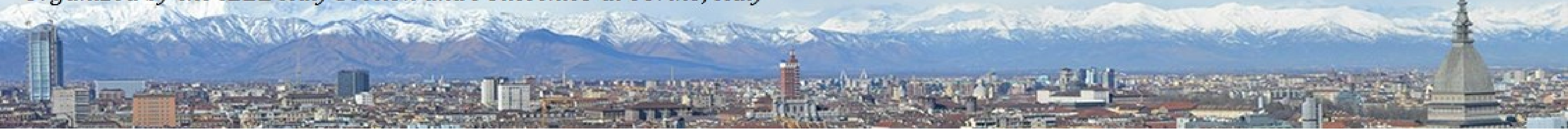
1st International Forum on

Research and Technologies for Society and Industry

Leveraging a better tomorrow

Torino, Italy, 16-18 Sep. 2015

Organized by the IEEE Italy Section and Politecnico di Torino, Italy



Tutorial

Cosimulation of power system and communications networks for smart distribution planning and operation studies

Dr. Emilio Ghiani
University of Cagliari - Italy

Outline

- Purpose of the tutorial
- Basic co-simulation issues
- Co-simulation of active distribution networks
- Co-simulation platform
  - Centralized DMS model
  - Power system model
  - Communication system model
- Application example
  - Smart distribution network
  - Discussion on simulation results

Purpose of the tutorial

- To provide insight to co-simulation methods and techniques as well as how they are being applied in distribution systems
- To assist smart grid simulator developers that wish to gain insights and learn more about simulator paradigms, architectures, etc
- It is not our intention to provide a detailed implementation guide for smart grid simulators

Basic co-simulation issues

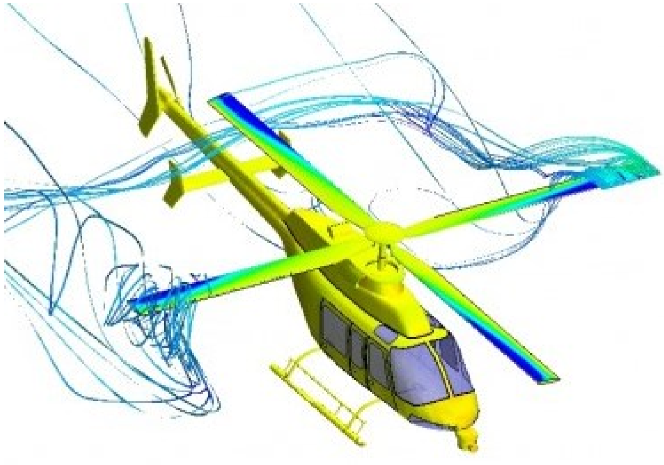
- What is co-simulation?

- Integration of software packages?
  - How can I create or retrofit a simulation program to exchange information with other simulation programs?

- Composition of models?
  - How can I take two models that differ in their resolution of time, aggregation of entities or phenomena, or in some other way and put them together to create a useful whole?

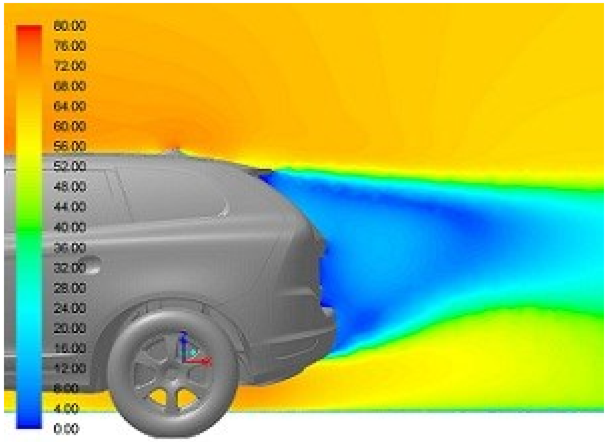
Basic co-simulation issues

- The co-simulation approach usually involves the integration of two or more simulators to capture the cyber (multi)physical dependency of a process/complex system.



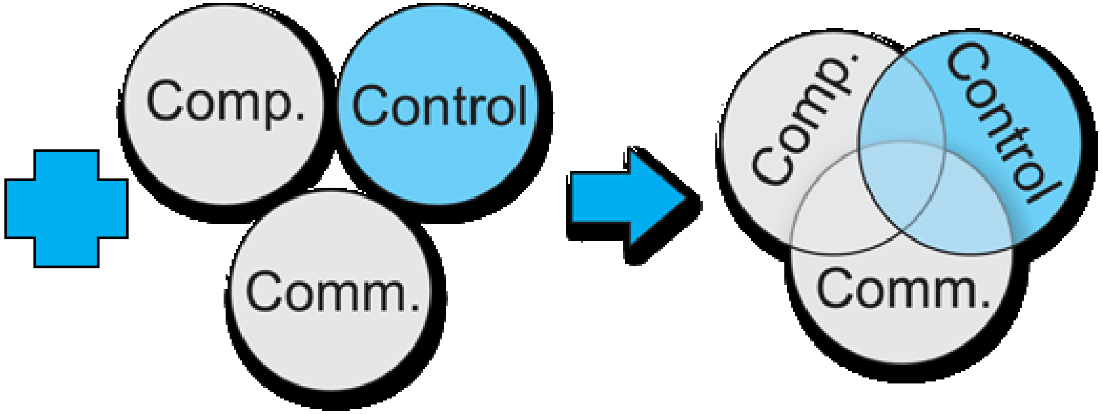
Basic co-simulation issues

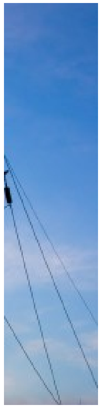
- Automobiles are typical examples of Cyber-Physical Systems
- Chemical energy (gasoline, diesel, ethanol fuel...) or electrical energy is converted to kinetic energy.
- Electronic controllers and networks present in vehicles interact with vehicles components that are sub-systems of multi-physical nature (mechanical, thermodynamic, electrical ...) and whose design involves multi-disciplinary teams.



Basic co-simulation issues

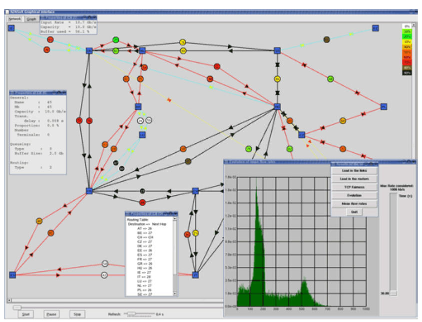
- The design of next generation high-tech smart electricity grids requires a tight coordination between computation, communication and control elements (the cyber part) on the one hand, and physical processes (the physical part) on the other hand.

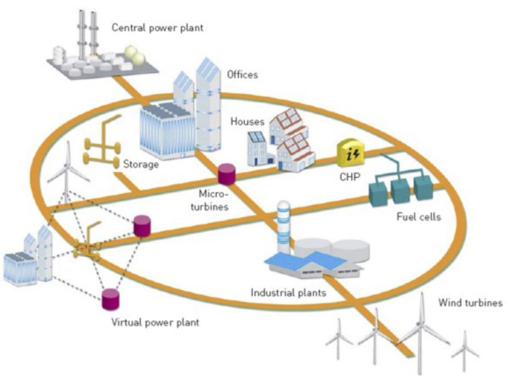


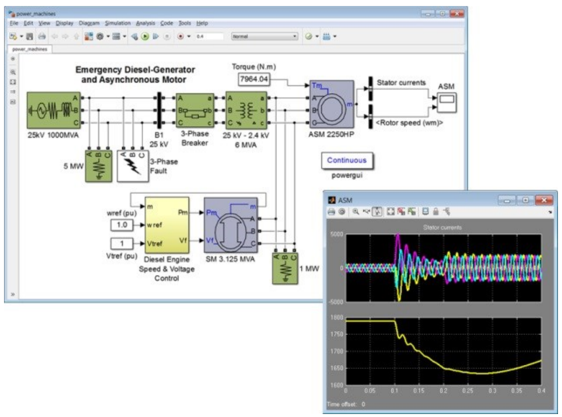


Basic co-simulation issues

- Smartgrid co-simulation involves the interaction of, at least, 2 models of sub-systems: Power System and ICT System

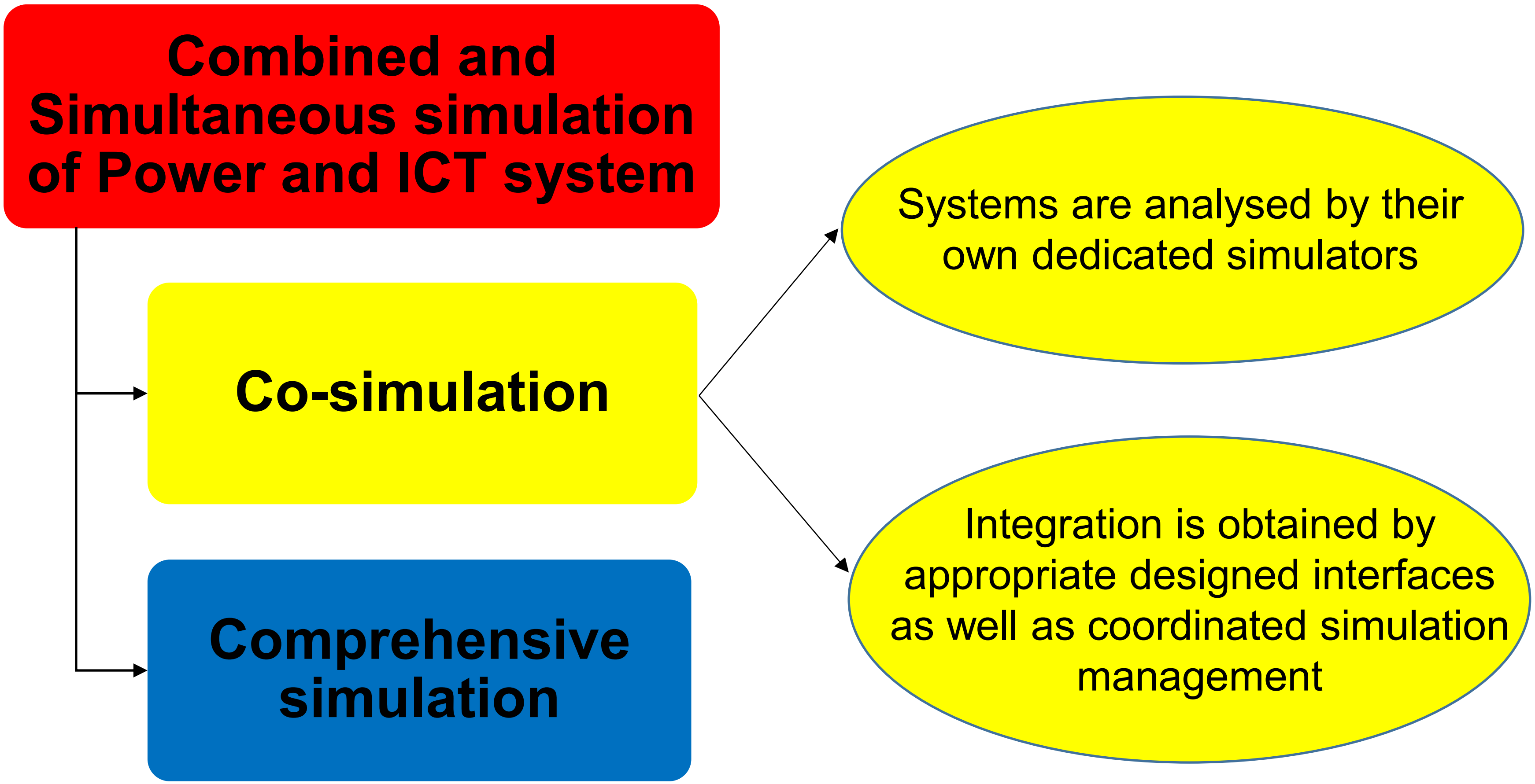






Information and Communication Tecnology System simulator ⟷ Smart grid ⟷ Power system simulator

Integrated simulation of smart distribution systems



Integrated simulation of smart distribution systems

Combined and Simultaneous simulation of Power and ICT system

- **Co-simulation**
- **Comprehensive simulation**
  - Analyzes both domains combining power system and communication network simulation in one environment
  - The challenge is to bring together both system models and solving routines which leads either to integrate power systems simulation techniques into a communication network simulator or vice versa

Simulation of active distribution networks

SDN will consist of diverse components that need to be modelized in co-simulation:

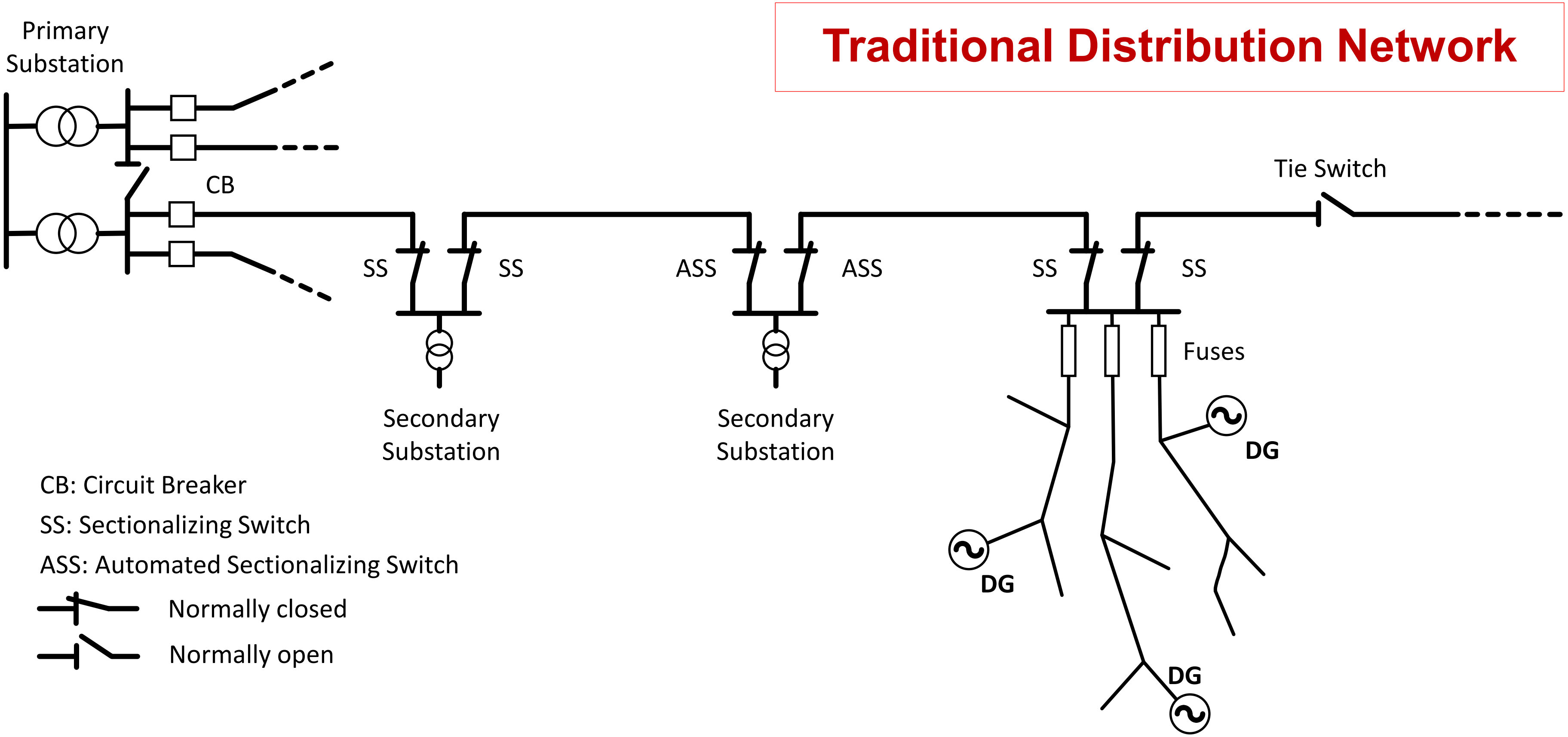
- Sensors for signal (voltage/current) acquisition
- Elements for transmitting the information to the command/control unit
- Command/control units that take decisions and give instructions based on the available information
- Components transmitting decisions and instructions
- Actuators that perform or trigger the required action

Simulation of active distribution networks

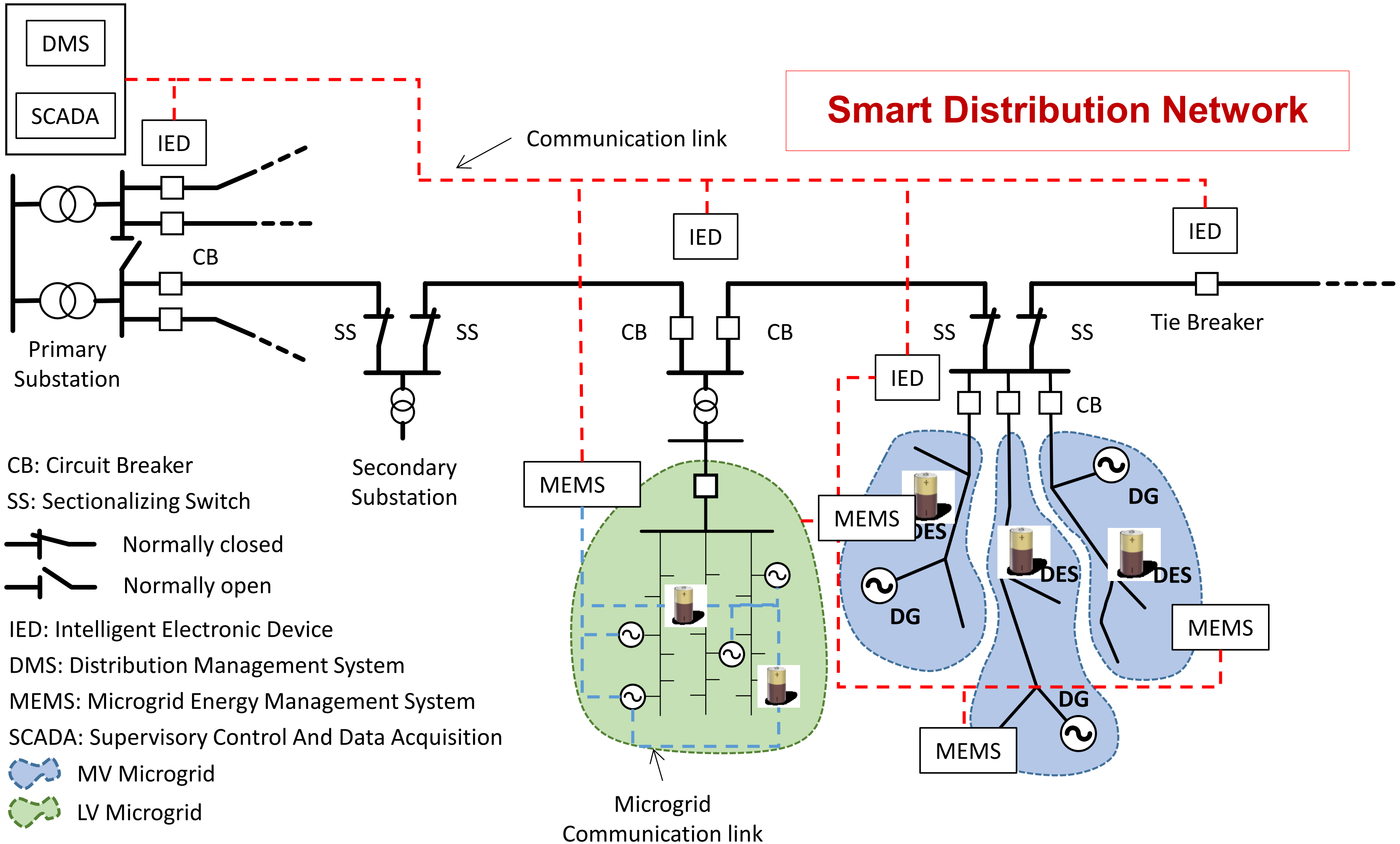
- The development of the future energy system requires a radical change in the operation of the electricity distribution network (smart/active grid paradigm)
- Smart distribution networks (SDN) have systems in place to control a combination of distributed energy resources (DERs), and distribution system operators (DSOs) can operate the electricity flows

Simulation of active distribution networks

Traditional Distribution Network



Simulation of active distribution networks

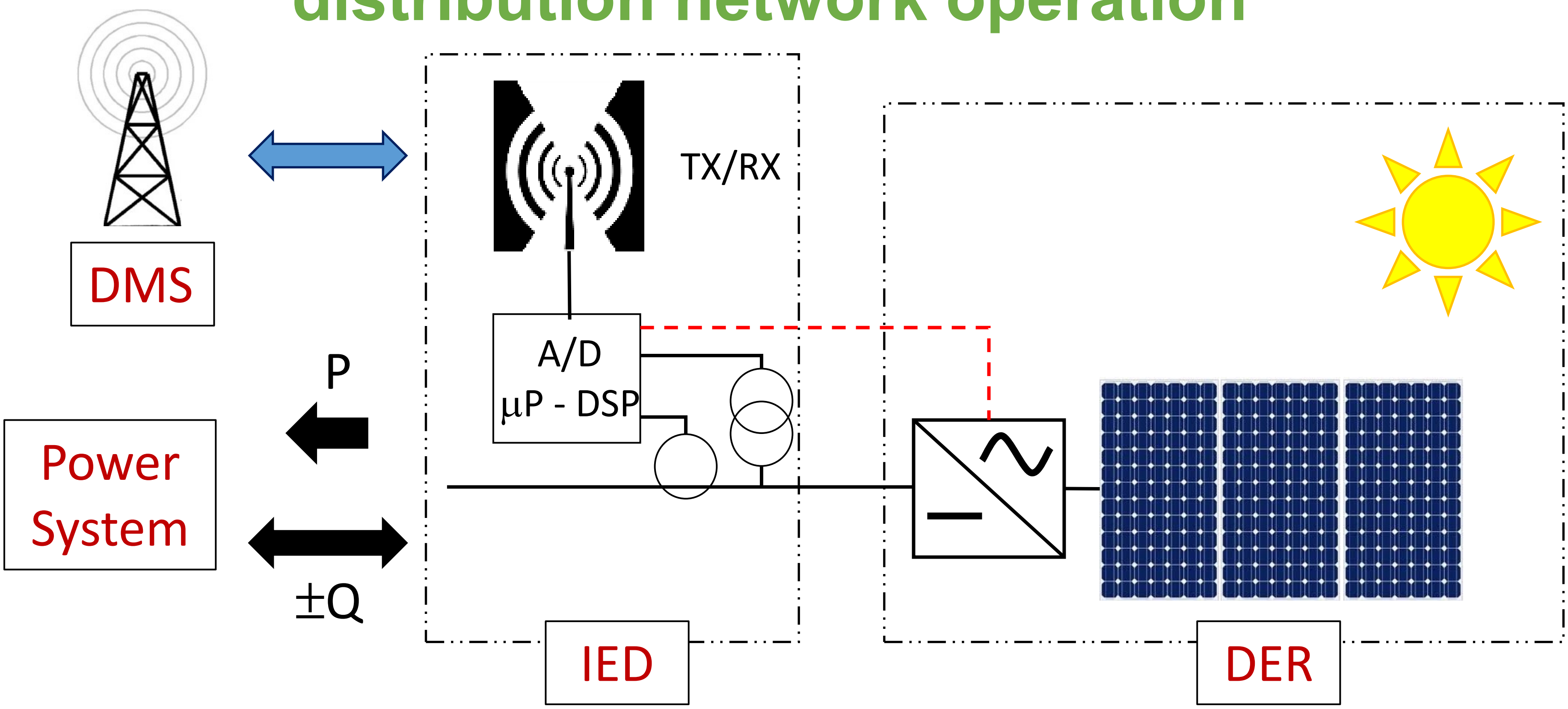


Simulation of active distribution networks

❑ Intelligent Electronic Devices (IEDs)

- smart meters, sensor and PMUs
- two-way digital communication
- actuators
- able to perfom control commands to DER
- able to communicate with SCADA systems
- enable distributed intelligence to be applied to achieve faster self-healing methodologies
- fault location/identification

Introduction to simulation of active distribution network operation



- IEDs are going to be RTU/PMUs with control and communications capabilities
- Today RTU/PMU applications could be dedicated to the observability of the distribution grid

Introduction to simulation of distribution network operation

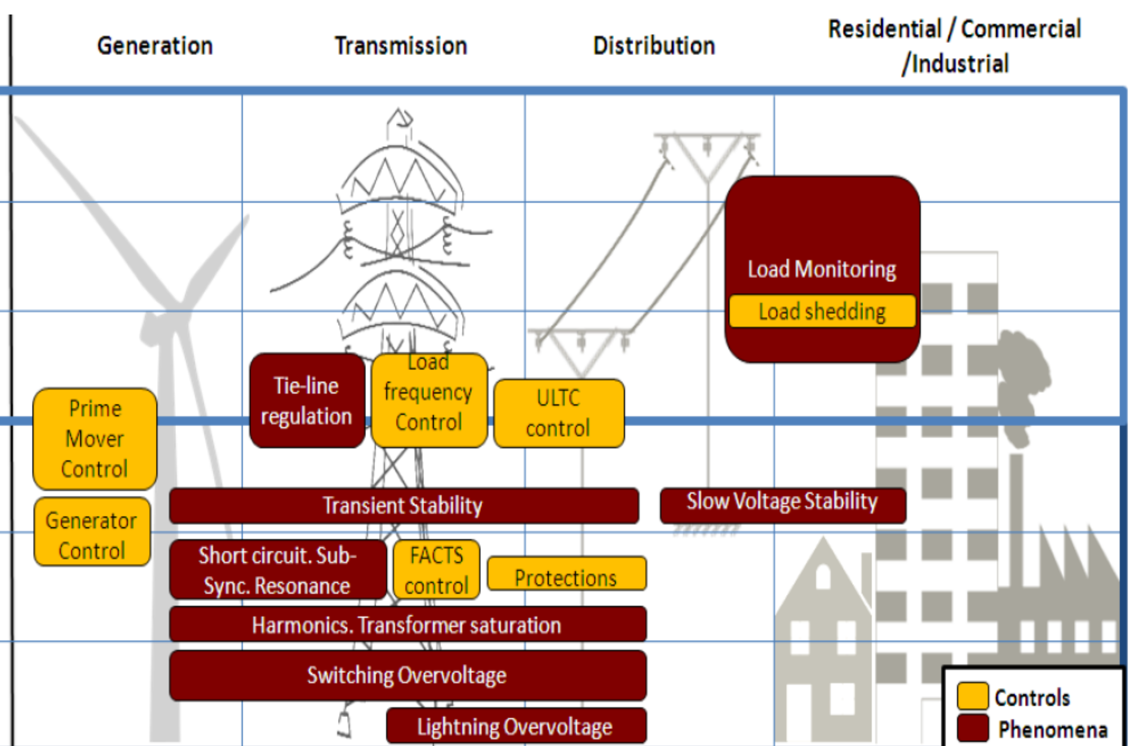
- In SDN context, ICT is not a simple add-on of the electrical system, but its availability and efficiency is essential to the operation of the entire power distribution system
- Co-simulation is then essential for analyzing different issues related to SDN implementations, since it allows to simulate the power distribution system and the ICT system behaviour simultaneously, taking into account the interdependences among the two systems.

Simulation of active distribution networks

- Co-Simulation based approaches should be utilized to develop, test and verify paradigms for next generation monitoring, control and operation of smart power systems
- Co-simulation, is a potential avenue for performing proper smart distribution planning and operation studies

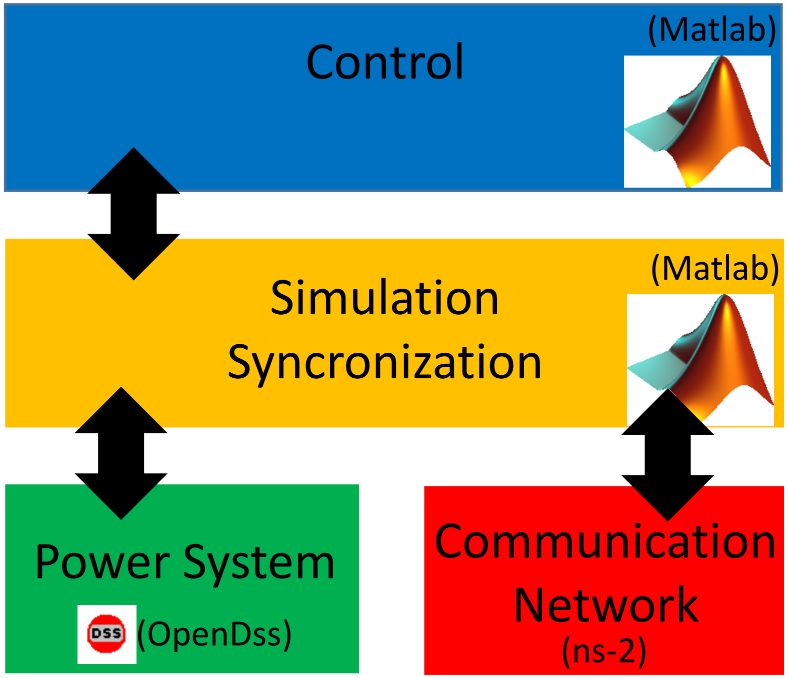
Simulation of active distribution networks

	Timescale	Representation	Typical Use Cases
Steady-State	days	Probability Density Function (PDF) / Stationary Load Flow	Max. renewable energy consumption
Steady-State	hours	Time Series / Stationary Load Flow	Power Quality
Steady-State	minutes	Stationary Load Flow	Design, Planning, Economics
Transient & Dynamics	seconds	Stationary Load Flow / ODE	Islanding detection
Transient & Dynamics	milliseconds	Ordinary Differential Equations (ODE)	Voltage regulations
Transient & Dynamics	µseconds	Partial Differential Equations (PDE)	Lightning Protection



- depending on the time scale different model representations are adopted
- the time scale considered depends on the use case, related to a part of the grid

Co-simulation Platform – Conceptual Scheme



Co-simulation is performed with an architecture in which “a single dedicated component is responsible for synchronizing and connecting all the different components offering a unified interface for the control logic (federated simulation).

Power System Simulator – Open DSS

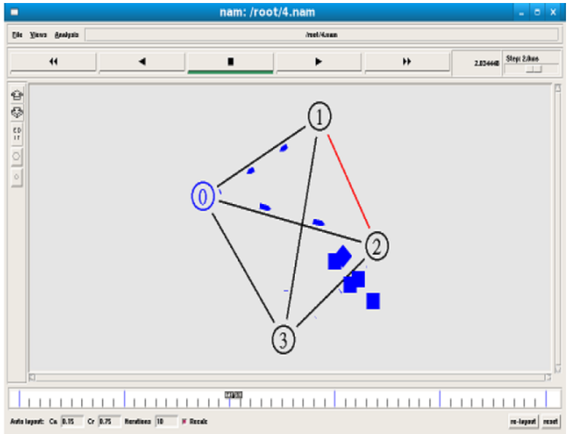
- Designed to simulate utility distribution systems
  - In arbitrary detail, unbalanced power flow, 1-phase & unbalanced 3-phase modeling.
  - Distributed energy resources
  - For most types of analyses related to distribution system planning and analysis.

- It performs its analysis types in the *frequency domain*,
  - Power flow, Harmonics and Dynamics.
- It does NOT perform electromagnetic transients (*time domain*) studies.

Download from: http://sourceforge.net/projects/electricdss/

TLC network– network simulator 2

- ns-2 is an open source (linux based) software designed to simulate:
  - Wired/wireless TLC networks.
  - Protocols
  - Traffic
  - Variable bit-rate and bandwidth



- It permits to evaluate network perfomance, latency, errors, QoS
- Large number of models available

Download from: http://nsnam.isi.edu/nsnam/index.php/User_Information

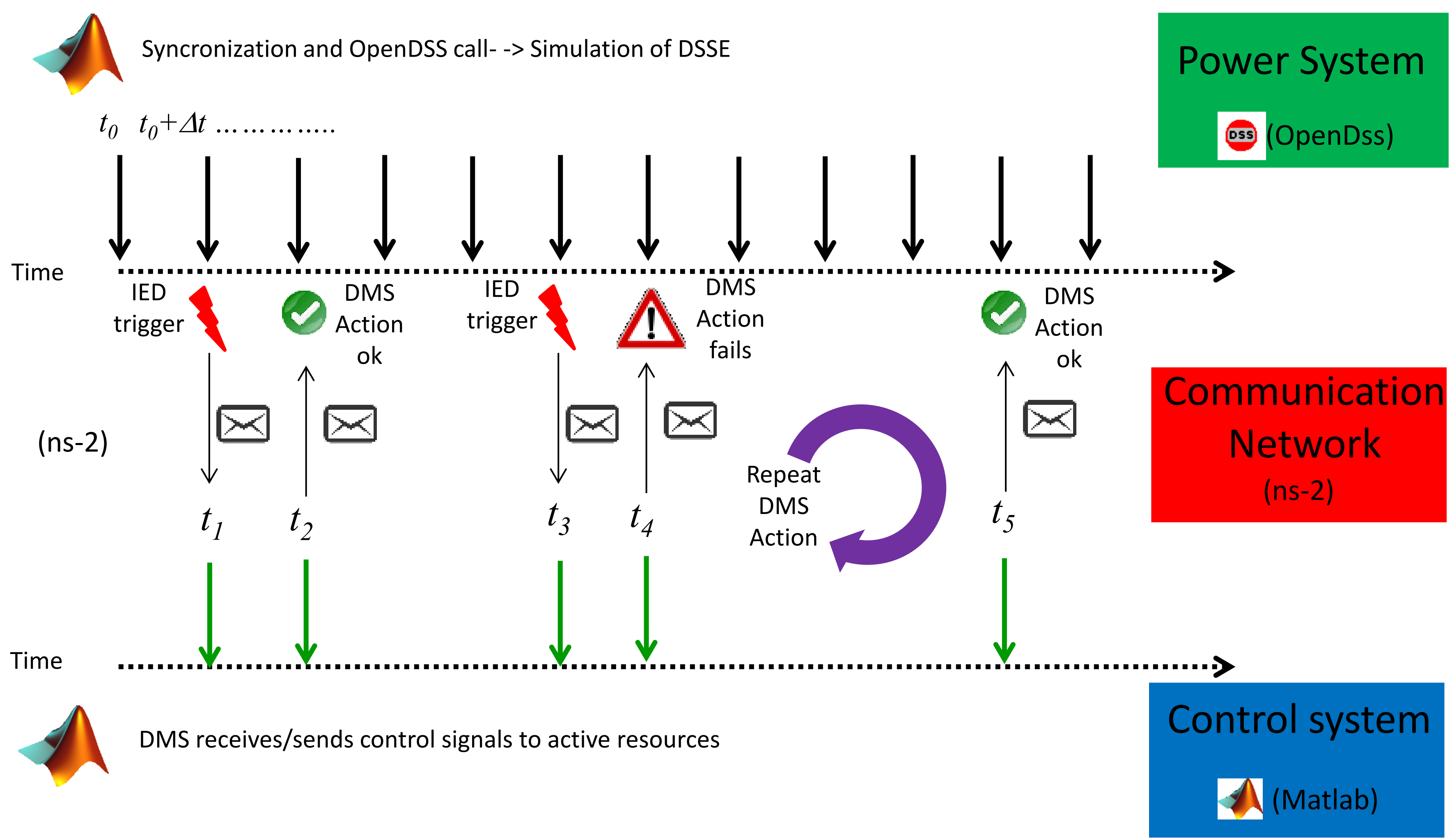
TLC network– network simulator 2

- ns-2 is used in this application to simulate Wi-MAX communication network
- WiMAX (Worldwide Interoperability for Microwave Access) is a wireless communications standard designed to provide 30-40 Mbit/s data rates
- The bandwidth and range of WiMAX make it suitable for the following potential applications:
  - Providing portable mobile broadband connectivity across cities.
  - Providing a wireless alternative to cable and digital subscriber line (DSL) for "last mile" broadband access.
  - Providing a source of Internet connectivity.
  - Smart grids and metering

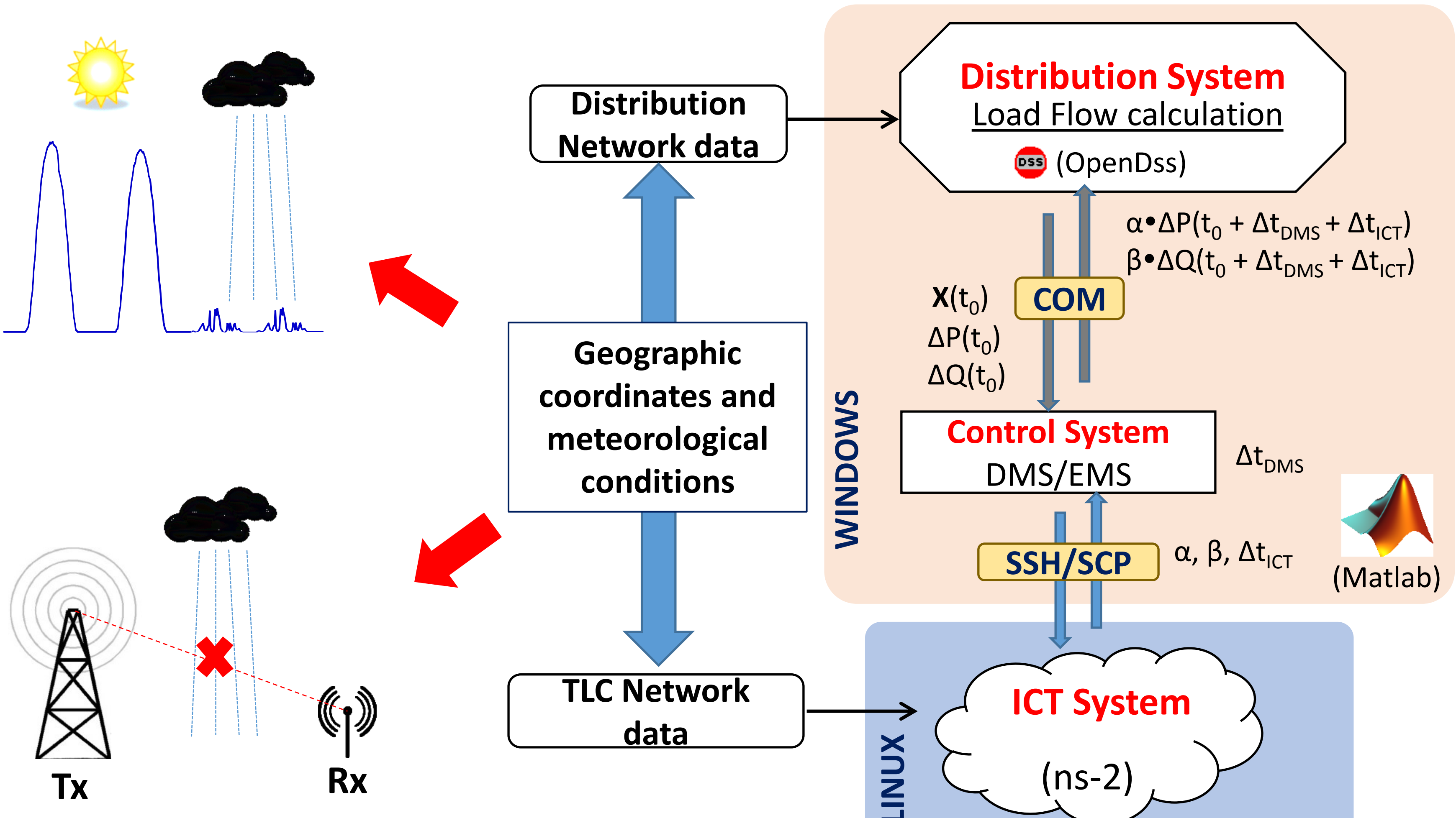
Reference:

V. C. Gungor e F. C. Lambert. A survey on communication networks for electric system automation. Comput. Netw., vol. 50, n. 7, pp. 877-897, May 2006.

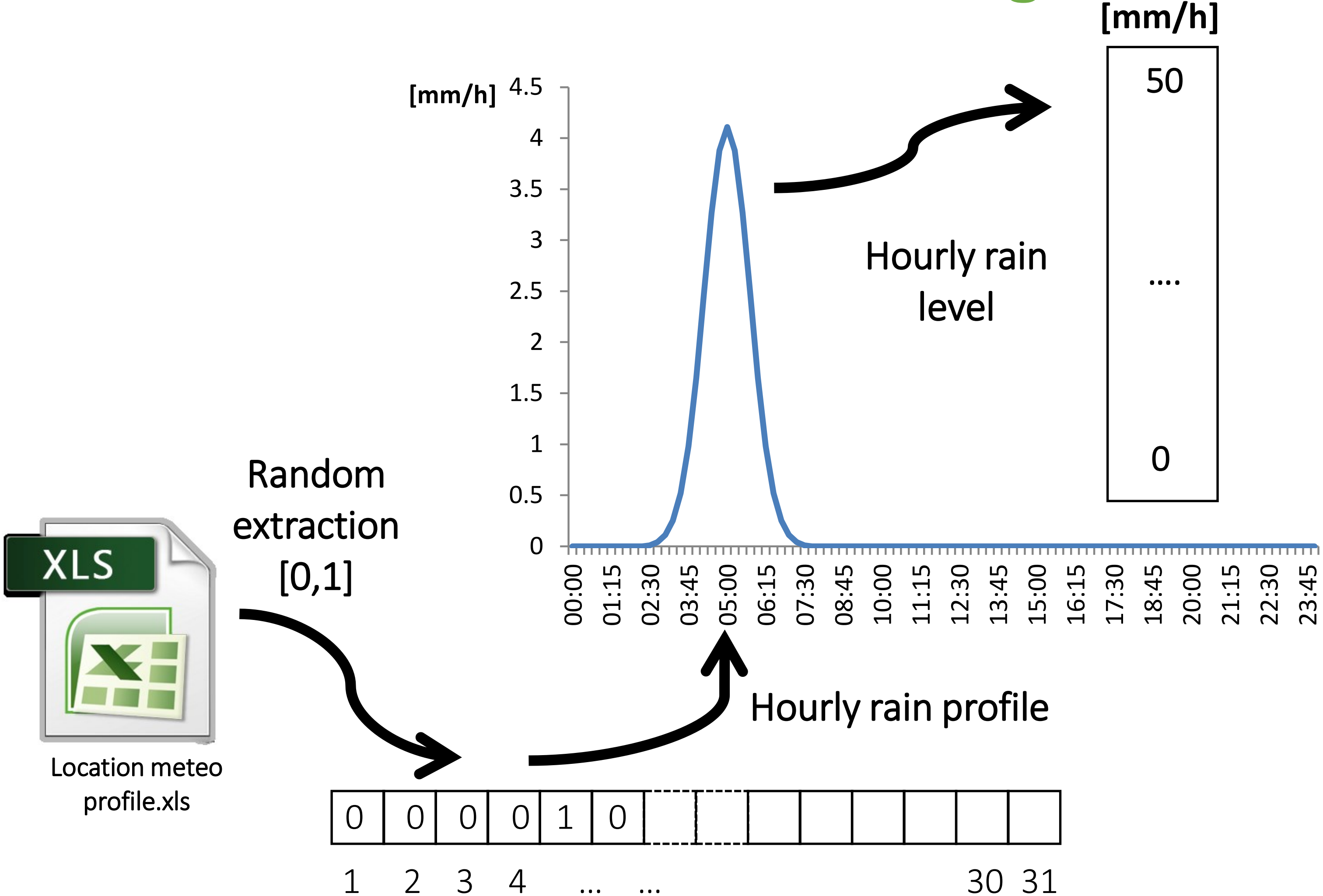
Co-simulation Platform - Syncronization



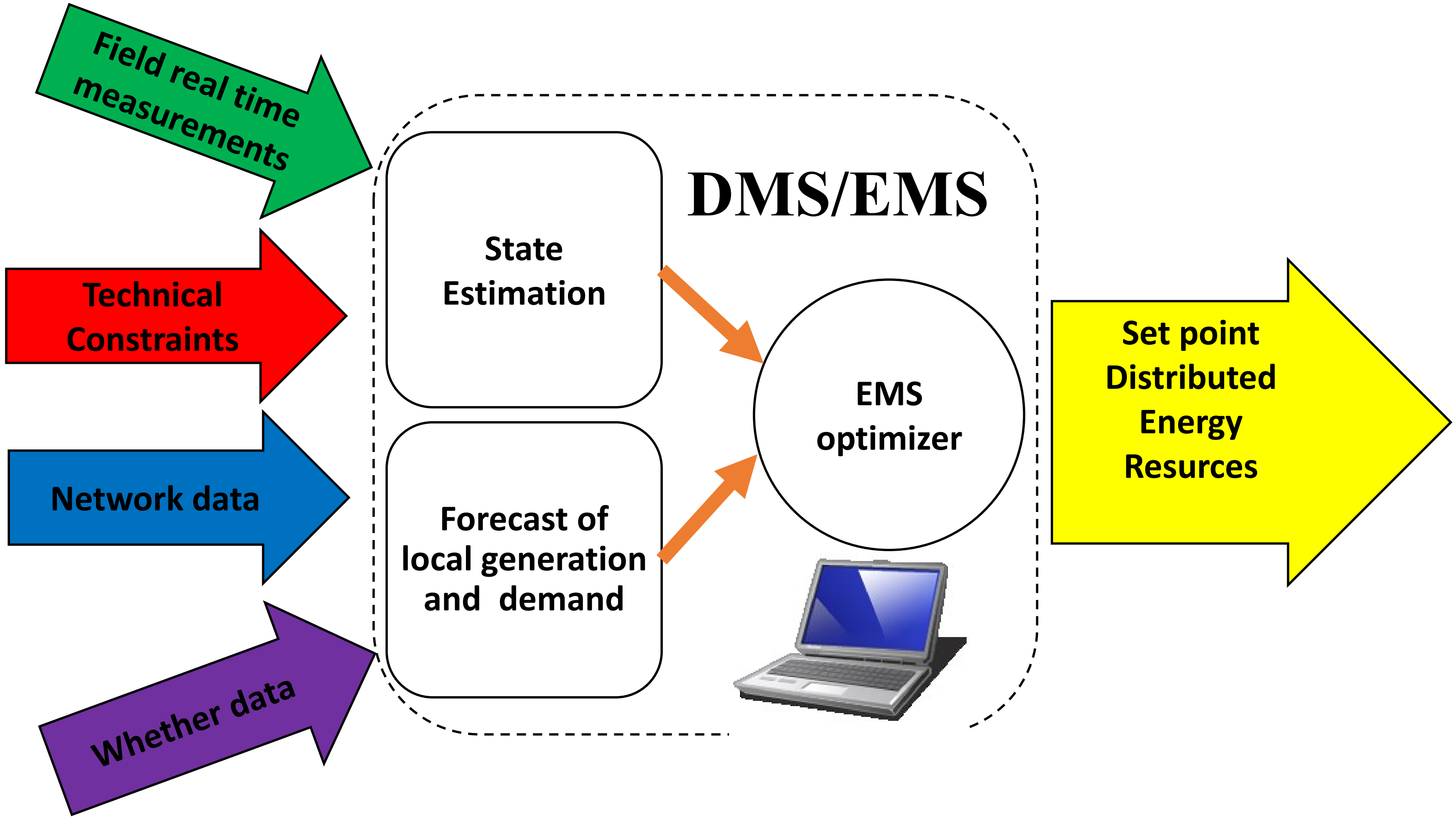
Co-simulation Platform



Co-simulation Platform - Meteorological Model



Co-simulation Platform – DMS/EMS



Co-simulation Platform – DMS/EMS

- Optimal Power Flow for the management of Smart Distribution Networks

$$\min\left\{C_{P\_GD} + C_{Var} + C_{AD} + C_{DES} + C_{losses}\right\}$$

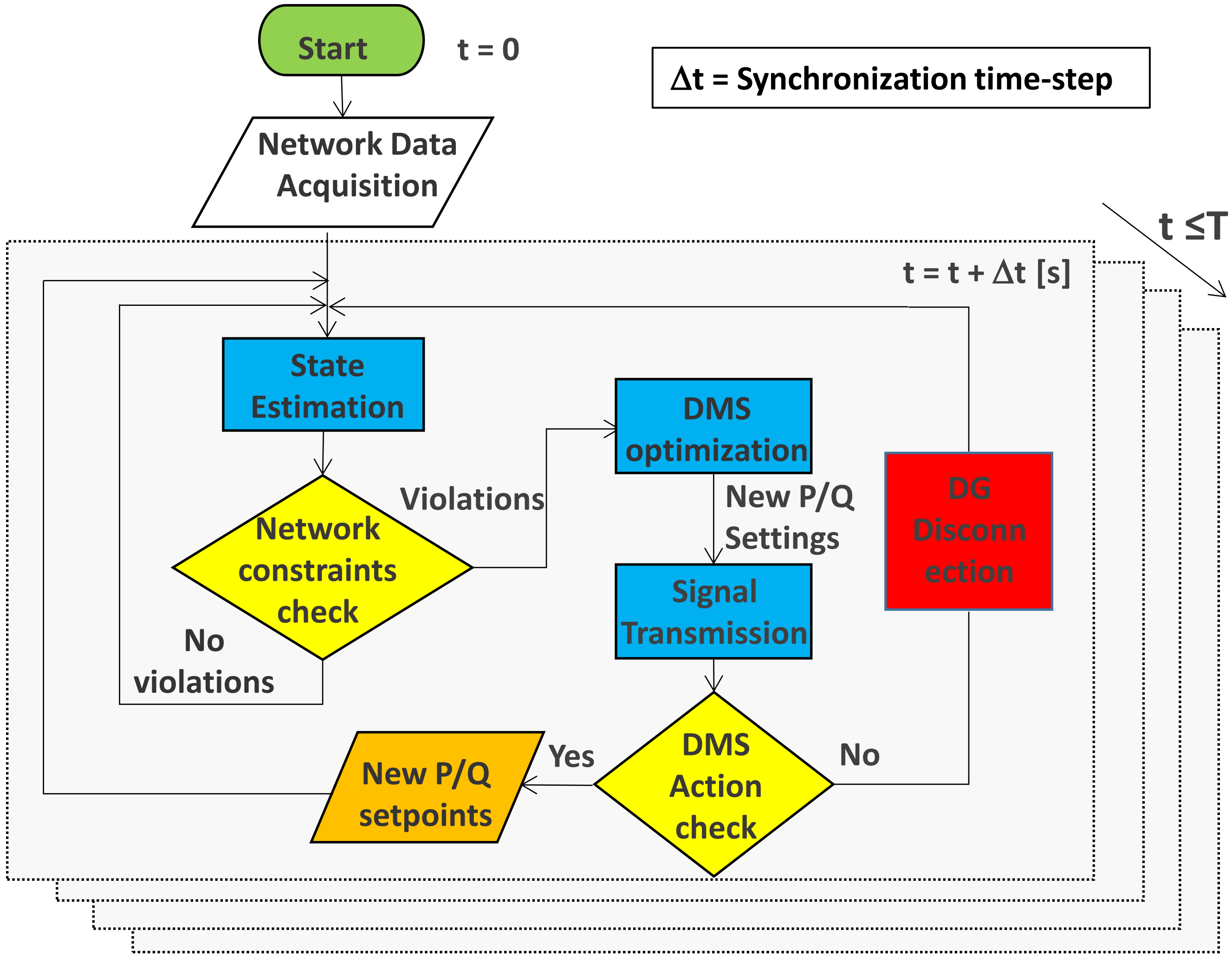
- C_{P_GD} is cost for active power dispatching
- C_{Var} is the cost for reactive power dispatching
- C_{AD} is the cost for demand side integration
- C_{DES} is the cost for distributed energy storage dispatching
- C_{losses} is the cost for energy losses

Subject to technical (e.g. node voltages and branch power flows during normal and emergency conditions) and economic constraints (e.g. costs for dispatching active resources and joule losses).

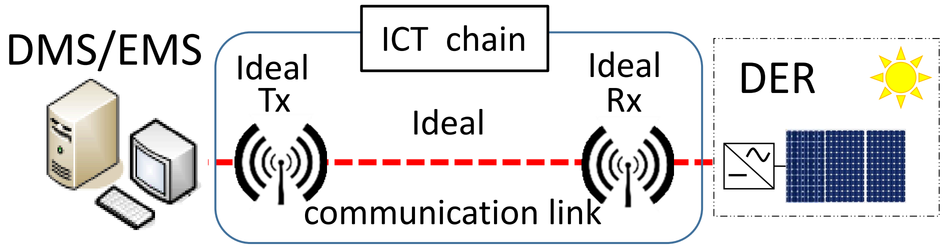
Reference:

F. Pilo, G. Pisano, G. G. Soma. Optimal coordination of energy resources with a two-stage online active management. Industrial Electronics, IEEE Transactions on, vol. 58, n. 10, pp. 4526-4537, 2011.

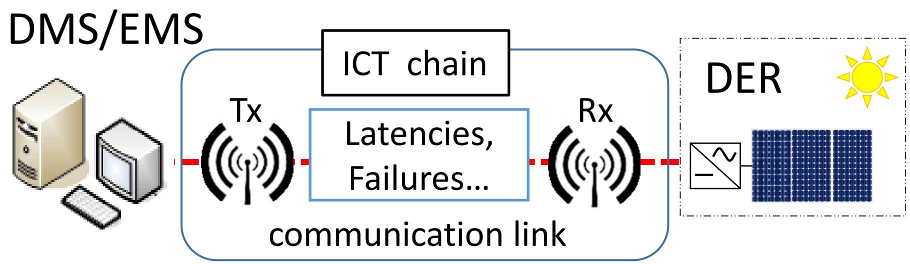
Co-simulation Platform – Flow diagram



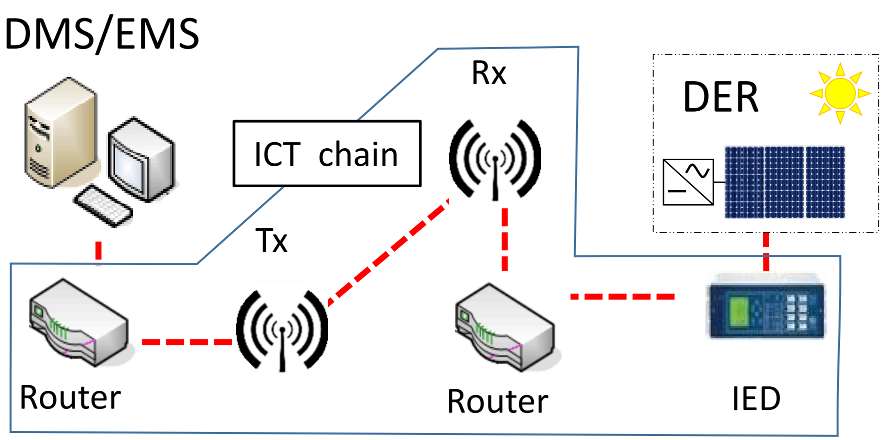
Co-simulation Platform – ICT Reliability



- ideal modelling of ICT network
- co-simulation study allows to verify the correctness and the efficiency of the control algorithms



- black-box modeling of the ICT network
- useful to demonstrate the robustness of the smart grid in conditions of non-delivery of the control signals

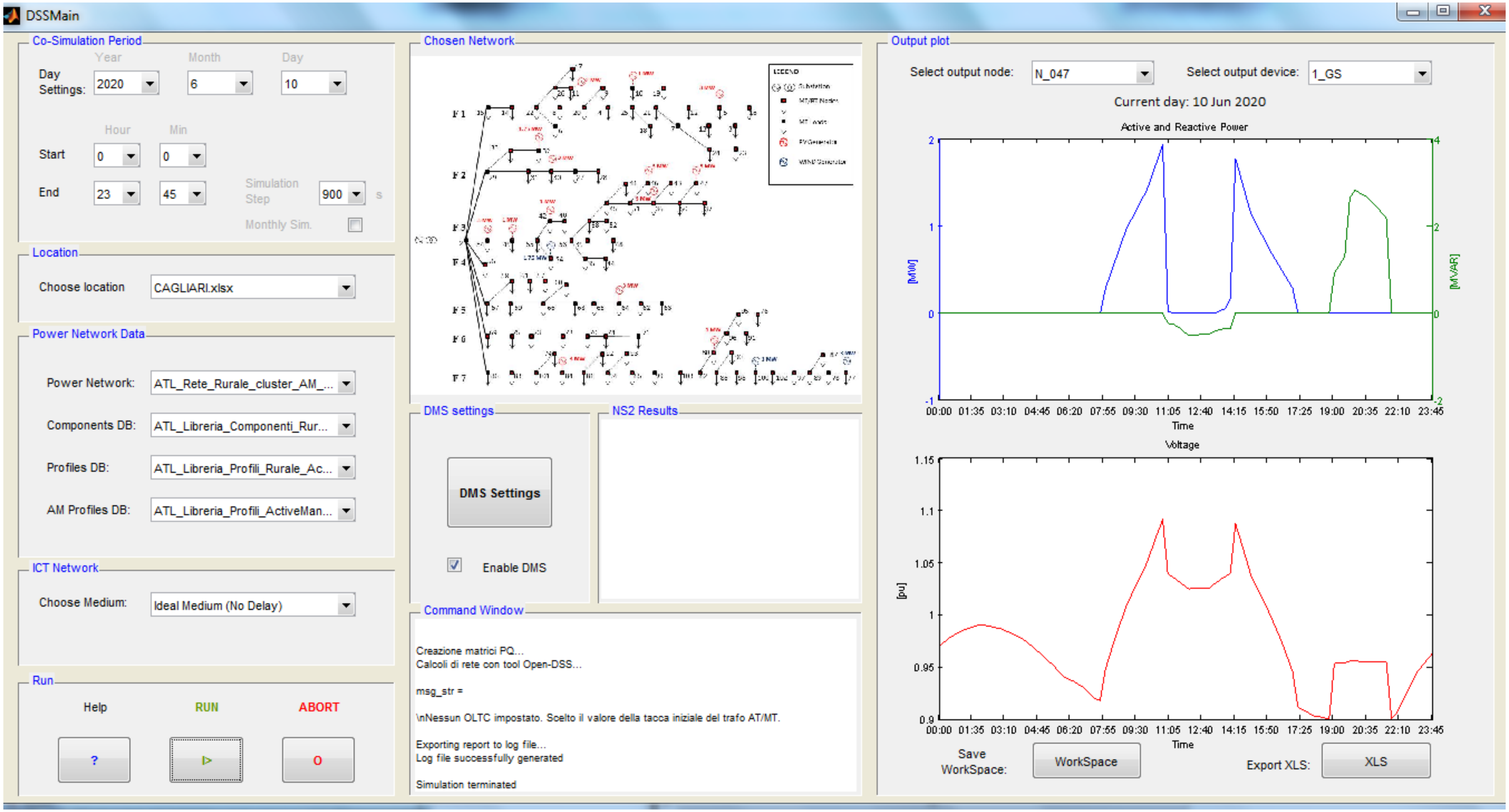


- detailed modeling of the ICT network
- highest degree of detail and consistence of simulation to reality
- greater trustworthiness of results
- easier examination on weaknesses in the ICT structure

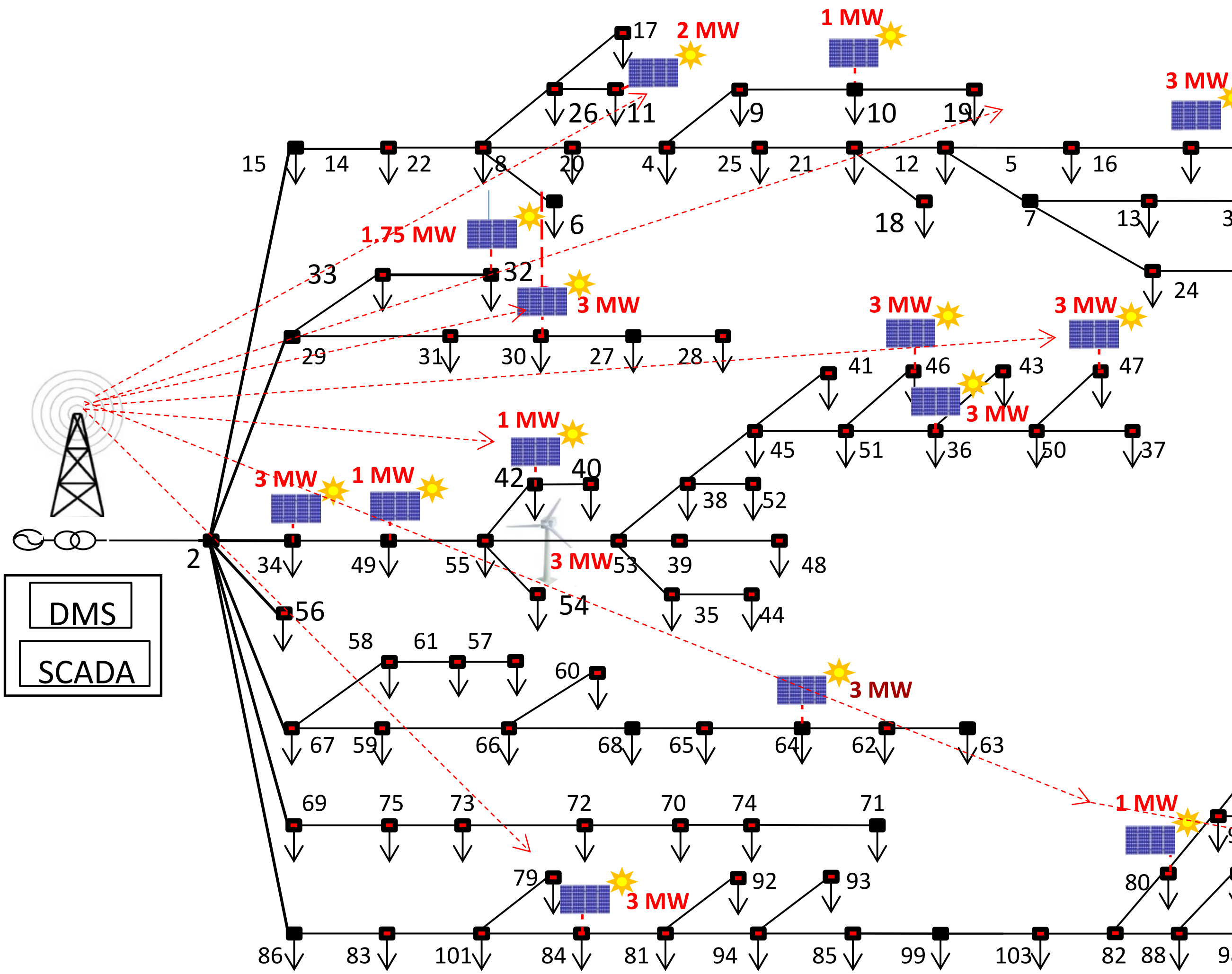
Application example

- Analysis of a centralized DMS/EMS actions on active power distribution nework
  - No DMS/EMS intervention
  - P/Q control
  - P control
  - Q control
  - TLC network performance analysis

Application example - Software Interface

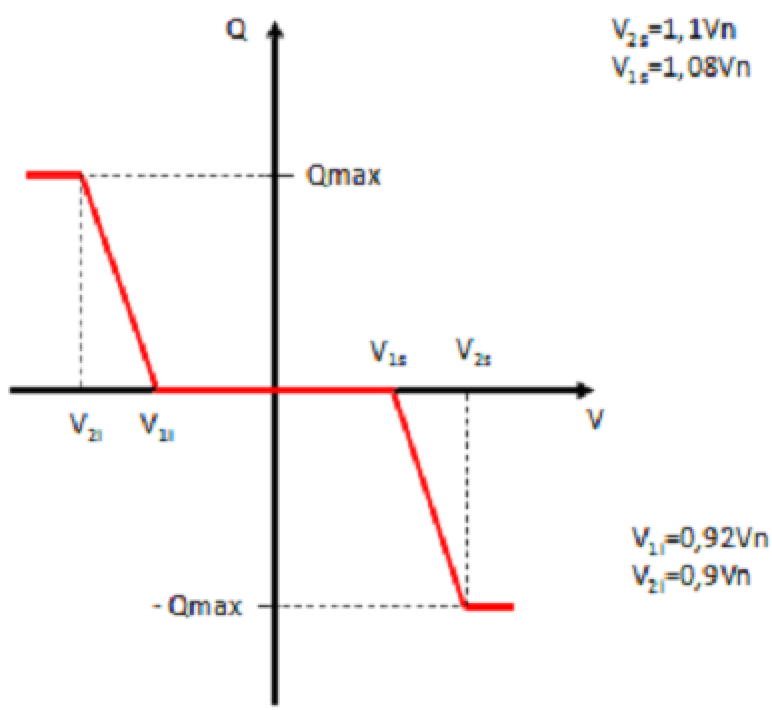


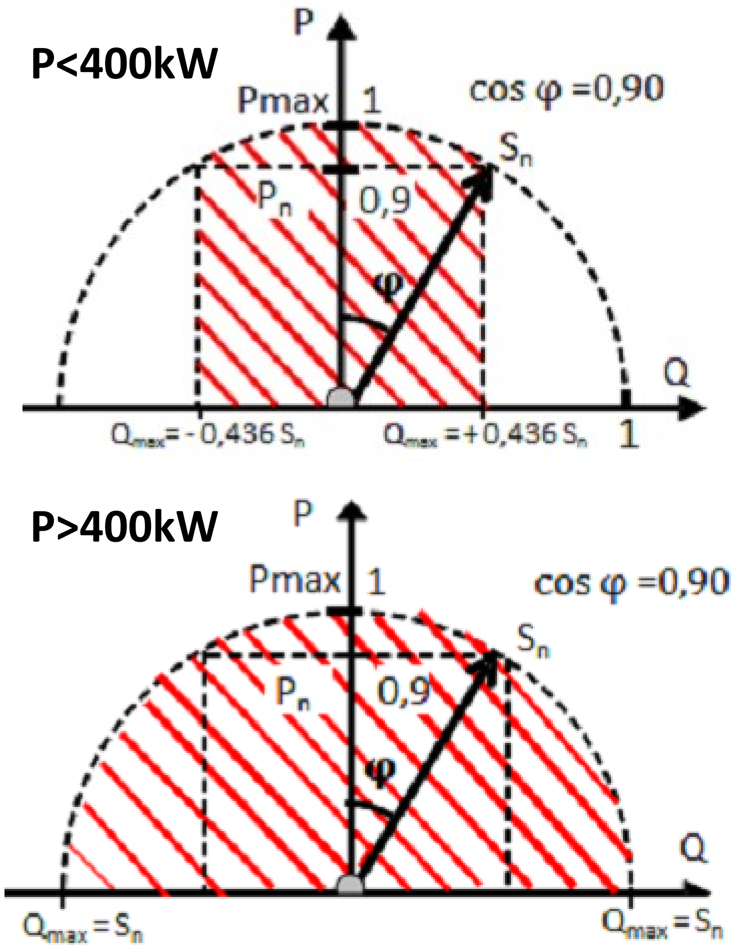
Application example – MV 103 Nodes



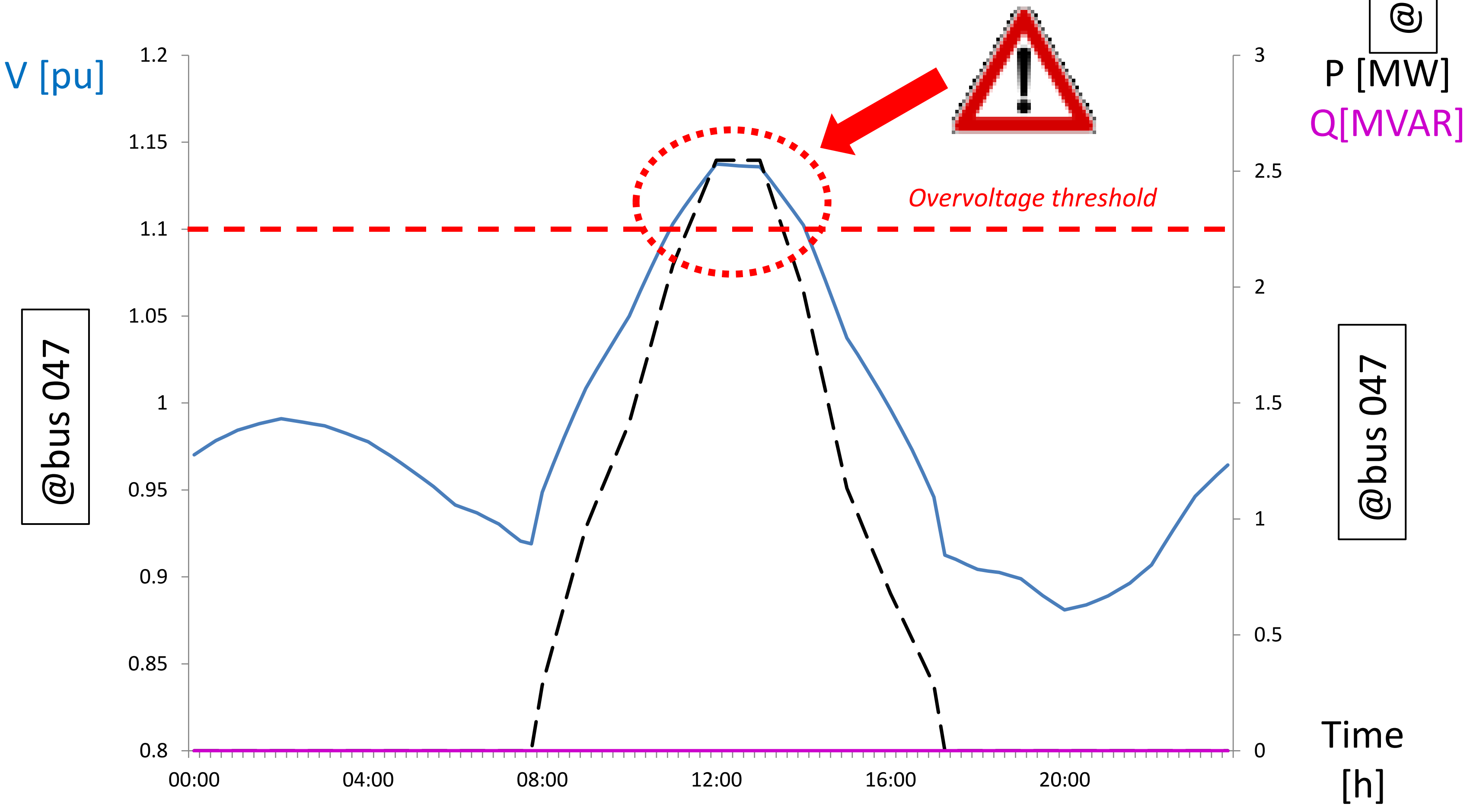
Feeder	Wind [MW]	PV [MW]	LOAD [MW]
F1	0	6	4
F 2	0	4.75	2.5
F 3	1.75	14	4
F 4	0	0	0.3
F5	0	3	2.8
F 6	0	0	3.7
F7	6	4	2.5

Application example - DER with P/Q variable capability curves





Summer day - No *EMS intervention*



Summer day - No *EMS intervention*

- DER @bus 047 – most critical node
- Overvoltages and undervoltages are detected by IED and transmitted to control center.

Day 10: 10 Jun 2020

00:15:00

00:30:00

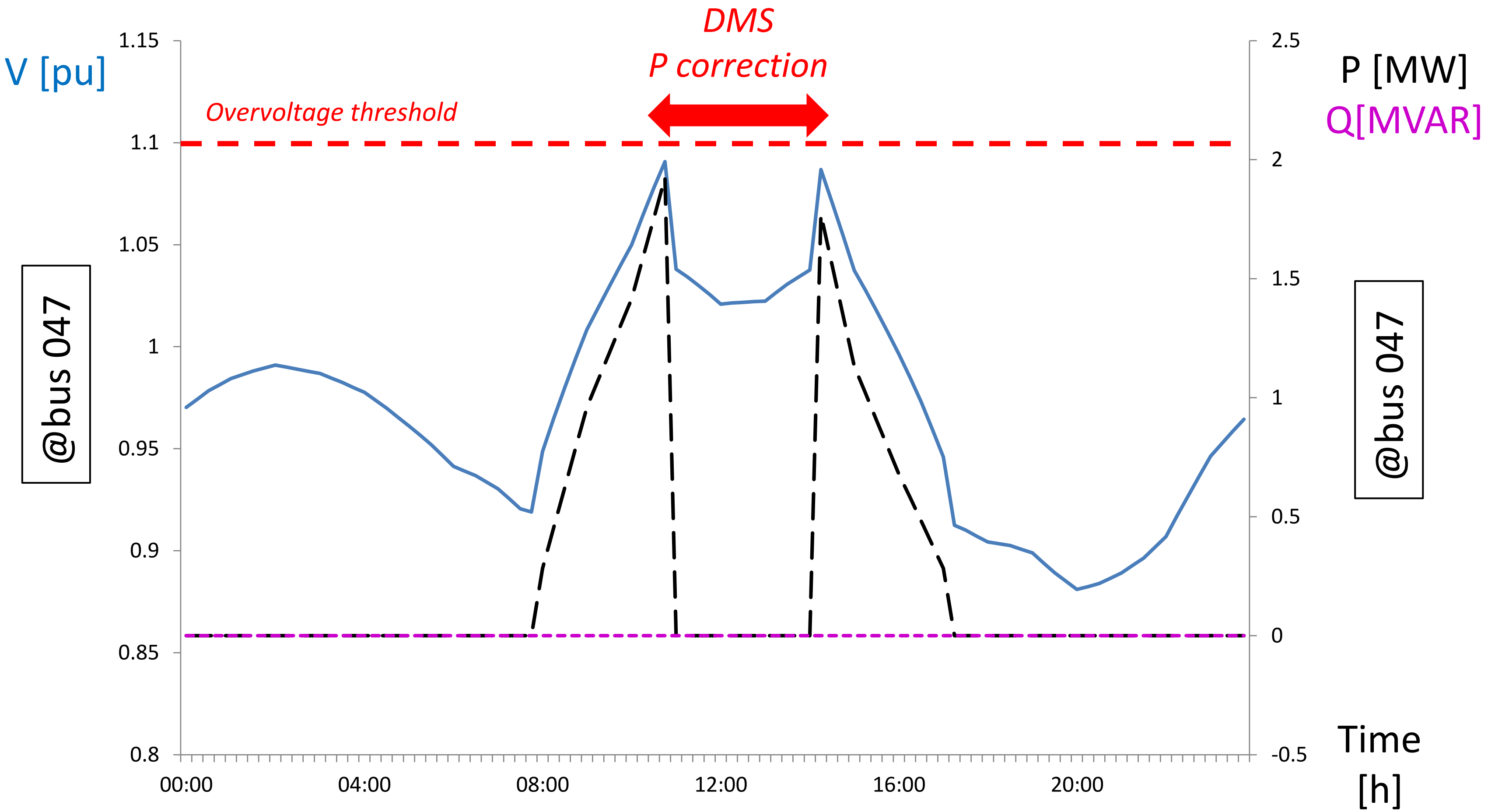
[...]

10:45:00

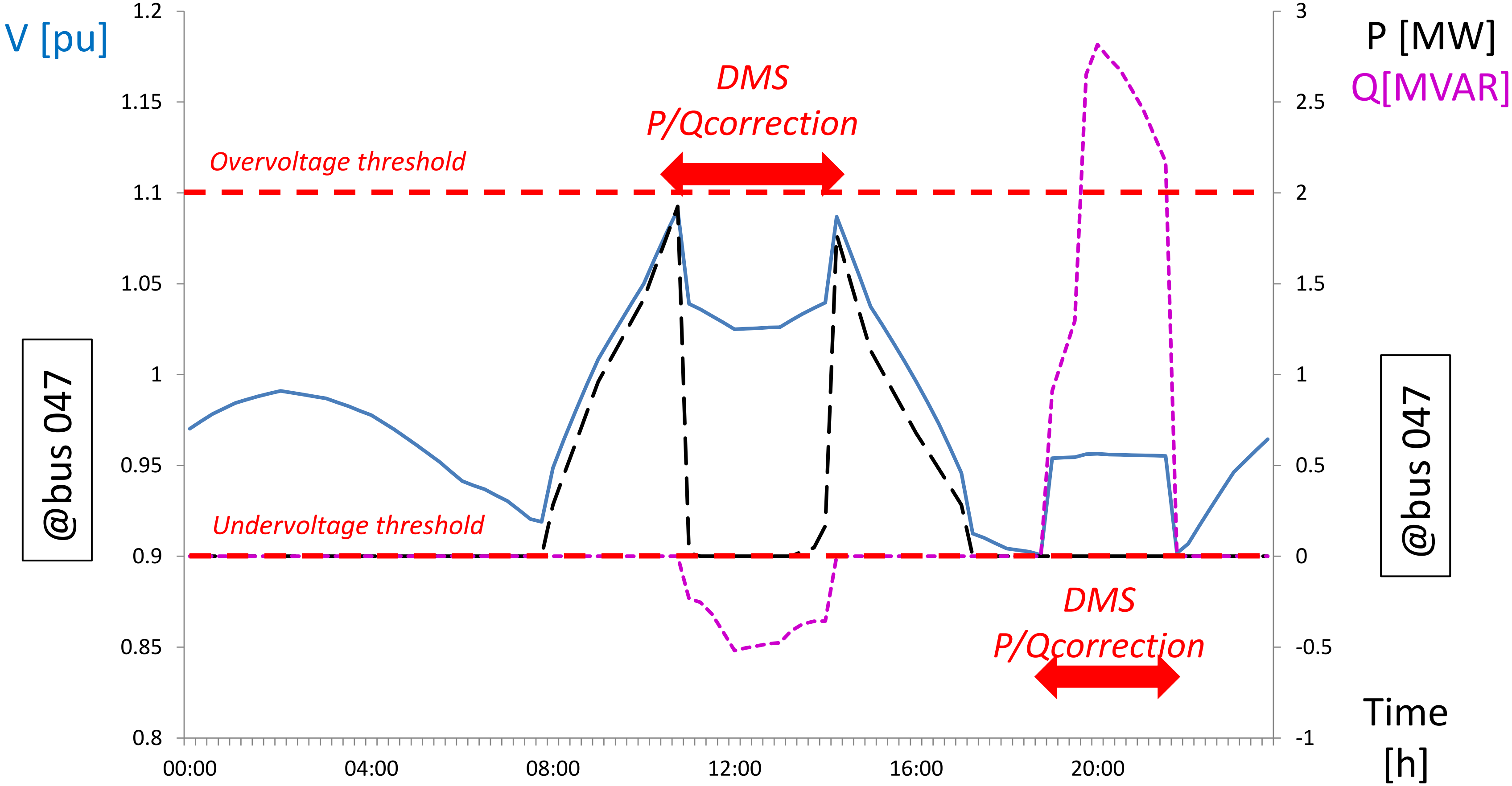
11:00:00

Overvoltage on N_047 @ 11:00:00 detected by IED

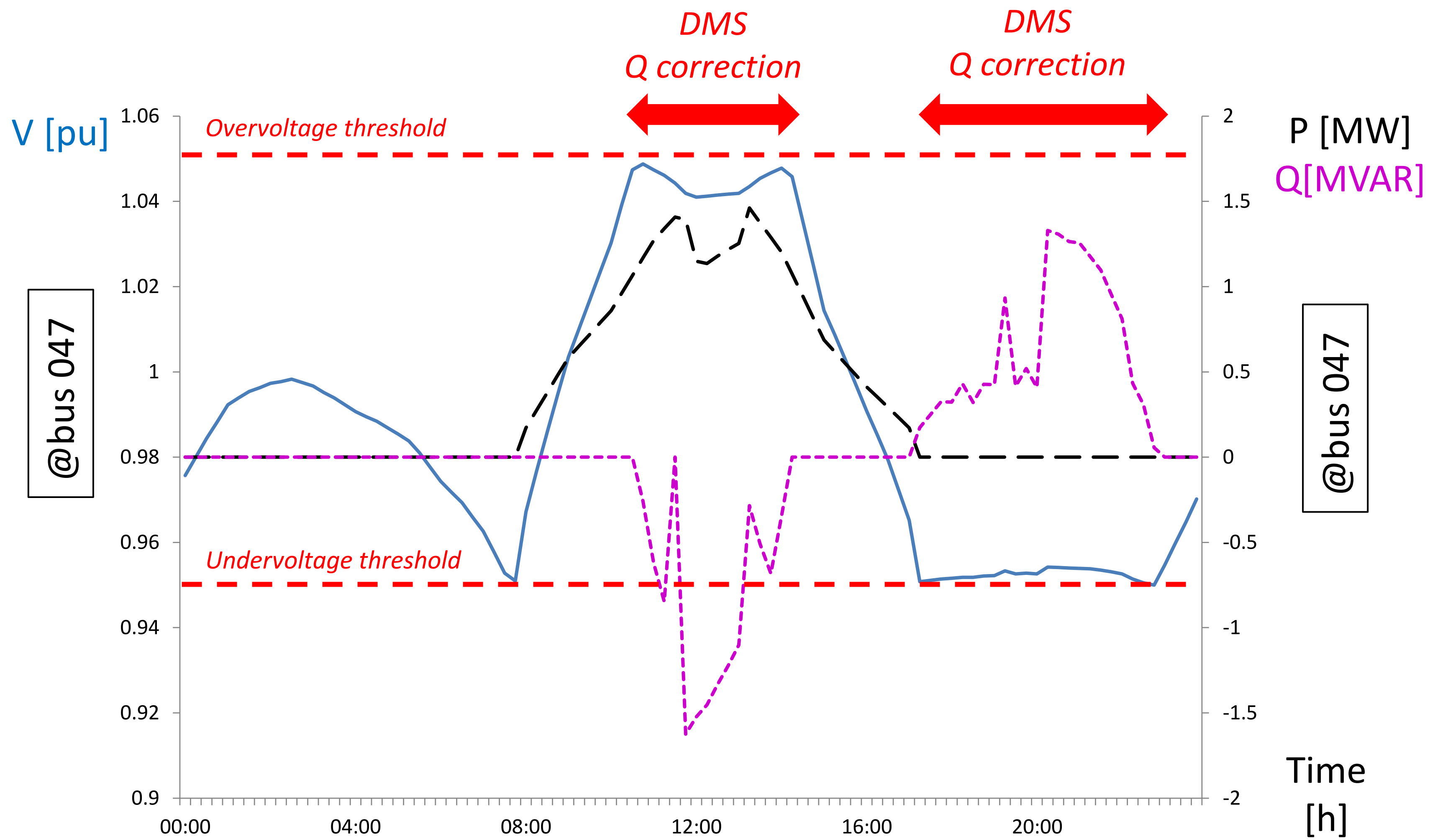
Summer day - P control



Summer day – P/Q control



Summer day- Q control

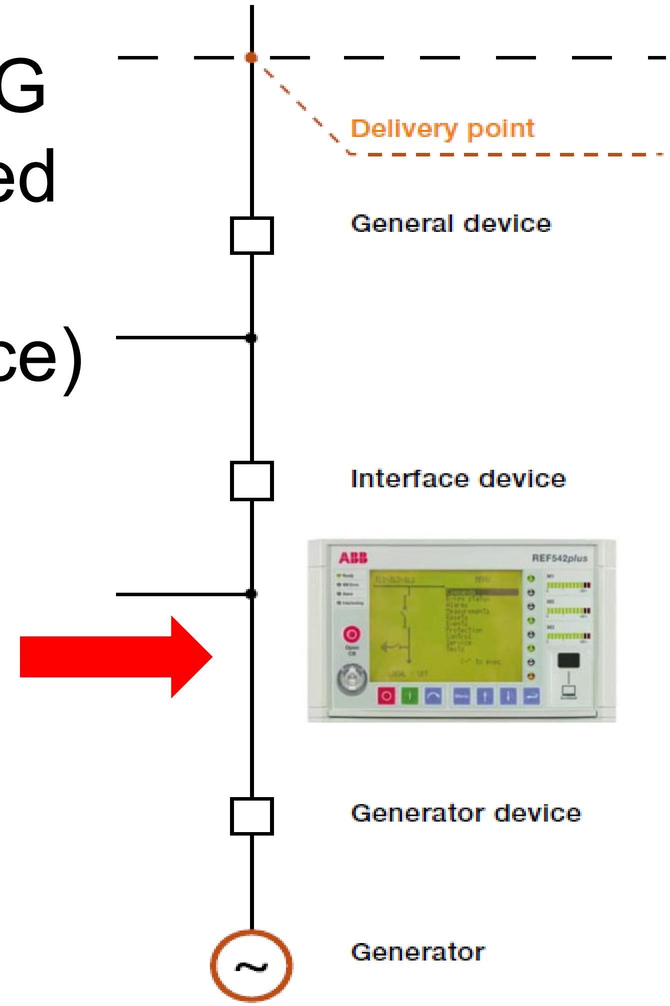


Summer day – *ICT not delivering signal*

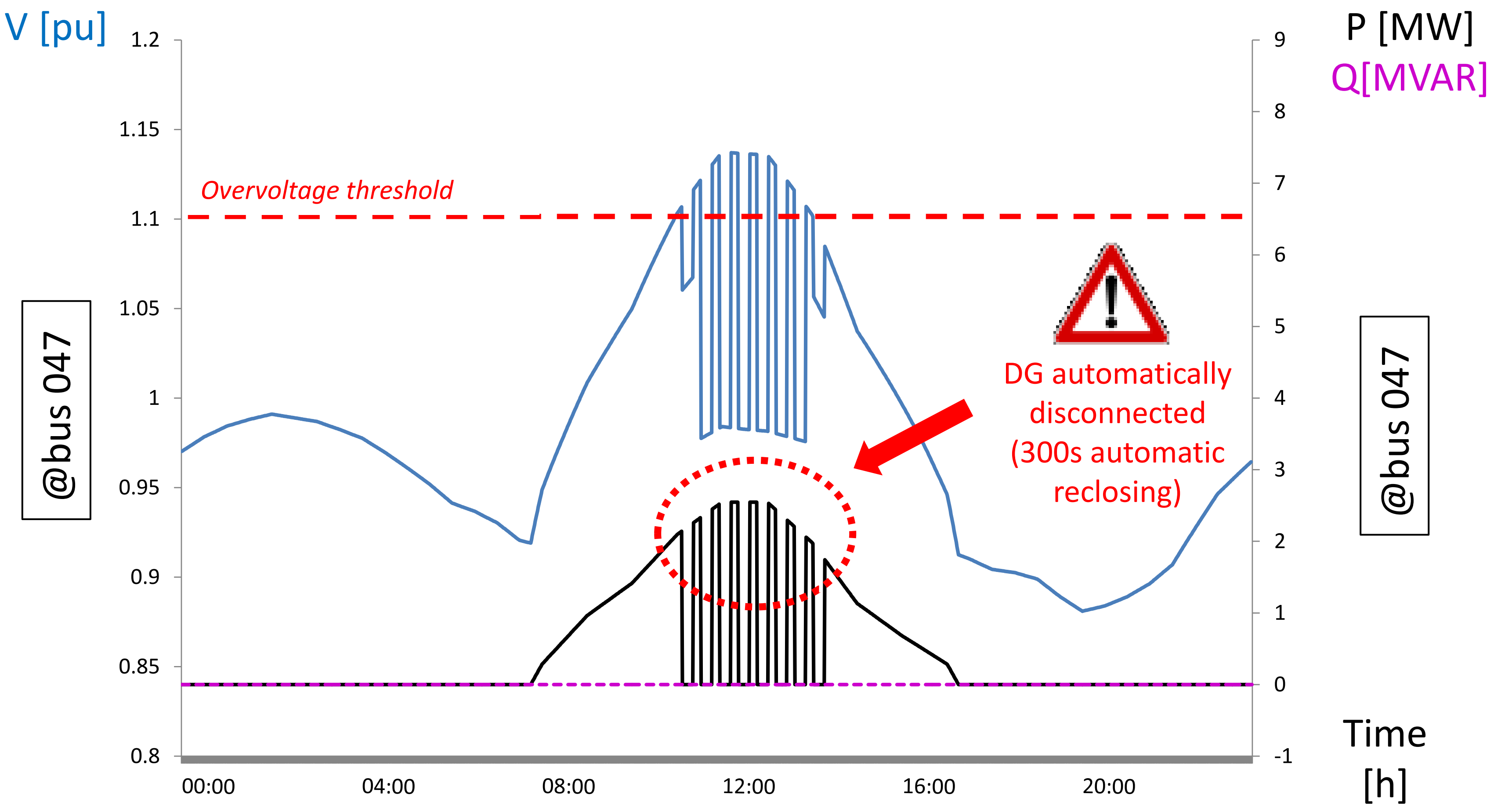
- In case of no ICT available DG are automatically disconnected from network in case of contingencies (interface device)

Voltage: 85% Vn ≤ V ≤ 110% Vn

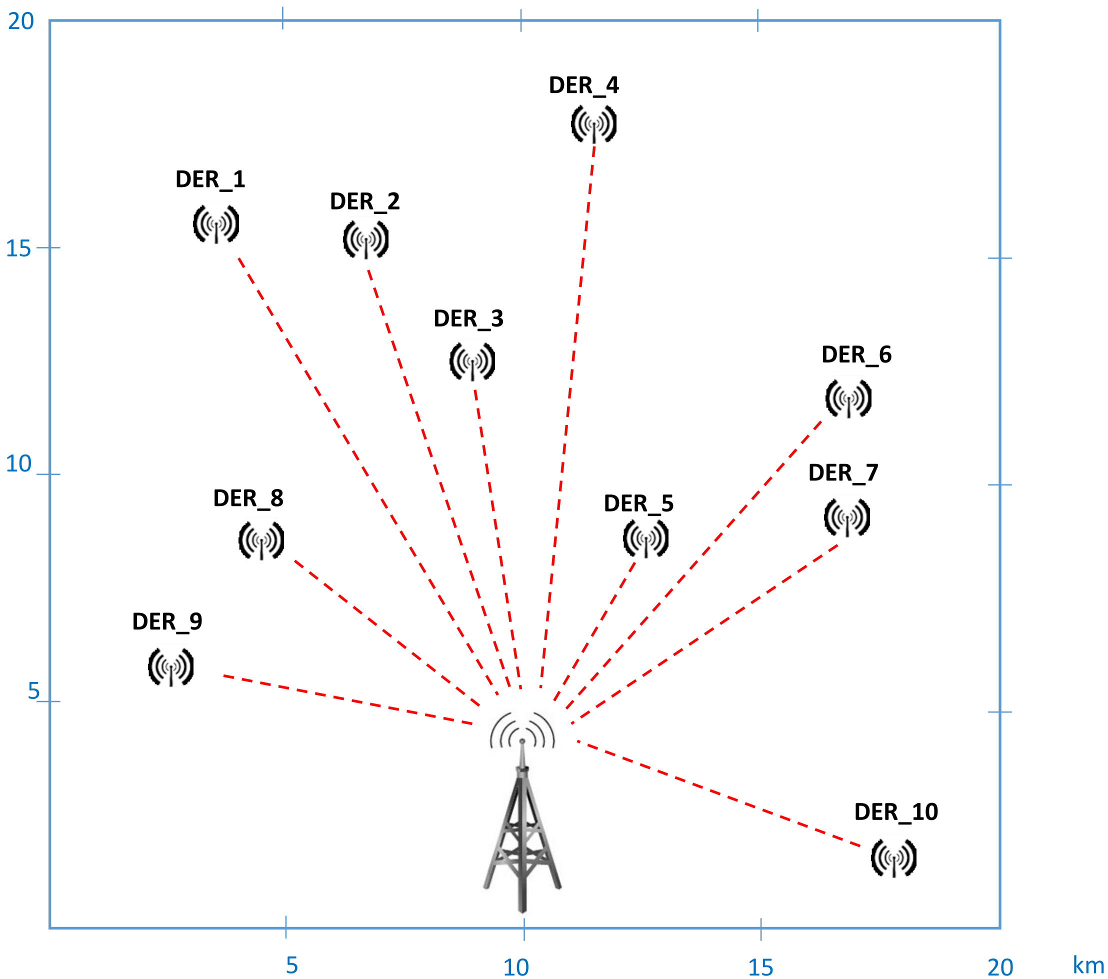
Fequency: 47.5Hz ≤ f ≤ 51.5Hz



Summer day – *ICT not delivering signal*

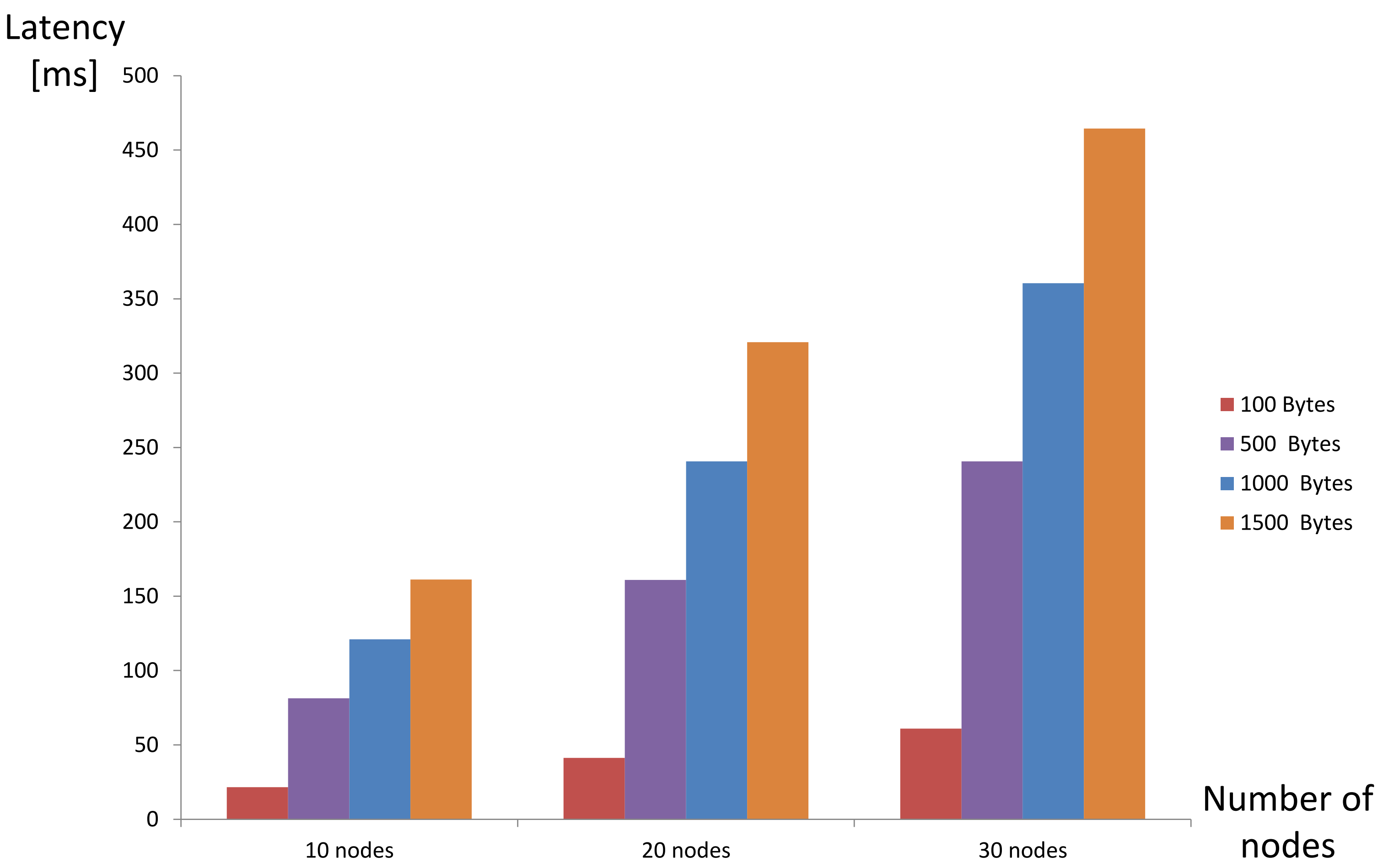


Further analysis: influence of packet size on communication latency – 20kmx20km area

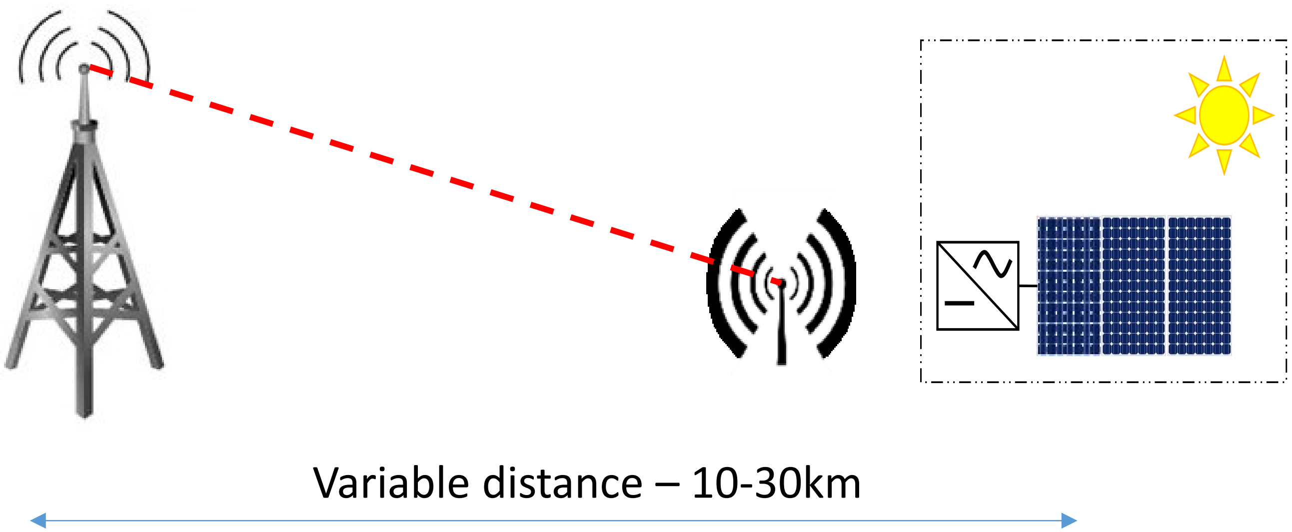


- ns-2 ICT network analysis of WiMAX performances
- 10-30 IED/DER randomly spread along a 20kmx20km area
- Variable bit packet size

Further analysis: influence of packet size on communication latency – 20kmx20km area

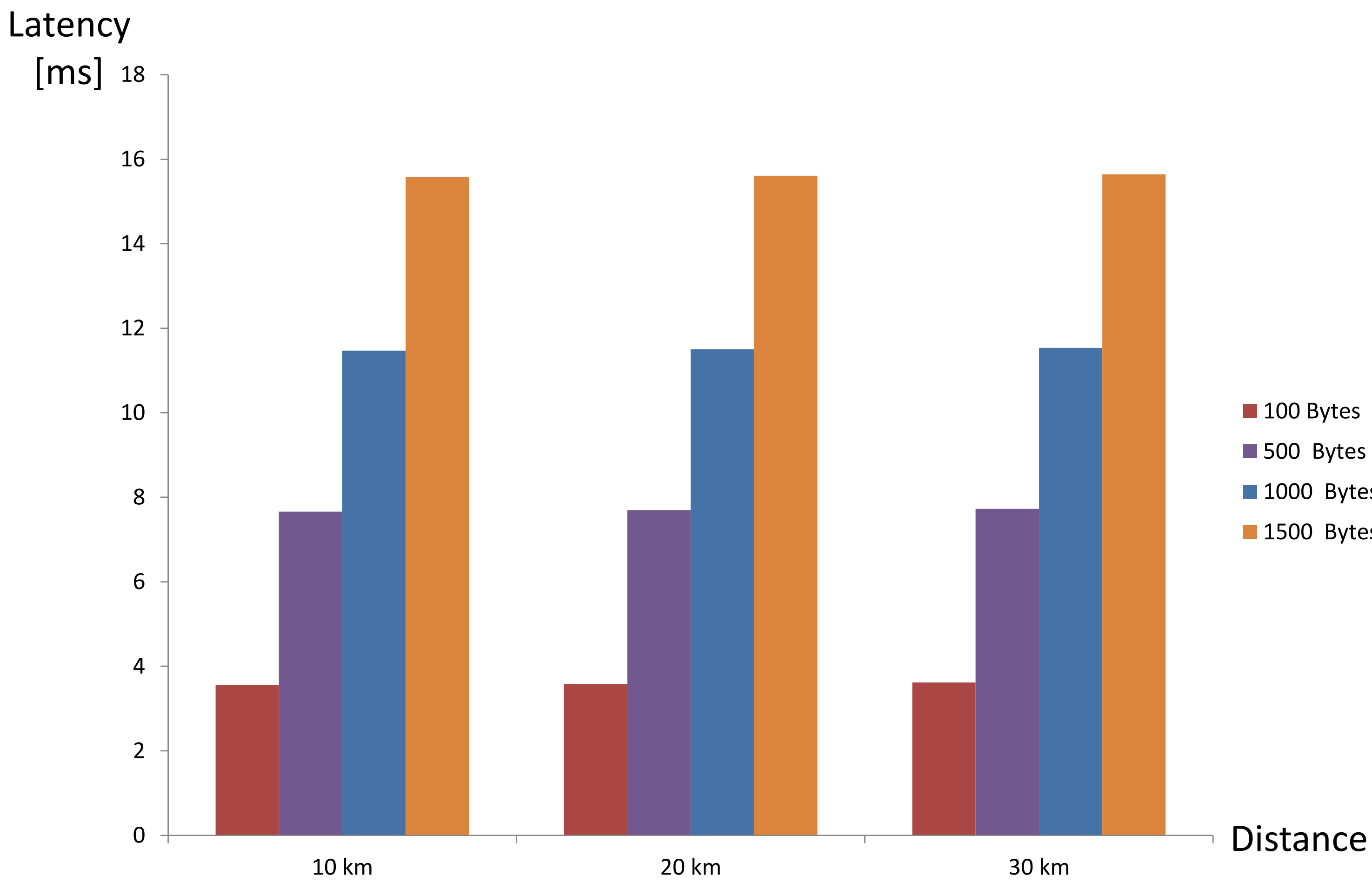


Further analysis: influence of distance to cover on communication latency – point to point link



- ns-2 ICT network analysis of WiMAX performances
- 10-30 km distance
- Variable bit packet size

Further analysis: influence of distance to cover on communication latency – point to point link



Co-simulation software output for for operation and planning analysis

- Information available
  - Hourly/daily V/P/Q plots
  - .xls reports (long term analysis)
  - Single/average point to point communication latency
  - ICT reliability metrics
  - Number of DG disconnections
  - Energy curtailment evaluation
  - …..

Conclusions

- This presentation has showed the capabilities of a co-simulation platform based on commercial and open source software for active management of distribution networks
- In order to simulate all possible smart grid environments, different co-simulators need to be built
- Steady state power system simulators are useful for control operation strategies of active distribution networks
- Protection studies need co-simulators with power system transient analysis capabilities

Relevant Bibliography

1. K.Mets, J.A.Ojea, C.Develder. Combining power and communication network simulation for cost-effective smart grid analysis. IEEE Communications Surveys and Tutorials, 16 (3), art. no. 6766918, pp. 1771-1796. 2014.
2. G. Celli, P.A. Pegoraro, F. Pilo, G. Pisano, S. Sulis, DMS Cyber-Physical Simulation for Assessing the Impact of State Estimation and Communication Media in Smart Grid Operation, IEEE Transactions on Power Systems, vol.29, no.5, pp.2436,2446, Sept. 2014.
3. M. Garau, E. Ghiani, G. Celli, F. Pilo. S. Corti. A Co-simulation tool for active distribution networks. Proc. of CIRED Workshop 2014. Rome 11-12 June 2014. Paper No 0198.
4. F. Pilo, G. Pisano, G. G. Soma. Optimal coordination of energy resources with a two-stage online active management. Industrial Electronics, IEEE Transactions on, vol. 58, n. 10, pp. 4526-4537, 2011.
5. V. C. Gungor e F. C. Lambert. A survey on communication networks for electric system automation. Comput. Netw., vol. 50, n. 7, pp. 877-897, May 2006.
6. X. Yuzhe; C. Fischione, "Real-time scheduling in LTE for smart grids," Communications Control and Signal Processing (ISCCSP), 2012 5th International Symposium on , vol., no., pp.1,6, 2-4 May 2012.
7. Atlantide project network database. www.progettoatlantide.it