


QoS of a SCADA system interconnecting a Power grid and a Telco network

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MICIE FINAL WORKSHOP

Universita' Roma Tre, Rome 28 February 2011

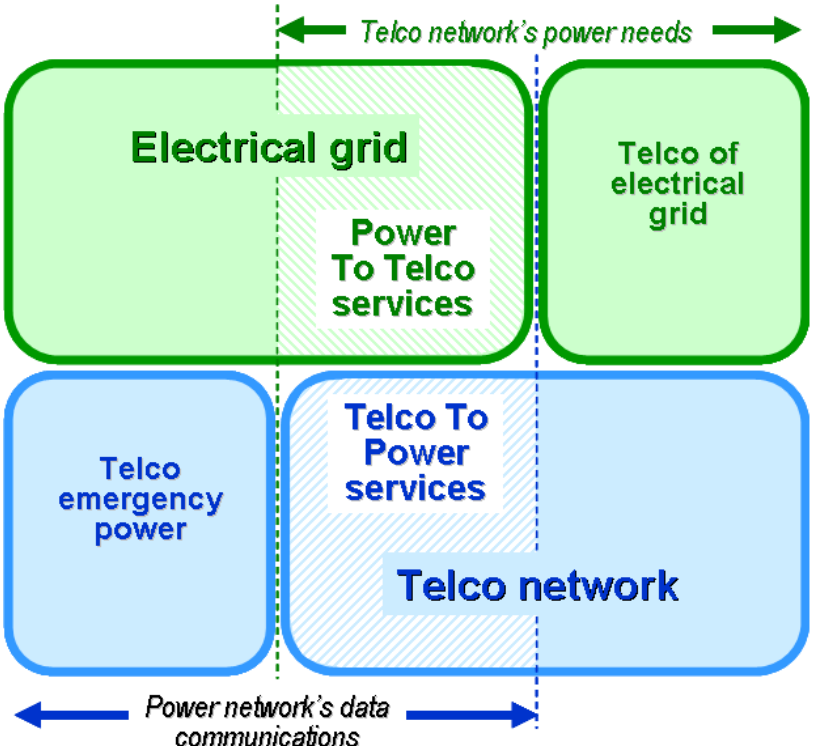
Summary

- Introduction
  - SCADA system
  - Critical Interdependent Infrastructures
- Loss/degradation of quality of services
- Prediction of risk of loss/degradation of quality of services
- FISR models by heterogeneuos modelling approach
- Performance and rerouting of FISR by discrete event simulation
- indicators of FISR performance and numerical results
- The animation of a running NS2 model that predicts performance indicators of FISR
- Comparison among the different modelling approaches

Introduction

- SCADA (Supervision Control and Data Acquisition)
  - nervous system of Power grid
  - communication links dependent on (private but even public) Telco network
  - mutual propagation of disturbances and adverse events between Power grids and Telco networks

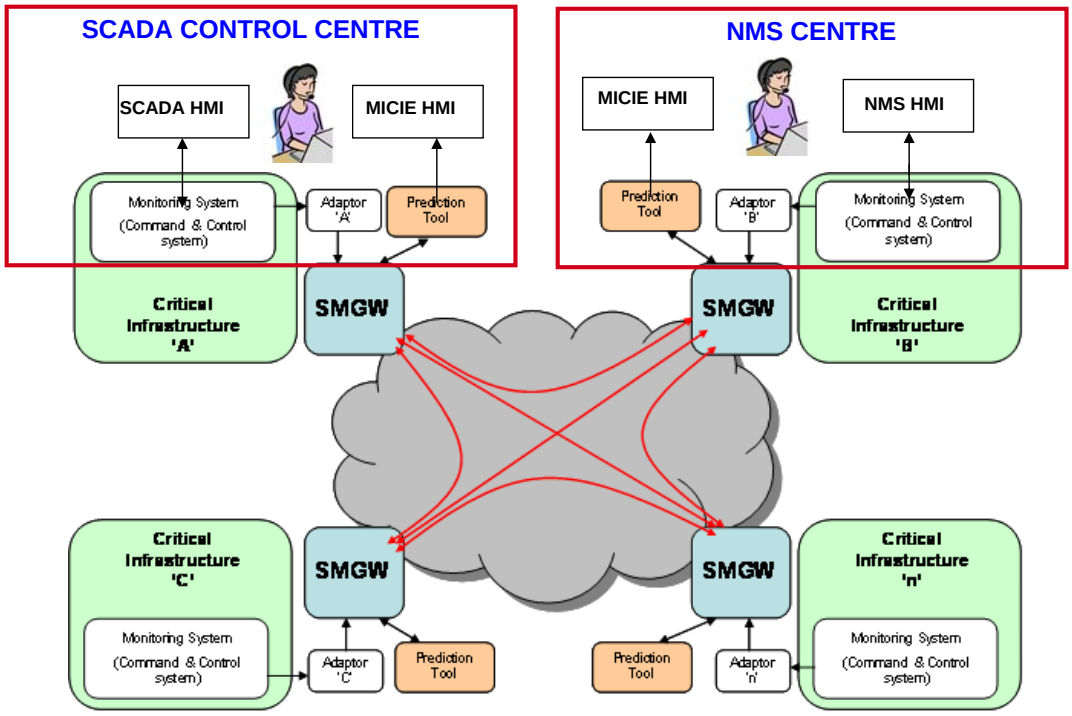
Critical Interdependent Infrastructures



Main product of MICIE EU Project

- MICIE has designed and implemented a so-called "**MICIE alerting system**"
- MICIE alerting system intends to support **CI operators** by means of an on line Risk Prediction tool that provides them a **real time risk level** making use of CI models

MICIE alerting system supports SCADA and NMS operators



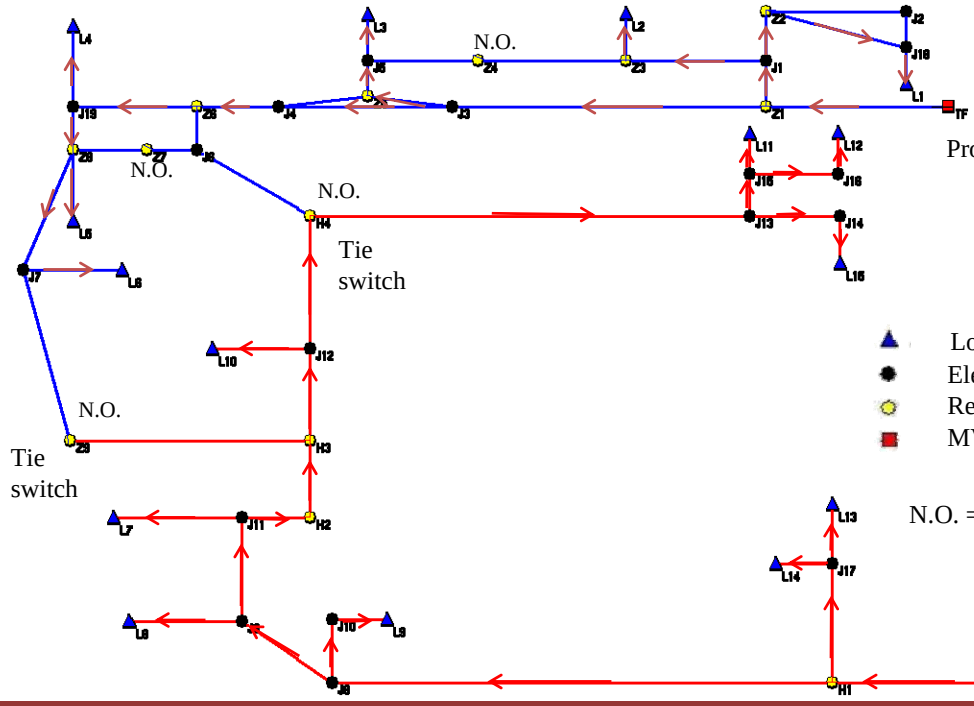
Quality of services of SCADA operator

- How can models predict the risk of loss/degradation of the QoS of SCADA operator with the final aim to improve the quality of power supplied to grid customers?
  - Reference scenario and service oriented approach
  - Fault Isolation and System Restoration (FISR) service
  - Risk of loss/degradation of FISR and indicators
  - FISR models

Reference scenario and service oriented approach

- limits the extension of the real word
- provides a concrete context of operation focused on interdependencies
- consists in identification of:
  - service
  - sequences of adverse events that impair QoS
  - interconnected networks supporting the service
  - interconnections among networks and systems

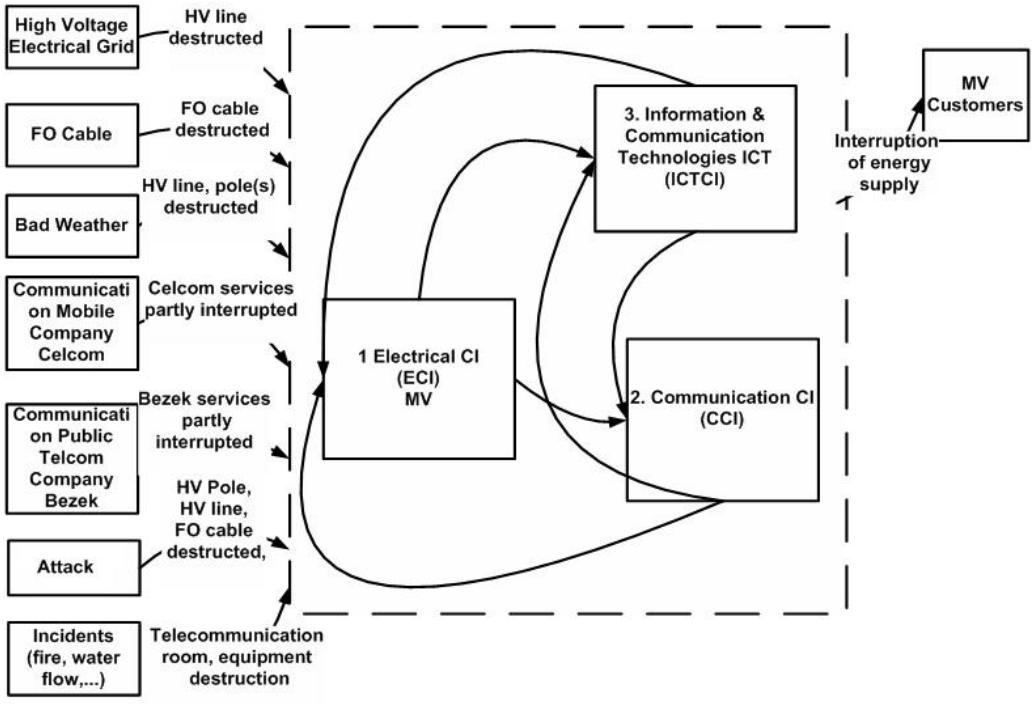
MV power grid



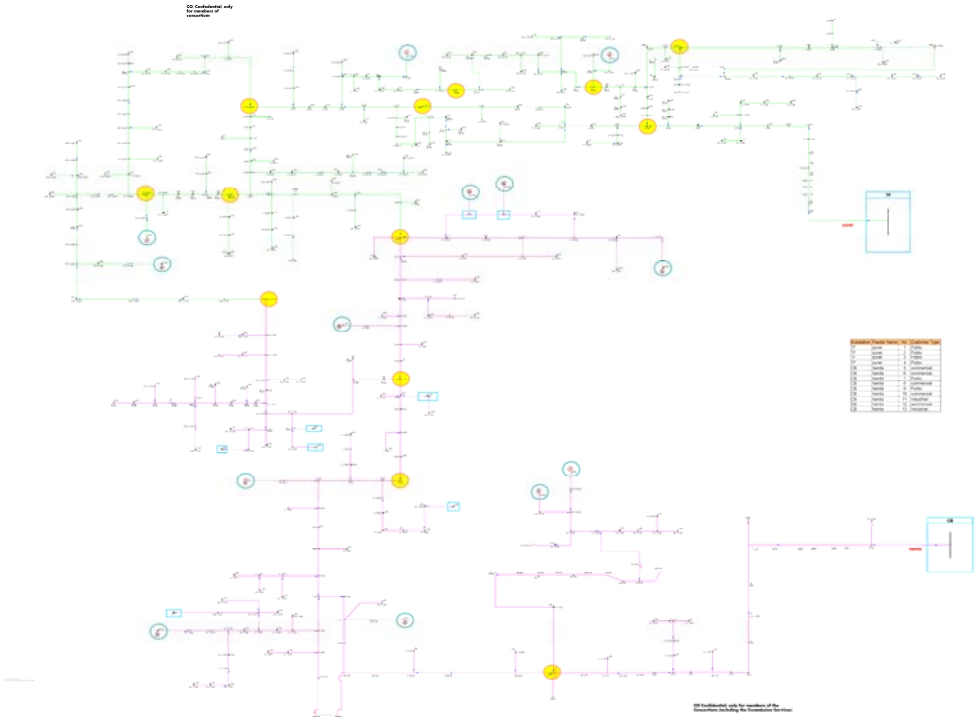
FISR service performed by SCADA operator

- In Power grids, failures may cause the de-energisation even of large part of power customers and need to be located, isolated and repaired quickly and safely.
  - Failure location
  - The failure location process ends when the feeder protection at substation is activated and the faulty section is located and isolated.
  - Finally, on the repair of the faulty section, the grid is restored to its original configuration.

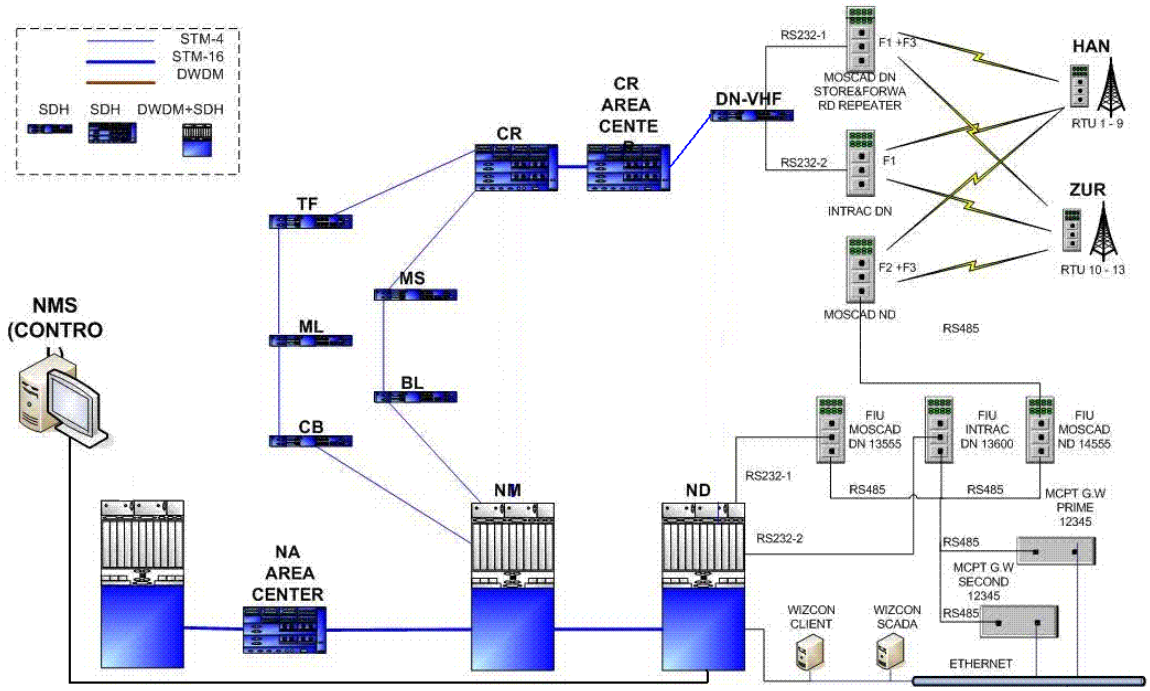
Events impact (through interconnected networks) on quality of power supplied to MV customers



Interconnected networks supporting FISR:
Electrical 22 KV grid portion



Interconnected networks supporting FISR:
SCADA and Communication network



Risk

Risk can be thought as answer to three questions:

1. What can happen (scenario)
2. How likely is it (probability)
3. How bad is it (consequences)

Risk of what?

- Of degradation or loss of power supplied to to customers:
  - upon degradation or loss of services performed by SCADA operators
  - due to mutual propagation of disturbances and adverse events between Power grid and Telco network

Loss/degradation of FISR service

- The quality of *FISR s*ervice, in terms of
  - performance,
  - dependability
  - operability level

- affects the quality of power supply, in terms of
  - SAIDI
  - SAIFI
  - CAIFI

A timely actuation of FISR service, consequential to a permanent failure of the grid, reduces the outage duration

Indicators of loss/degradation of services
(in green presented today)

- **Performance indicators (NS2 models)**
  - Dynamical path (i.e. between SCADA control centre and RTUs)
  - Throughput of nodes of Telco network
  - Round Trip time (i.e. between SCADA control centre and RTUs)
  - Service response time:
  - outage duration
  - % of affected customers
- **Dependability indicators**
  - Connectivity (i.e. between SCADA control centre and RTUs: minpaths and mincuts) (WNRA models)
  - Reliability and availability (i.e. between SCADA control centre and RTUs) (WNRA models)
  - QoS indicators (i.e. SAIDI, SAIFI, CAIDI) by RAO simulator – Multitel
  - Security: RESCI MONITOR – Real time Security monitoring – Henry Tudor
- **Operability level indicators**
  - Risk prediction tool by Mixed Holistic Reductionistic method – UNIROMA3

Modelling assumptions: representation of heterogeneous networks

- Power grids are described by differential equations with some discrete dynamics needed to represent circuit breakers
  - then, typically power flow simulators are used.
- On the other way around, SCADA and Telco networks are packet switching networks
  - then they need to be represented by discrete event simulators

Modelling assumptions: representation of heterogeneous networks for FISR

- To compute QoS of FISR, we need:
  - a full scale representation of SCADA and Telco network, which act to implement FISR on the power grid and
  - a proper representation of the power grid, as it is observable by the SCADA control centre (SCC)

Discrete event simulation of FISR accounting heterogenous networks

- To represent power grid observability from SCC limited to FISR service, we may resort to a discrete event simulator
- Among discrete event simulators we choose NS2, one of the most widely used open source network simulators.
- NS2 allows to simulate packet networks and it may well represent SCADA and Telco networks
- First, we built a separate NS2 script to implement FISR each sub model: SCADA system, telco network and power grid submodel
- then we integrate the three scripts in a single FISR model that relies on the single heterogeneous network

Modelling assumptions: a single heterogeneous network supporting FISR

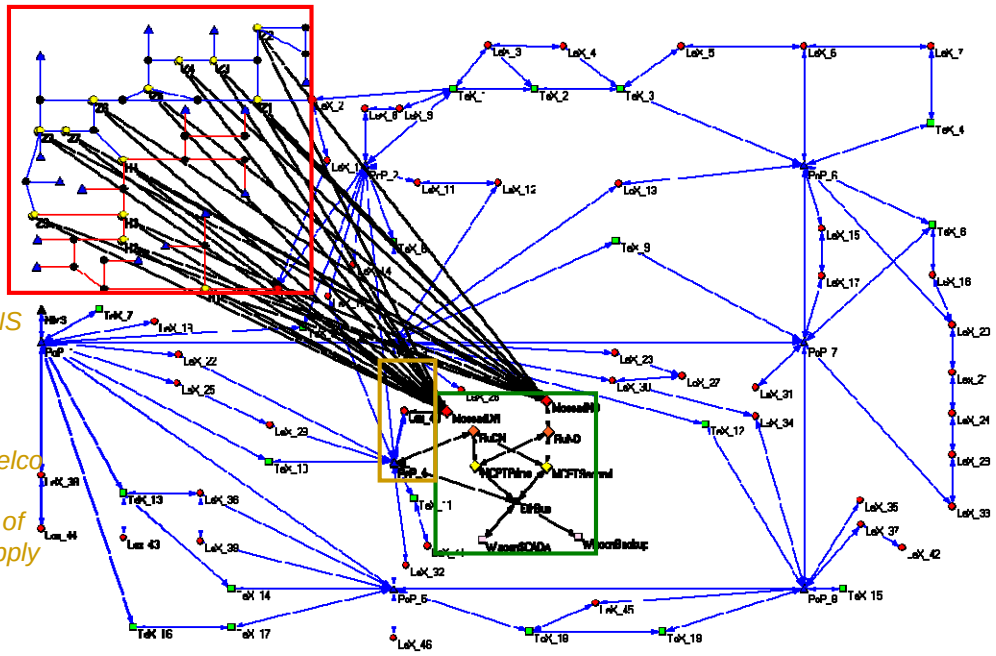
Power grid, SCADA system, Telco network

INTERCONNECTIONS

SCADA and Telco

Telco and HV grid

RTUs, SCADA and Telco devices energised by Power grid by means of emergency power supply systems



Performance indicators (NS2 models)

- **Dynamical path (i.e. between SCADA control centre and RTUs)**
- **Round Trip time - RTT (i.e. between SCADA control centre and RTUs)**
- **Response time**
- **outage duration**
- **% of affected customers**

FISR: modelling assumptions on SCADA and Telco network

Assumptions on telco network

Link Type	Backbone (DWDM)	TeX (STM-16)	LeX (STM-4)
Capacity	10 Gbps	2.5 Gbps	600 Mbps
Source/Destination Node	PoP-PoP	PoP-TeX, TeX-TeX	PoP-LeX , TeX-LeX, LeX-LeX
Traffic Type	TCP+UDP	TCP	TCP
Traffic Bit-Rate	12 GB (TCP) + 8 GB (UDP)	12 GB	12 GB
Type of Agents	CBR for UDP		FTP for TCP
Number of Agents	100 for UDP		100 for TCP

Assumptions on SCADA communication links

Link Type	Ethernet	RS-485	RS-232	VHF-radio
Capacity	100 Mbps	19.2 Kbps	19.2 Kbps	4.8 Kbps
Source/Destination Node	SCADA - MCP_T – PoP	MCP_T-FIU FIU- RF modem	RF modem - Telco Nodes	RF modem - RTU
Traffic type	DLC (TCP)+ TCP	DLC (TCP)	DLC (TCP)	DLC (TCP)
Traffic bit-rate	256 bytes /30 sec	256 bytes /30 sec	256 bytes/30 sec	256 bytes /30 sec

FISR performance model: NS2 simulation time steps on a failure within an intermediate section of the grid

T0 (0 sec): simulation start

T0-T1 (0 sec-15 sec): initializing routing tables of SCADA (DV routing protocol)

T1-T2 (15-30): normal conditions of grid and SCADA (normal power flow on power grid and polling cycle of SCADA)

T2 (30): failure on intermediate section of power grid (opening of protection breakers at substation)

T2-T3 (30-33): automatic reclosure attempts of protection breakers (twice)

T3-T4 (35-46): after 2 sec automatically, progressively, successfully and permanently reclosing switches by RTUs up to detect the switch that bounds the failed section

T4-T5 (46-47): the RTU controlling this switch senses power loss, re-open the switch and sends an alerting message to SCADA Control Center (SCC)

T5-T6 (52-53): after 5 sec the response of SCC to RTU

T6-T7 (57-58): after 5 sec the SCC sends a closing command message to RTU controlling tie switch

T7-T8 (62-63,70): after 5 sec the response of RTU to SCC

T8 (64,70 - 65): after 2 sec the new configuration of power grid

T8-T9 (65-70-72): after 5 the repair of the failed section of the grid and after 2 sec restoration of the original configuration

Computation of FISR performance under normal and failure conditions of SCADA and Telco network

Case 1) normal condition of SCADA and Telco network

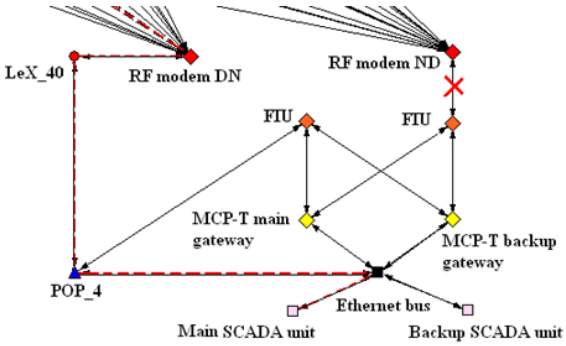
Case 2) a failure on SCADA (the link between FIU and Moscad)

Case 3) a failure on SCADA and a failure on Telco network

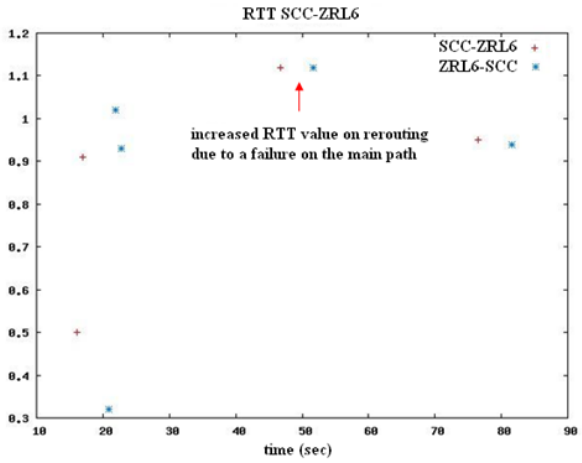
- the link between FIU and Moscad
- the link between PoP ND and LeX DN-VHF

FISR performance model: some numerical results

SCADA Control Centre – RTU Dynamical path



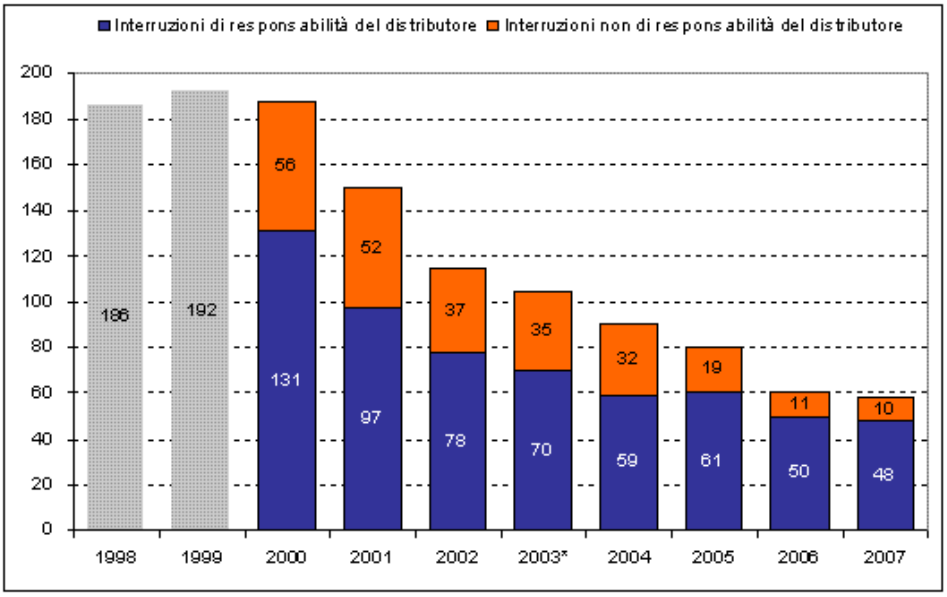
SCADA Control Centre - RTU Round Trip Time



FISR response time

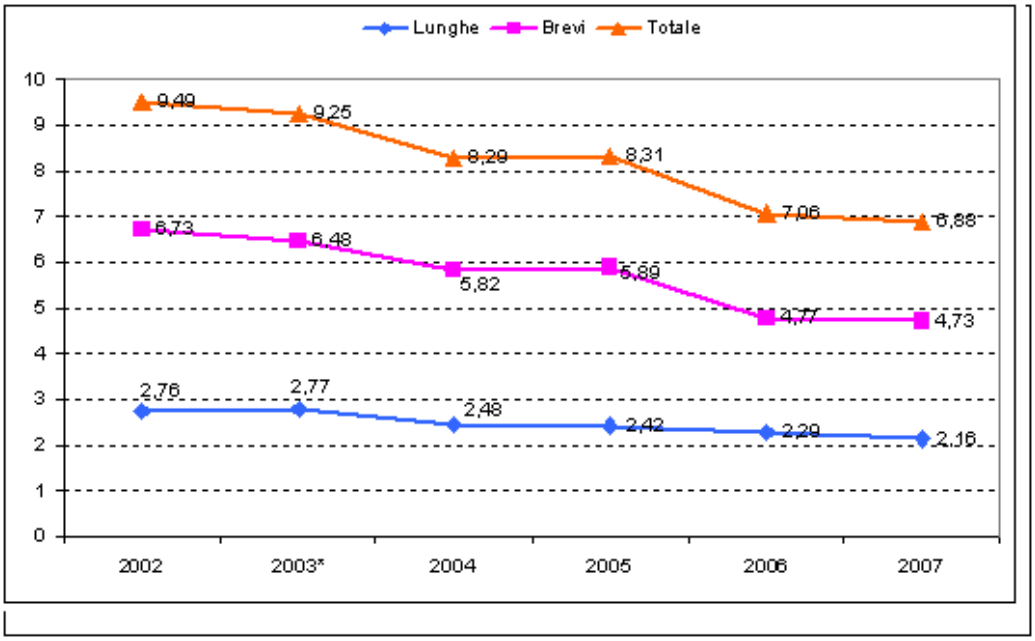
Section of failure	Response time (case 1)	Response time (case 2)	Response time (case 3)	% of affected customers	
				Before FISR	*after FISR*
Initial	18.4 sec.	18.6 sec.	> simulation time	46.6	0
Intermediate	34.8 sec.	35.2 sec.	> simulation time	26.6	0
Terminal	29.1 sec.	29.4 sec.	> simulation time	26.6	6.6

Duration of power supply interruptions – minutes for client for year



Quality of power supplied to grid customers

Number of long and short interruptions for LV clients



Comparison of modelling approaches in MICIE (tools) [online/offline]

- **FISR performance and rerouting (NS2 simulator) [offline]**
- **FISR dependability (WNRA reliability analyzer) [online]**
- **FISR worst case measures in presence of hacker attacks (MILP algorithm) [online]**
- **Bayesian Belief Networks (GENIE) [online]**
- **Mixed Holistic Reductionistic models (Risk prediction tool) [online]**
- **Deterministic and Agent Based simulation (RAO) [online]**
- **Security Monitoring (RT-SM) [online]**

Offline models can be reverted in online models by simplification.
Warning: no rationale in model simplification could result in useless toy models