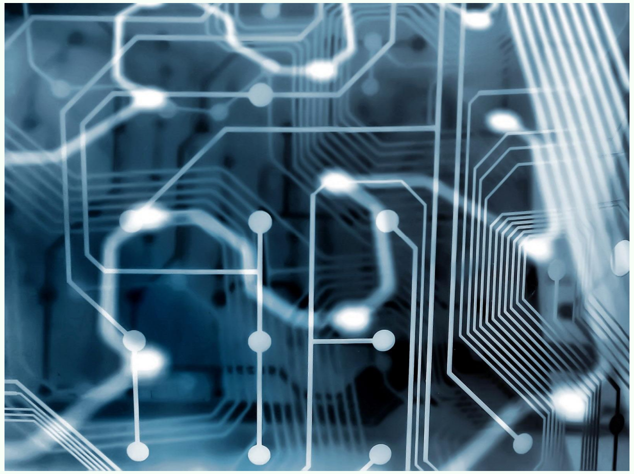
TeamWare Engineering Services



- Turnkey design for third parties of electronic devices (from feasibility study and specifications to pre-production samplings).

- Relevant expertise in applying advanced technologies in hardware (digital, analog, FPGA), firmware and software design.

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TeamWare Research Area

- Cooperation with University & R&D Centers.
- Participation to innovative research projects, with high technological contents, having positive outcome in terms of industrial application.

- Main projects where TeamWare is currently involved:
  - FINESCE - EU-FP7 (Future Internet)
  - BSL - IT Ministry of Instruction & University (Smart-living services).

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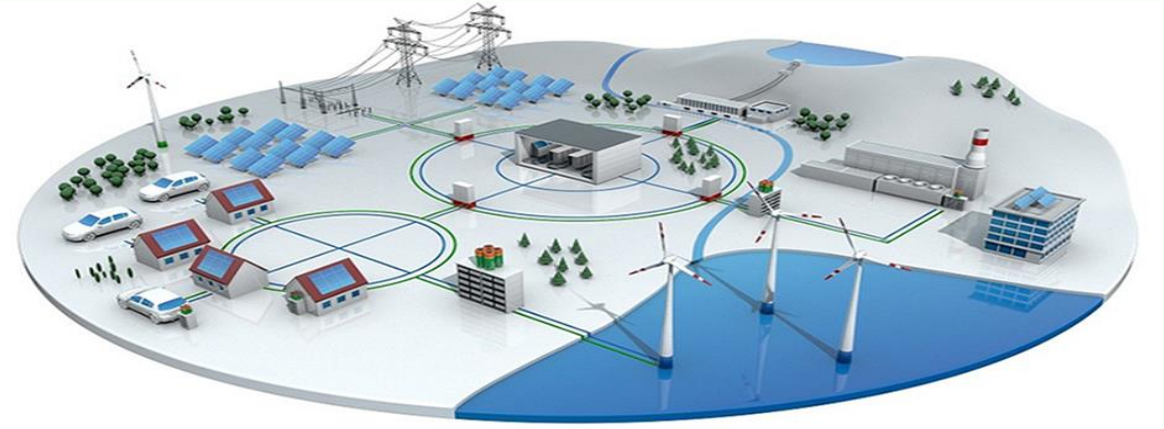
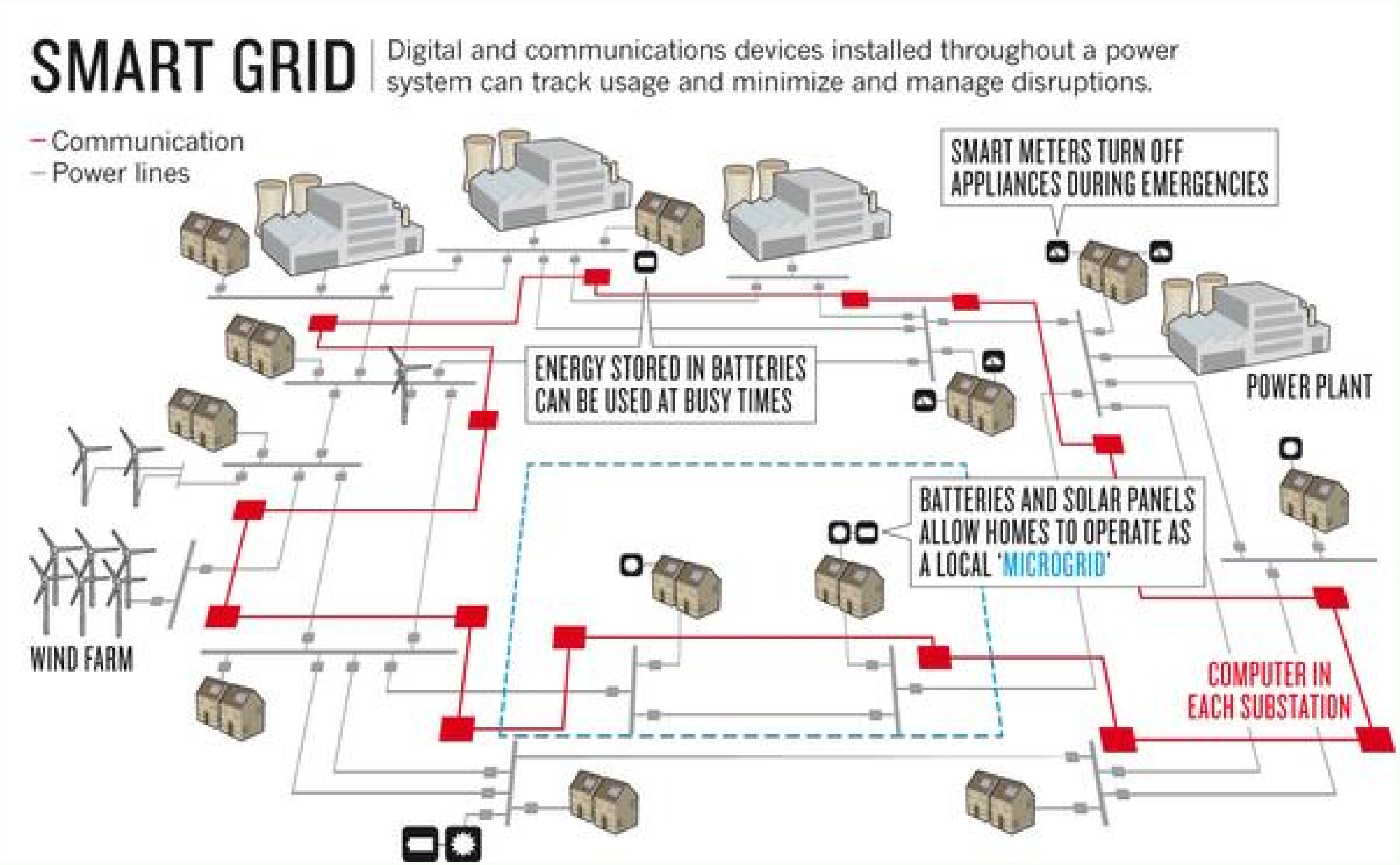
Case study

Network services increasing efficiency on LV grids



Smart Grid Scenario



Source: http://www.nature.com

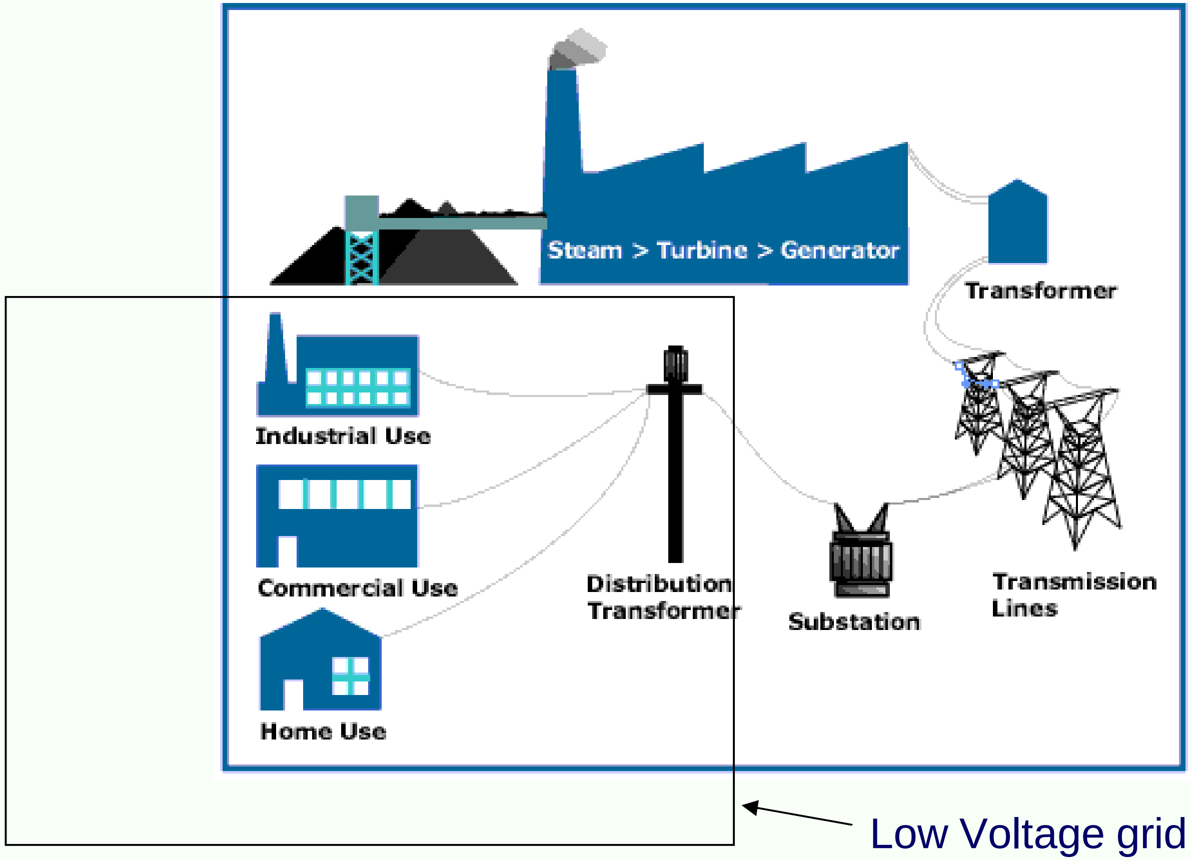
Main topics related to Smart Grids

- Power flows are bidirectional and ñvolatileò, due to intermittent nature of DG and storage systems.

- Grid equipments (IED) exchange information one another in order to allow grid control and optimization.

- Control strategies are much more complex than in the past and involve multiple stakeholders (DSO, users, energy brokers, aggregators, etcé).

Low Voltage Network Services



- Expected investments: 10 Billion EUR in next 5 years in Italy

Low Voltage Grids

Users Cluster	MV/LV transformers	Montly average consumed active energy [MWh]
25<n<100	105.722,00	1.797.947
100<n<200	62.876,00	2.052.207
200<n<300	33.991,00	1.673.426
300<n<400	16.417,00	1.057.826
>400	12.274,00	1.033.249

Italy LV Network Figures (ENEL source)

- Cable length: approx. 300-500 mt.
- Avg Power Factor: å 0.89 for users > 16.5 kW
  å 0.92 for users Ò16.5 kW
- MV/LV transformer size: from 100 to 400 kVA

Low Voltage Network Services

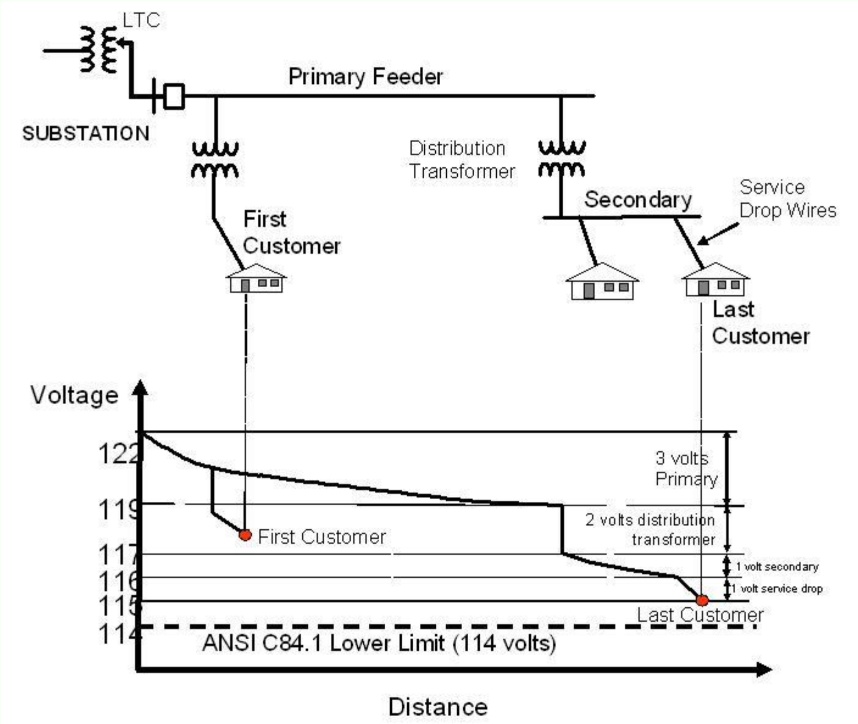
- **Voltage Level Compensation**

Power Quality standard (EN 50160) claims to keep voltage level at service entrance within a tolerance band (±10% Vn in EU, ±5% in USA) under changing load conditions.
Conventional feeder regulation (load tap changers) may be inadequate in presence of DG.
Intelligent distributed controls can solve the problem, if coordinated by optimization algorithms.

- **Increasing the lines transfer capability**

By reducing reactive power flows, optimal lines utilization is achieved with energy saving. Intelligent electronic compensators can make real-time compensation (< 10-12 cycles) of reactive components on 4 quadrants, either for inductive loads either for capacitive ones (ex. PSU of data centers).

Voltage profile distribution



Note: the presence of Distributed Generation (solar plants, wind turbines) can reverse the voltage profile.

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Low Voltage Network Services

- **Increasing MV/LV transformer efficiency**

  The magnetizing current (inductive) of MV/LV transformer may become prevalent at light loads, resulting in excessive reactive power and poor PF.
  An active intelligent power device could dynamically compensate the substation transformer, maximizing the efficiency curve.

- **Not interfering with data traffic over PLC links**

  All services needs to coexist with PLC links currently implemented by DSO for AMR billing systems, therefore there should not be present low impedances at typical frequencies of PLC band (ex. Cenelec-A band).

- **Real time measurements**

  By provinding a rich set of real time measurements, process knowledge about energy dynamics is achievable, making possible to elaborate user load profiles (NILM) and to formulate the decision support elements improving efficient demand-response management.

CHALLENGES

- Efficiency (close to 99%)
- Seamless connection to existing grid (no supply interruption)
- Small form factor to fit in existing junction boxes
- Reliability (lifetime > 10 years)
- Adequate price/benefits ratio (break-even time < 4 years)
- Time to market (not reinventing the ñwheelò)

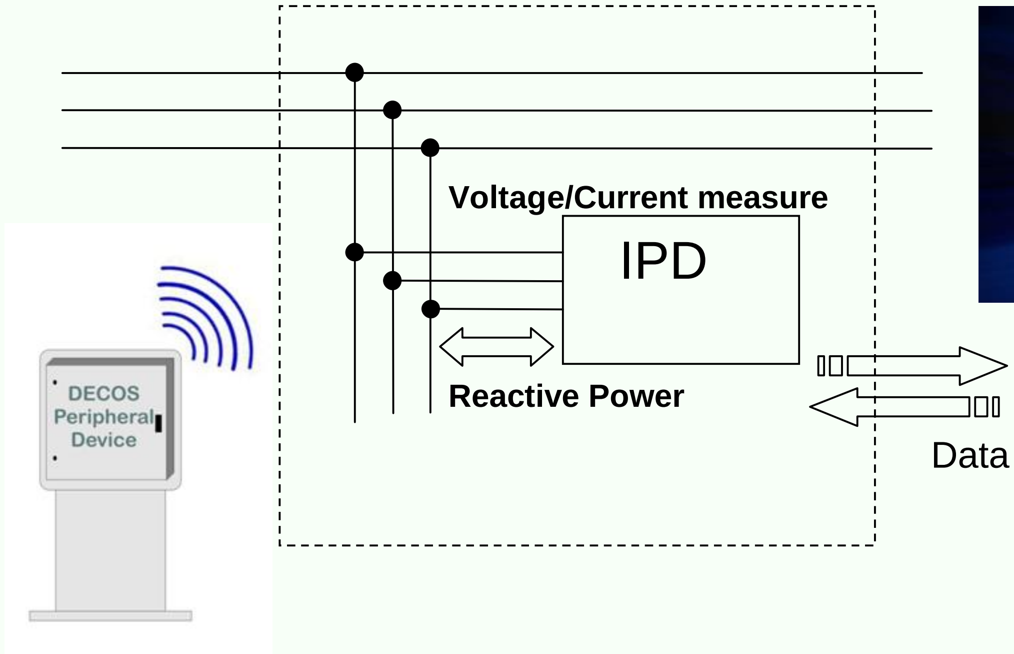
Proposed solution

DECOS, a three-level distributed Voltage and Reactive Power control system consisting in:

- IPD: distributed active shunt controllers grid connected (roadside or at building points of delivery)
- ITC: control unit executing voltage and reactive power coordination control algorithms
- IANUS: links to middleware

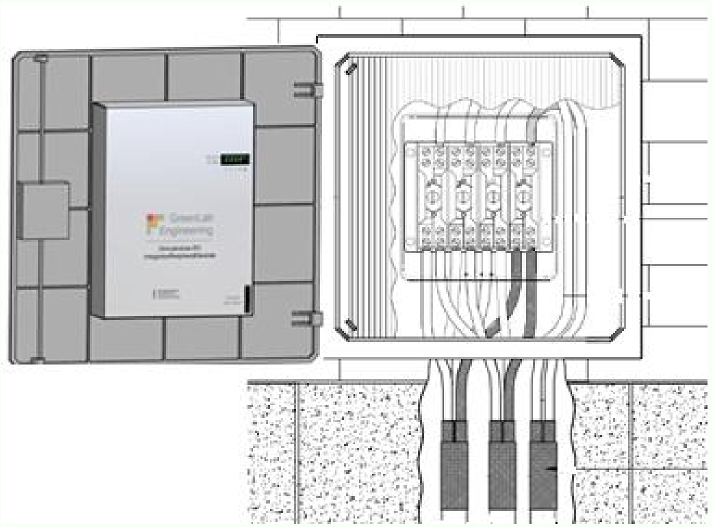
Winning proposal at ENEL Lab 2013 contest

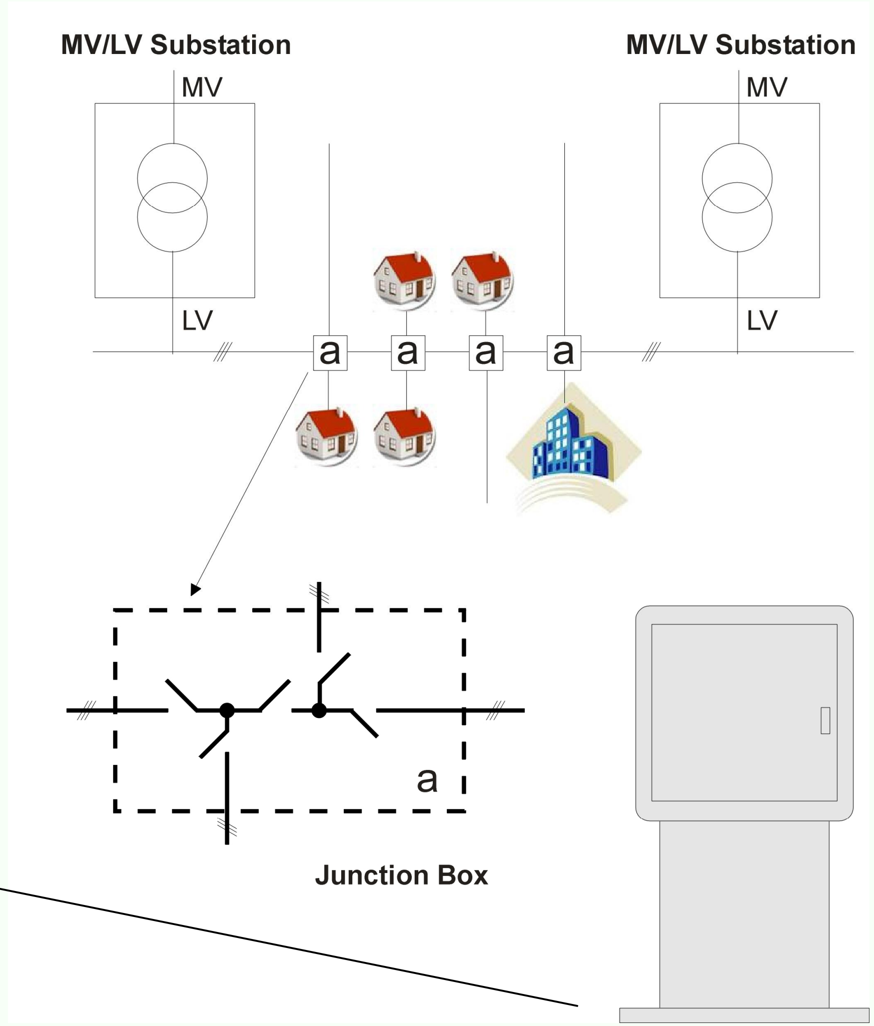
DECOS



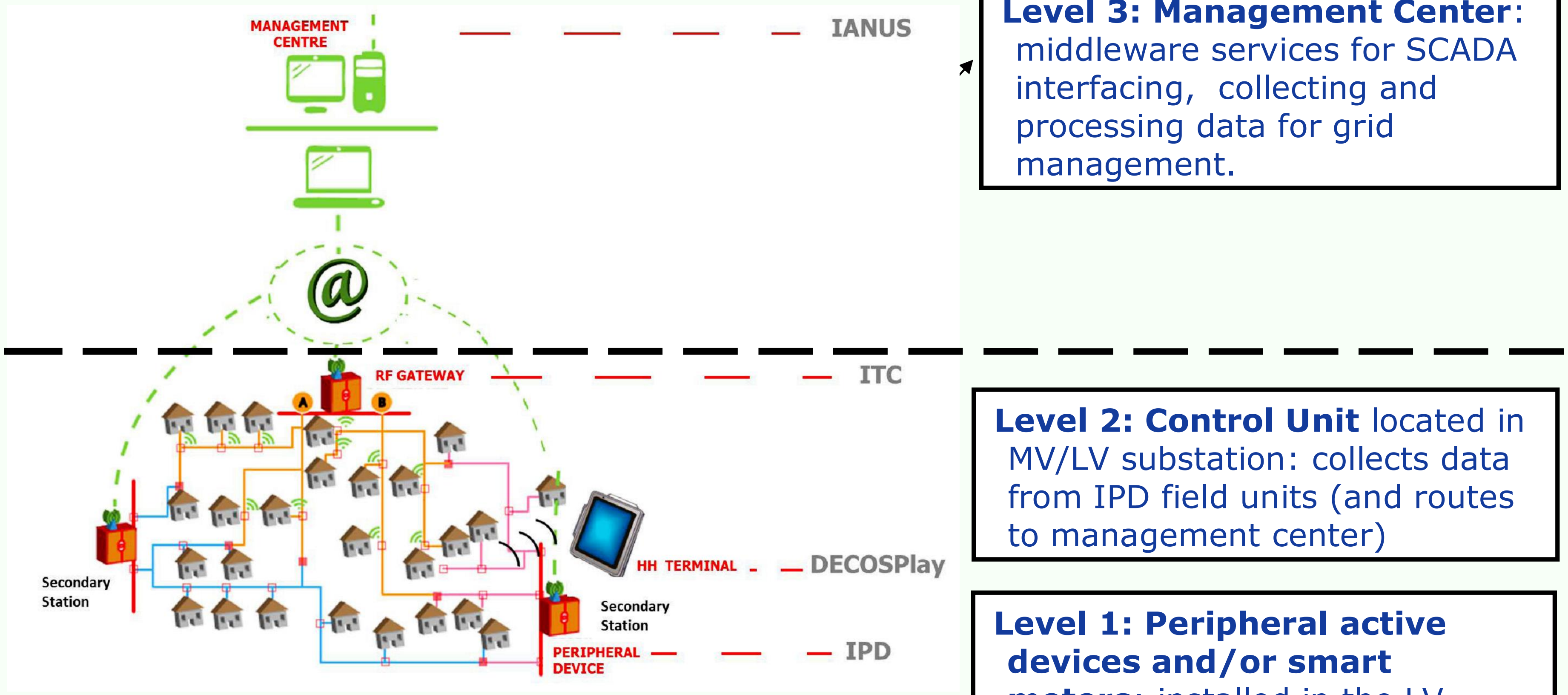
A full static distributed Volt/VAr control solution adopting the state-of-the-art hardware and software technologies.

DECOS




MV/LV Substation
MV
LV
MV/LV Substation
MV
LV
a
a
a
a
a
Junction Box

DECOS System Architecture



Level 3: Management Center: middleware services for SCADA interfacing, collecting and processing data for grid management.

Level 2: Control Unit located in MV/LV substation: collects data from IPD field units (and routes to management center)

Level 1: Peripheral active devices and/or smart meters: installed in the LV junction boxes interacts with control unit.

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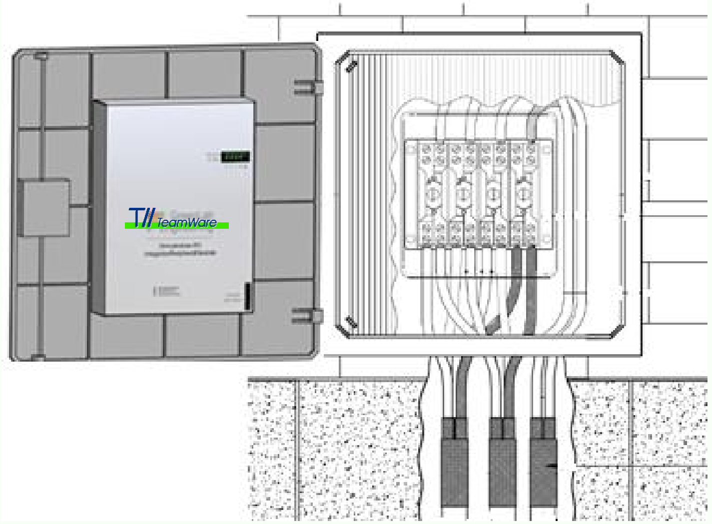
DECOS

Expected benefits:

- Reduction of energy losses due to the Joule effect: (rising PF from 0.89 to 0.95 ➔ loss reduction of 12 %).
- Reduction of voltage drops over the LV line voltage at end of the line, closer to the Vn reference value.



- Better use of voltage transformers and cables reducing investments in the upgrading of the network in case of overload.
- Detection of **non-technical losses** (energy thefts). The energy measurement makes possible energy balance along the power line.

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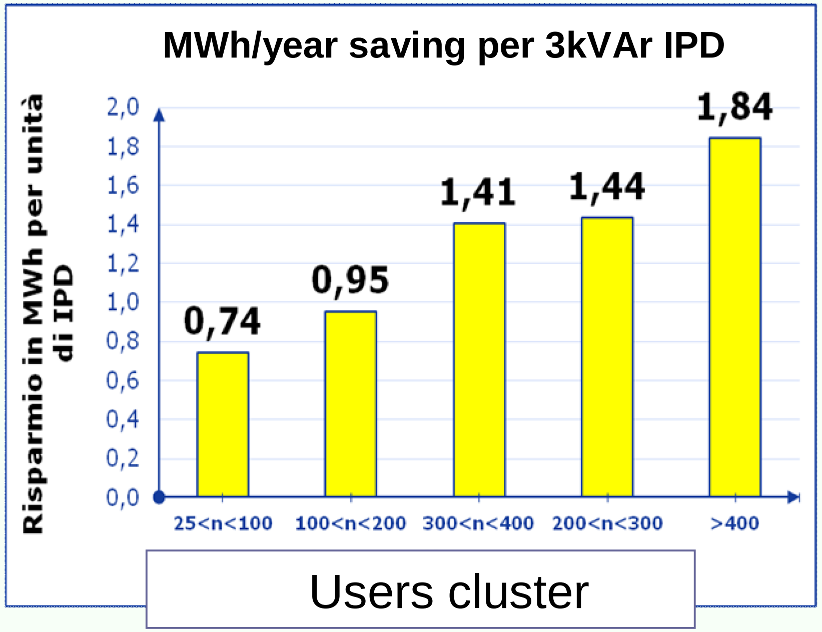
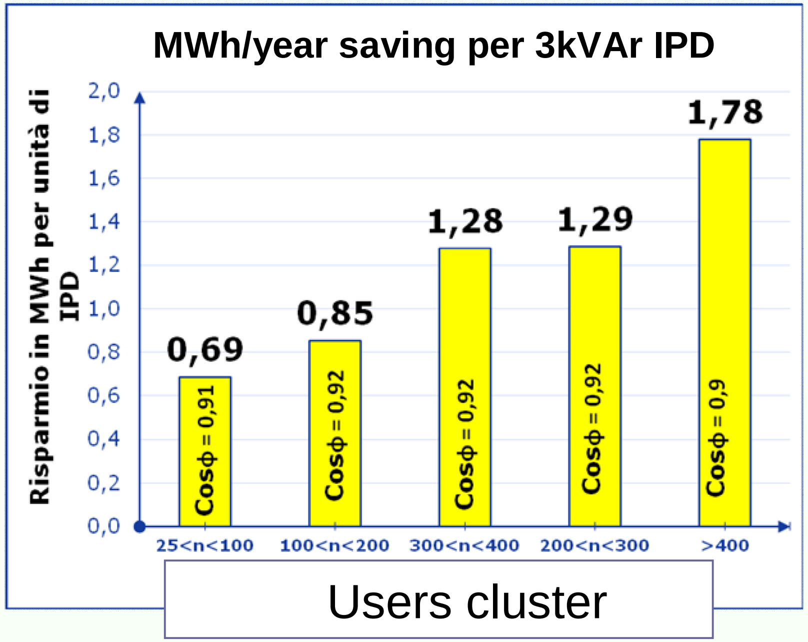
DECOS

Expected benefits (*):

(*) Italy LV grid



Best case: loss reduction 12% (from PF 0.89 to 0.95)



Worst case: loss reduction 7% as per IT-Regulator estimation

- Additional benefit: Energy Efficiency Credits (white certificates)

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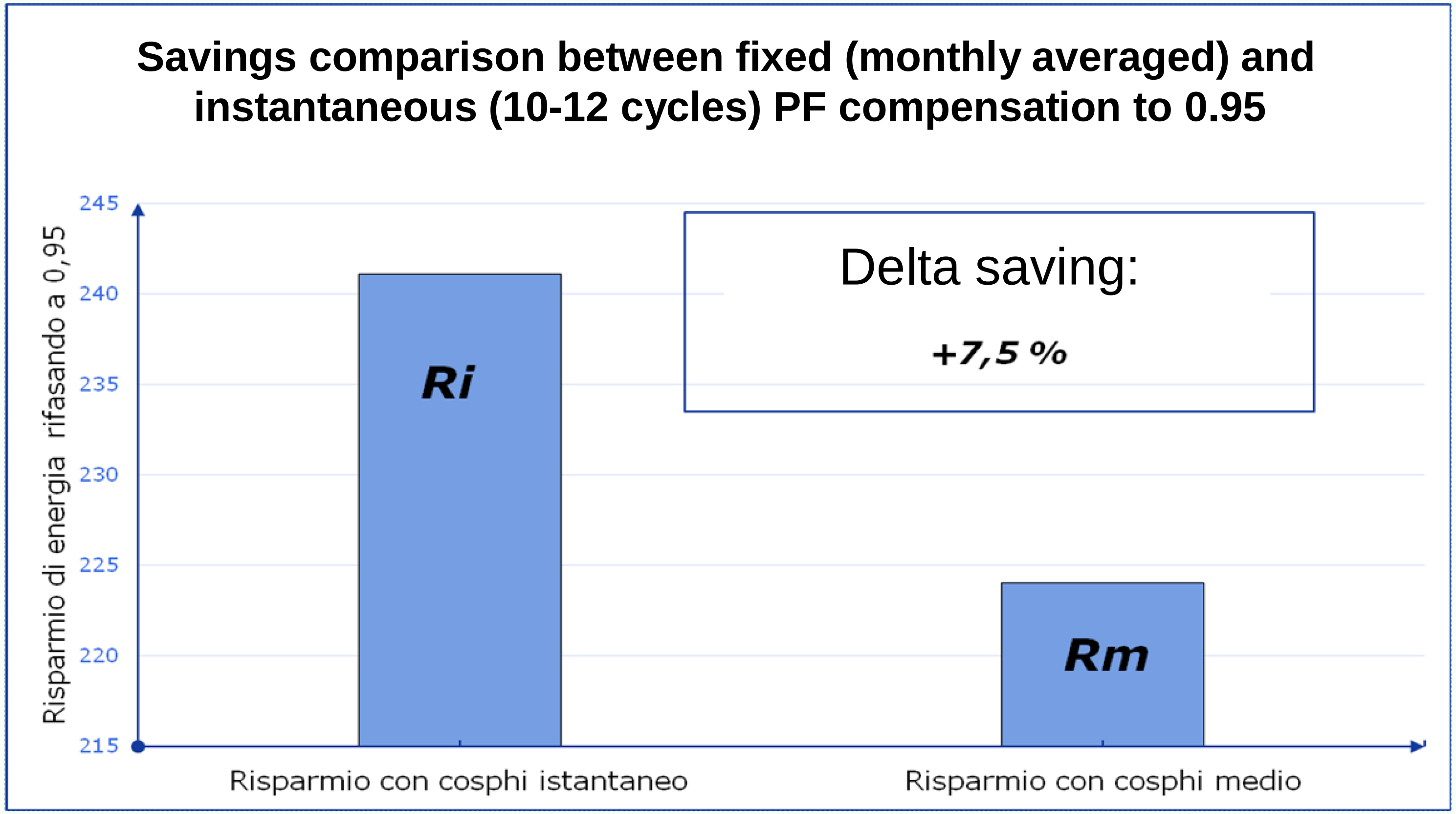
DECOS

Expected benefits:



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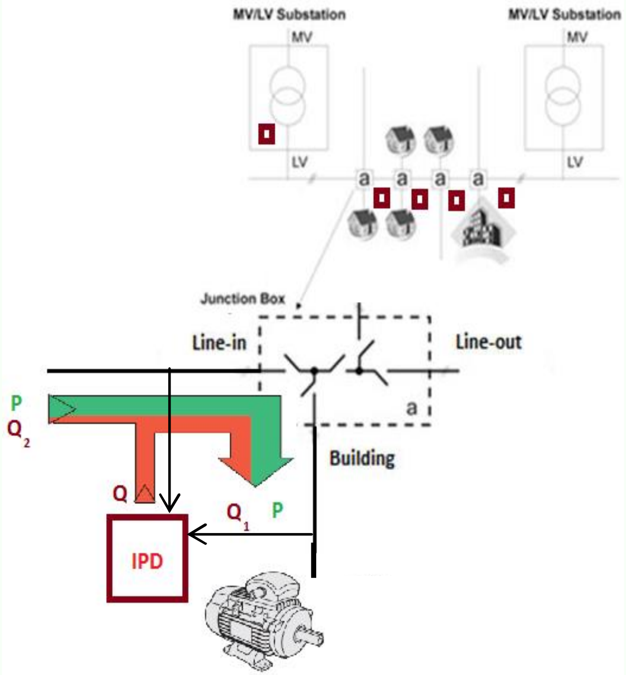
DECOS Level 1: IPD

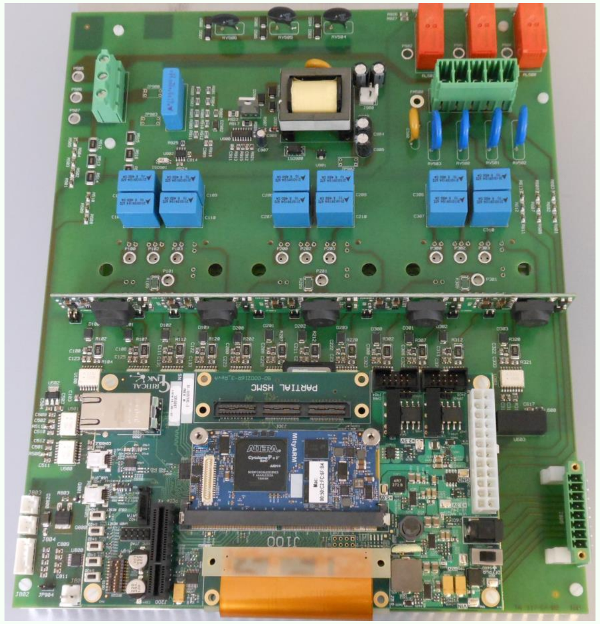
- Located into roadside junction boxes or at the buildings premises.
- Makes reactive power compensation of each type of load (ind / cap)
- Measures of V, I, P, Q, PF,THD, Freq (instantaneous and average) and energy.
- Lowers the reactive unbalance reducing the neutral wire losses.



DECOS Level 1: IPD

Technology:

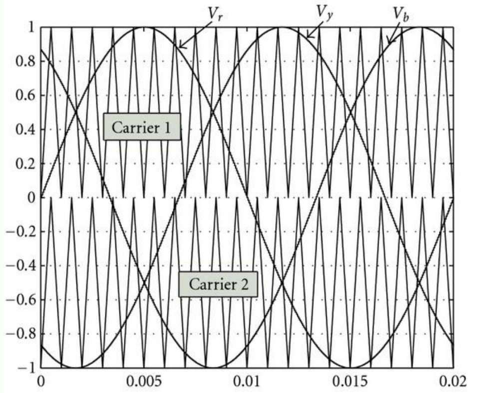
- Full static, no capacitors
- 10 to 25 kVA three-phase
- SOC (dual core CortexA9 + FPGA)
- Online connection (wired, G3-PLC, 3G mobile) with ITC control unit in MV/LV substation and other IPDs.
- Standard protocols:
  - Modbus/TCP
  - MQTT (acting as IoT device)
  - IEC61850 (over wired link)



Three-Level NPC grid connected IGBT inverter

DECOS Level 1: IPD

Control design (1/3)

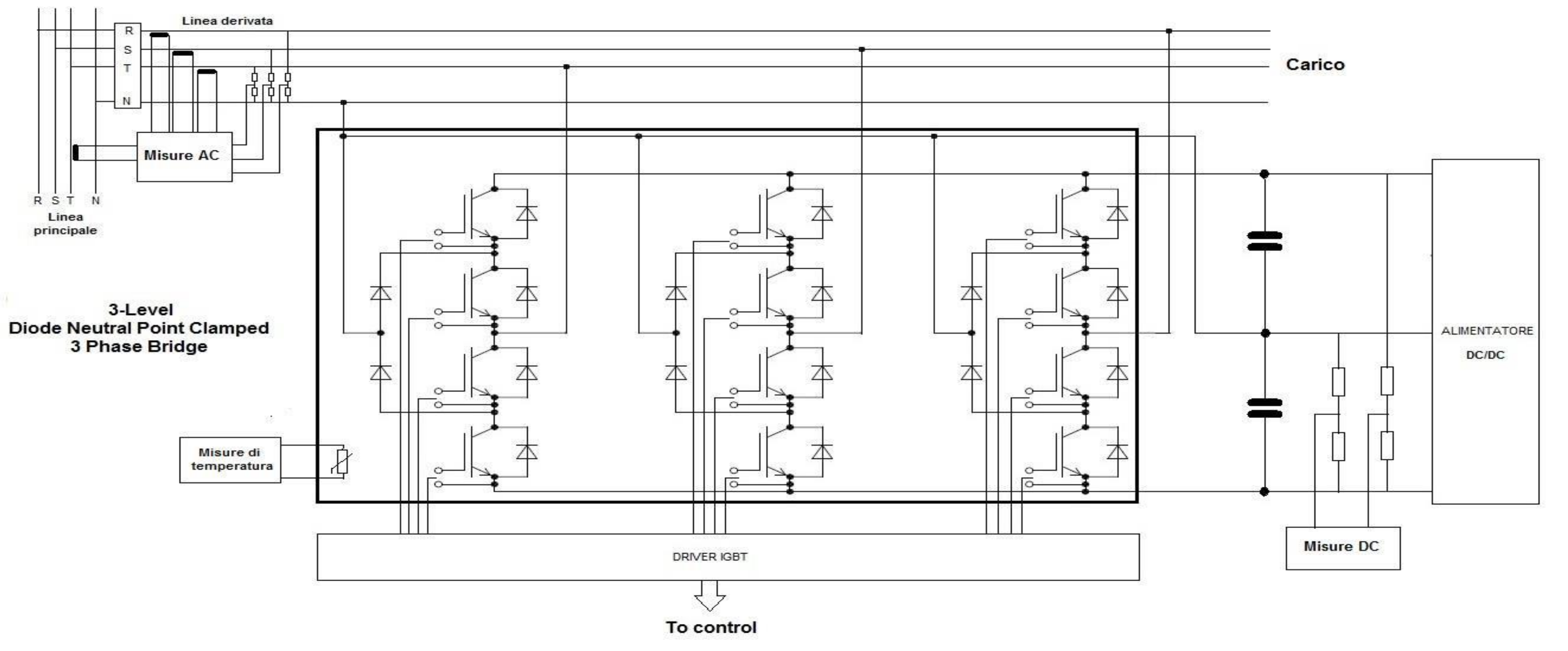


- **Mission critical tasks (related to power electronics):**
  - Parallel high speed loops (PLL, PID controllers, SYNC3 filters, Park/Clarke transform, etcé) through FPGA at 20 εs cycle time, due to strict constraints imposed by synchronous grid connection.

*No event-driven (yet**é**) control*

DECOS Level 1: IPD

Control design (1/3)



- 15 analog channels with ΣΔ samplers at 20MHz
- Bridge PWM frequency 20 kHz

DECOS Level 1: IPD

Control design (3/3)

- **Outer ñless stressedò controls follow event-driven paradigma:**
  - State machine for operation logics and working-point assessment.
  - Publishing of measure data items (ñeventsò), providing real-time grid status.
  - Synchronization and link with ITC control unit and/or other IPDs.

DECOS Level 1: IPD

Full static design grants cycle-by-cycle response time, allowing the different ñenergy efficiencyò control strategies:

- ñ*PF priority*ò
- ñ*Voltage level priority*ò

} Each IPD works mostly stand-alone

- ñ*Cooperative mode*ò

} Multiple IPDs work togheter coordinated by ITC controller

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DECOS Level 1: IPD

Applied relevant technologies:

- SOC design (FPGA + Risc)

- FSM logic architecture descripted with SCXML (W3C Proposed Recommendation)
- Asynchronous programming supporting a RESTful API for remote interfacing and control (node.js).
- Message driven publish/subscribe protocol (MQTT ï OASIS standard), lightweight transport for bandwidth constrained channels (ex. G3-PLC, 3G).
- Event-driven metering core principles.

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DECOS Level 1: Event Driven metering

- Variations of power flows from steady conditions (namely referred as "events") produce asynchronous data submission to the subscribers (control unit and/or other IPDs).
- Compared with the traditional datasets from time-driven RTU/meters, the event-driven metering data set contains valuable information but reducing traffic rates over band limited channels (ex. G3-PLC).
- Embedded into IPD and smart meter EDM.

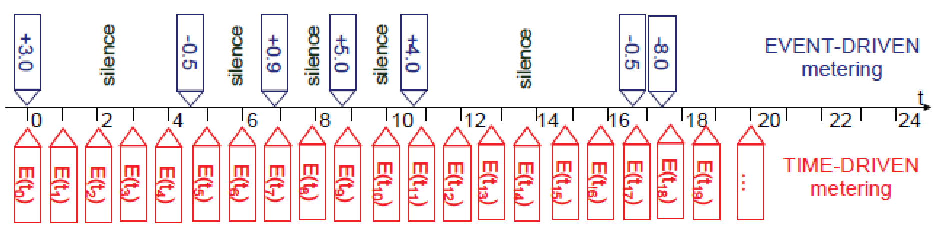
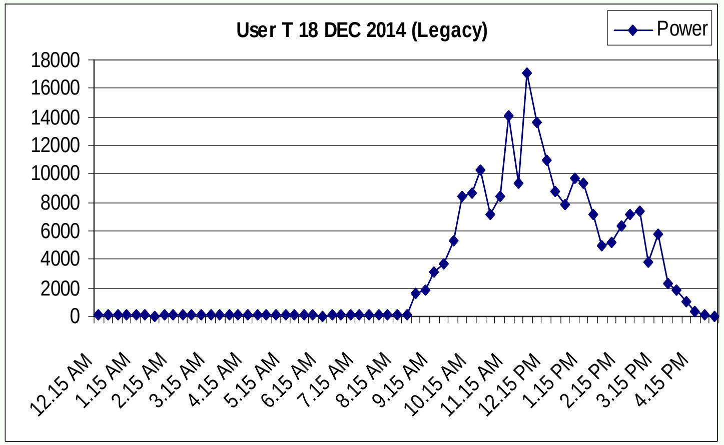


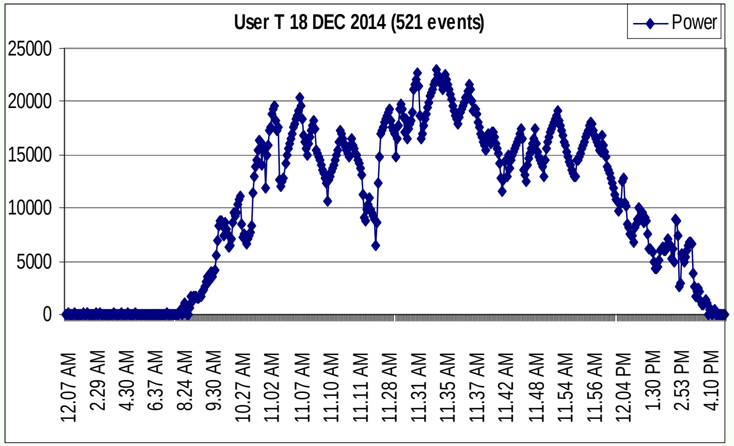
Fig. 5. Time scale in event- and time- driven metering.

Based on M. SImonov patents

DECOS Level 1: Event Driven metering

- Event-driven energy metering provides better knowledge on the processes characterizing the electricity usage, with respect to the traditional time-based energy metering.
- The ñHDòload profiling simplifies the implementation of efficiency and/or grid control programmes (e.g. demand response).





DECOS Level 1: IPD

Research topics:

- Improving efficiency applying new power electronics technologies (SiC, GaN) by reducing switching losses and/or implementing different power stage topologies / controls (e.g. increasing inverter levels, Mosfet ź IGBTs).
- Enforcing the foundation of a reference publish/subscribe messaging protocol designed to be open, lightweight, and providing security and authentication (username/password, pre-shared keys or TLS client certificates) for band constrained communication links.

DECOS Level 2: ITC

ITC - Control Unit

- Located at MV/LV substation
- Uses available real time measurements to compute the conditions that exist at observable points (IPD or EDM) on the power line, estimating electrical losses, and other parameters that are not practical to monitor directly.

Risc core PowerPC

- The ITC results determine the correct set of control actions to achieve ñoptimalò conditions required (Volt/VAR optimization, etcé).
- These control actions are sent back as new set-points to each IPD active controllers.

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DECOS Level 2: ITC

Relevant technology issues

- Event Driven model described in SCXML.
- Code generation in C++ from state-chart model.
- Integrated MQTT context broker (Mosquitto) for message events dispatching.
- IEC61850 for integration in substation automation (basically as Logical Nodes data measures provider).
- In-memory dataset (key-value store) based on open source REDIS data structure server.

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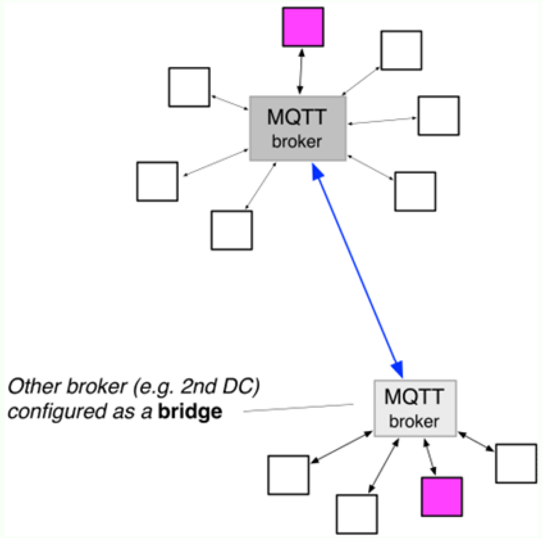
DECOS Level 2: ITC

Research topics:

- Definition & validation of distributed VVO control algorithms (cooperative mode).
- Interpreter capable to directly (and efficiently) execute a state machine defined using a SCXML document (ex. Apache Commons SCXML Java engine), for immediate reconfiguration of control algorithms.
- Scalability of message events dispatching to multi-broker architectures (e.g. bridging message broker with other brokers on other substations).



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DECOS Level 3: Middleware & Integration Services

- Software components and rest API layer for interfacing to utility SCADA systems.
- Data reports, storage and optimization services.

- Vertical integration to customer specific application environment.
- Integration with existing middleware ecosystems (e.g. Flex4Grid, Future-Internet FIWARE).

DECOS Level 3: Middleware & Integration Services

Research point: FIWARE http://www.fiware.org

- Open source componentized EDA-SOA architecture to develop, test and deploy smart energy applications and services.
- Wide catalogue of API and Generic Enablers (GEs). Examples:
  - ORION (context broker NGSI9-NGSI10)
  - COSMOS (HDFS big data storage)
  - IDAS Backend Device Management (translate the Device or Gateway specific communication protocol into NGSI).

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DECOS Level 3: Middleware & Integration Services

Research point: FIWARE http://www.fiware.org

- A Domain Specific Enabler has been developed and added to catalogue by TeamWare in cooperation with ISMB in the context of the FINESCE EU project to interface data items collected from energy meters to a FIWARE energy market place application.

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DECOS ï Technology Readiness Level

- TRL 7: System prototype demonstration in operational environment.
- Pilot Tests in two DSOs for > 20k hours total cumulated working time.
- Achieved results:
  - Reliability
  - Correct operation of control algorithms with true load variations
  - Validated data communications over mobile and G3-PLC networks
  - Efficiency: 98.2 %

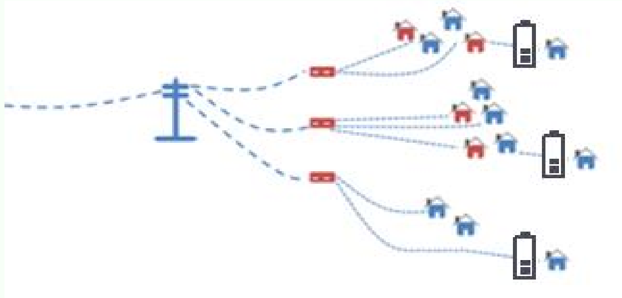
DECOS – Business Model

- Standard sale model.
- ESCO model (partly or full cost coverage by savings).
- Utility 2.0: energy as service.
- Special Industrial.

Future LV grid pathways 1/2

- Enlarging the potential of fully automated response of smart power-devices ñIPD-likeò combined with event-driven metering technology to deploy more integrated network solutions.

- **Examples**:



➢ Innovative energy-shifting demand/response services, integrating the existing grid connected IEDs (e.g. PV inverters, EV charging points) with compact low size (/cost) cooperative & distributed storage systems (grid similar to a ñhybrid carò).

➢ Multi-energy-shifting (electric & thermal energy) demand/response services, mixing electric and non-electric energy technologies (heat pumps, CHP, thermal energy storage) under a single ICT platform.

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Future LV grid pathways 2/2

Benefits for stakeholders:

- For the distribution system operators:
  - the opportunity to better estimate and forecast power flows in the network, to make the distribution network more efficient (Energetic Efficiency Credits) and to improve the power quality.
- For the electric energy suppliers:
  - the possibility to retain customers for the storage system amortisation time and to plan more efficiently the electric energy procurement with respect to the different consumption categories.
- For the customer:
  - the possibility to benefit from the improved power quality and to pay lower electricity tariffs.

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Conclusion

- LV Network services are becoming more and more pervasive in smart grid scenario.
- DECOS design demonstrates how most recent innovations in electronics (power and digital), communication and software technologies could be applied to promptly answer the need of efficient solutions.
- Regulation Authorities are encouraged to incentivize deployment of optimization voltage systems.
- Open standards will play a key role in driving exploitation of interoperable solutions.
- Research is mainly focused on increasing efficiency (new power conversion semiconductor technologies), improving control algorithms and integrating IEDs into middleware and future-internet ICT architectures.

Thank you
for your attention.