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Defence & Restoration Plans

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Lusaka, ZESCO 2018.09.05

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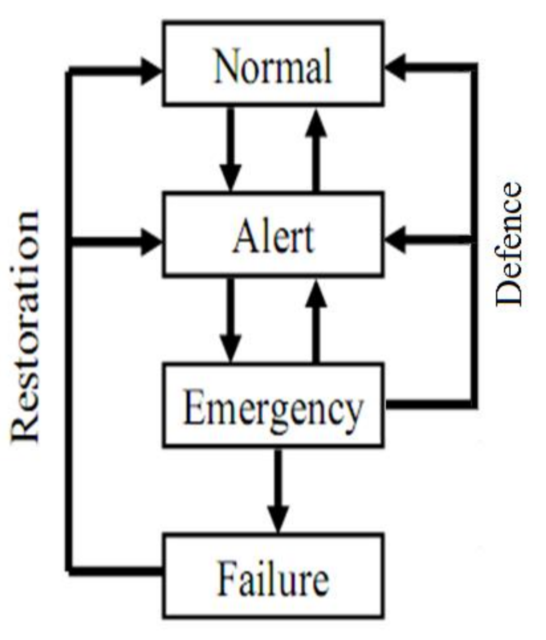
Summary

1. Objectives of Defense & Restoration Plans
2. Defense & Restoration Plans & Practices in Italy
3. Critical Aspects in presence of large amount of VRE
4. Case Studies from other TSOs

Objectives of Defense & Restoration Plans

- A Defense Plan is a set of coordinated automatic measures intended to ensure that the overall power system is protected against major disturbances involving multiple contingency events, generally not caused by natural calamity
- Defense plans are used to minimize and reduce the severity and consequence of low probability and unexpected events and to prevent system collapse.
- Defense plans are primarily used to increase power system security. A defense plan can be considered as an additional level of protection, designed to initiate the final attempt at stabilizing the power system when a widespread collapse is imminent.
- Individual System Integrity Protection Schemes (SIPS) such as automatic generation run back schemes, load or generation rejection, load shedding, reactive switching, bus or system splitting, etc. are then regarded as coordinated elements used within a defense plan.

Defence Plans



Objectives of Defense & Restoration Plans

The process for designing a Defense Plan is consists of the following stages:

- Definition of a general methodology specialized for the system to protect
- Off-line detailed verification of the performances of the Defense Plans through dynamic simulations
- On-line Static and Dynamic Security Assessment (SSA and DSA)
- Detailed reconstruction of real outages if any

How to Design a Defense Plan

Objectives of Defense & Restoration Plans

- References: CIGRE Task Force C2-02.24, **“Defense Plan Against Extreme Contingencies”**, April 2007

	Densely meshed power system with dispersed generation and load		Lightly meshed transmission systems with localized generation and load.	
	Located in a large interconnection	Not interconnected or by far the largest partner	Located in a large interconnection	Not interconnected or by far the largest partner
Transient angle instability	*	*	***	***
Frequency instability	*	***	*	***
Voltage instability	*	*	***	***
Small signal stability	**	**	**	**
Cascade tripping	***	***	*	*

Dominant Phenomena in Relation to Power System Types and Structure

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Objectives of Defense & Restoration Plans

- References: CIGRE Task Force C2-02.24, **“Defense Plan Against Extreme Contingencies”**, April 2007

Possible SPS Actions		Transient instability	Frequency instability		Voltage instability	Cascade line tripping	Small signal stability
			Over-frequency	Under-frequency			
Actions on generation	Generation Rejection	*	*		*	*	
	Turbine fast valving	*					
	Gas turbine start-up			*	*	*	
	Actions on the AGC				*	*	
Actions on load	Underfrequency load shedding			*			
	Under voltage load shedding				*		
	Remote load shedding	*				*	
Actions on shunt	Automatic shunt switching	*			*		
	Braking resistor	*					
Actions on power system equipment	HVDC fast power change	*	*	*	*	*	
	Quick increase of generator voltage set point				*		
	Controlled opening of interconnection	*		*	*	*	
	Tap changers blocking			*	*		
Closed loop controls devices	Excitation controls	*					*
	Power system stabilizers						*
	SVC voltage controls	*					*
	HVDC special controls		*	*			*

Actions to counteract power system instability

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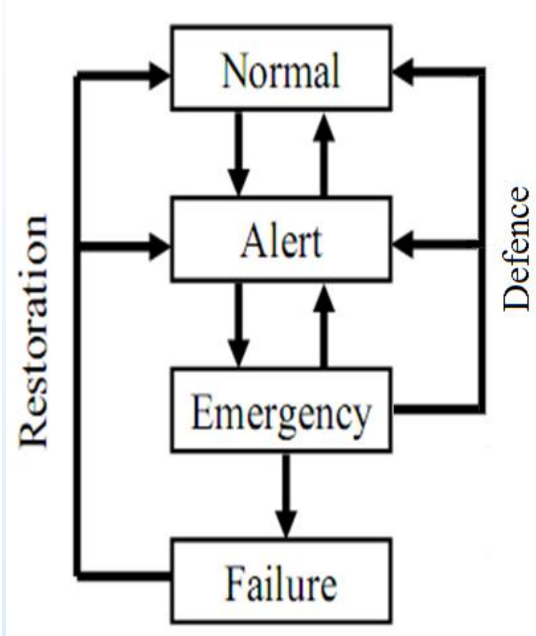
Objectives of Defense & Restoration Plans

- Restoration Plan (RP), as an extraordinary mode of transmission system operation, requires careful planning and operation training;
- The generic task of RP include:
  - ✓ Determination of system and equipment status (blackout determination and extension);
  - ✓ Preparation of plants and network for systematic restoration (power plant situation, autonomous maneuvers, cranking paths);
  - ✓ Re-energization of the network (voltage and frequency controls, thermal and mechanical problems, switching transients, harmonic resonance, inrush current, capability limits, load behavior);
  - ✓ System rebuilding (resynchronization and parallel conditions);
  - ✓ Coordination between the restoration stakeholders (TSO, Power plant control rooms, distributors ect.).

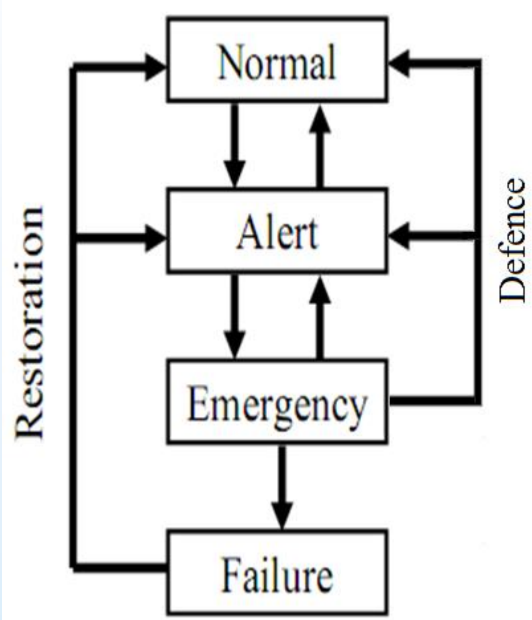
Restoration Plans



Objectives of Defense & Restoration Plans

- The procedure for developing an effective RP include:
  - ✓ Formation of a qualified planning team to provide the combined experience of personnel familiar with production, protection, operations, instrumentation, system analysis, system dynamic simulation and communications);
  - ✓ Review of relevant system characteristics (generation and load mix, transmission voltage levels, voltage and frequency controls, prime mover types, black start or house load capabilities, dynamic characteristics etc.);
  - ✓ Formulation of assumptions regarding blackout scenarios (worst case, light load, peak load etc.);
  - ✓ Agreements on restoration goals (units in house load modality, priority load, critical load etc.);
  - ✓ Development of strategy and tactics ("all-open", "build-down", "build-up");
  - ✓ Validation of the plan (power system simulations, real tests, dynamic models validation);
  - ✓ Training and documentation (OTS Operators Training Simulators, RP in the grid code).

Restoration Plans



Objectives of Defense & Restoration Plans

- Increasing exposure of power systems to extensive blackouts is a possible consequence of:
  - ✓ Changes in the power producers typologies (renewable energy, distributed energy);
  - ✓ Network changes;
  - ✓ Load demand increase and characteristics modification;
  - ✓ Energy market liberalization.
- An effective RP reduces the impact of an outage on customers and on the economy of the affected area while reducing the probability of damage to equipment.
- The major aspects of system operation in the Restoration state are as follow:
  - ✓ System status is abnormal (widespread unserved load, disconnected equipment, disrupted communications etc.);
  - ✓ Restoration objectives are to restore the system to normal operation as quickly as may be consistent with system security;
  - ✓ Restoration tasks include ascertaining the state of the system, preparing the equipment, reintegrating the system, and balancing generation and load, in a controlled manner, back to normal level;
  - ✓ Restoration strategies determinate the manner in which the various tasks are coordinated, and the sequence in which they are executed.

Restoration Plans to reduce the partial or total blackout effects

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Objectives of Defense & Restoration Plans

- Operators must work with limited information because:
  - ✓ Communications are impaired due to the energy situation;
  - ✓ The data is not needed in ordinary operation and therefore is not provided.

- SCADA systems and EMS application programs at the disposal of power system operators were normally not designed for and are not well adapted to the state of the system that pertains to restoration.

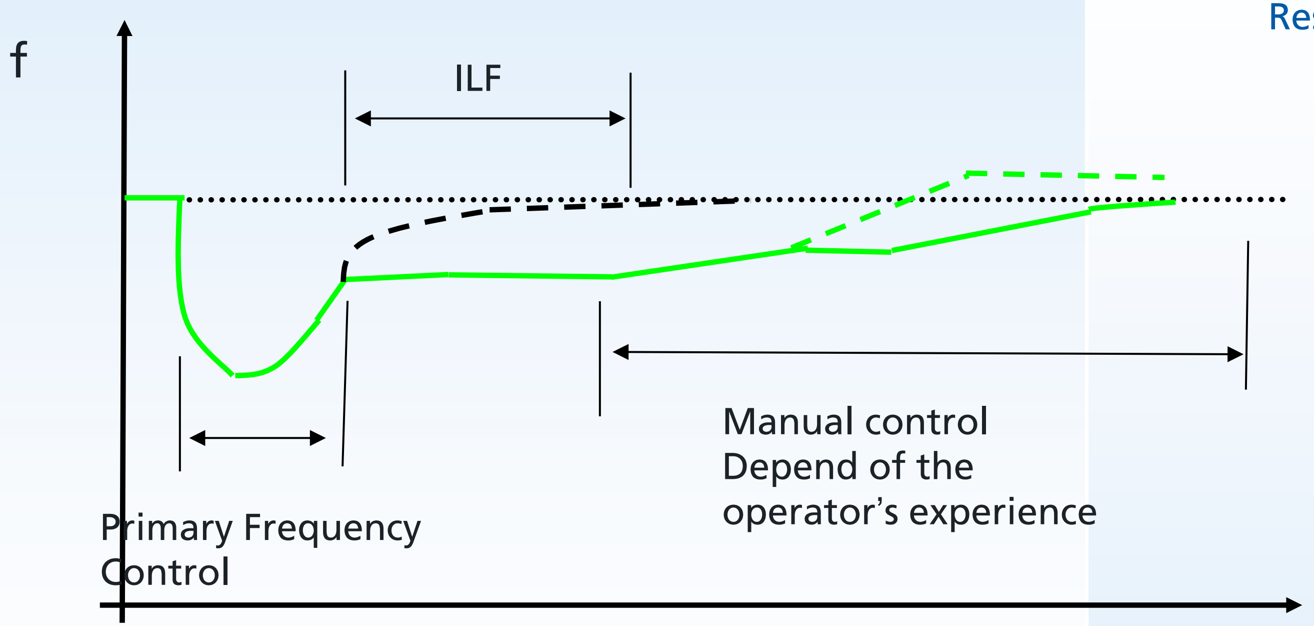
- Others negative factors that make restoration of a power system a difficult task are:
  - ✓ Pressure and stress;
  - ✓ Overall quantities of alarms;
  - ✓ Unavailability of many resources;
  - ✓ Unfamiliarity of operating personnel with the unusual conditions;
  - ✓ Adverse weather conditions.

Problematic Aspects of Restoration

Objectives of Defense & Restoration Plans

Problematic Aspects of

Restoration



If units haven't the local frequency control the effect is:

Objectives of Defense & Restoration Plans

- Restoration Philosophies:
  - ✓ Restoring loads around black start units or Trip To Houseload (TTH, or trip to auxiliaries) generators first, sometimes in parallel, build up these islands to eventually resynchronize the whole system (18 responses, 50 %);
  - ✓ Using strong interconnectors / tie lines first to start the restoration process, if available and build up from there (9 responses, 25 %);
  - ✓ Restoring the backbone system first, using available sources of generation, with or without opening breakers to isolate the "non backbone", then restoring the remaining system (3 responses, 8 %);
  - ✓ Mix and flexible (6 responses, 17%).

CIGRE WG 39,01 – August 2002

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QUESTIONNAIRE SURVEY

Most relevant restoration problems

Restoration problem		Relevance [pu]
Equipment:	Transmission switching	0.66
Information:	Lack of status information	0.63
System control:	Voltage control	0.44
System control:	Shortage of generation	0.43
People:	Coordination	0.39
System control:	Frequency control	0.36

Objectives of Defense & Restoration Plans

- Restoration priorities:
  - ✓ For 16 respondents (44%) the priority sequence is:
    (1) ensure stable supply capacity, via interconnectors or TTH or black start generators, and supply other generators, with nuclear units always the highest priority;
    (2) restore priority loads, typically defined as hospitals, mines, railways, industries, government institutions, major cities, airports, etc;
  - ✓ For 5 respondents (14%) the priority sequence is (with the only real difference being the lower priority of interconnectors):
    (1) Supply to generators;
    (2) Supply to priority loads;
    (3) Restore interconnectors;
  - ✓ 8 respondents (22%) simply indicated that loads are restored in priority order;
  - ✓ One respondent (3%) indicated that heavy industry and traction would be avoided early in restoration;
  - ✓ 6 respondents (17%) indicated a flexible priority.

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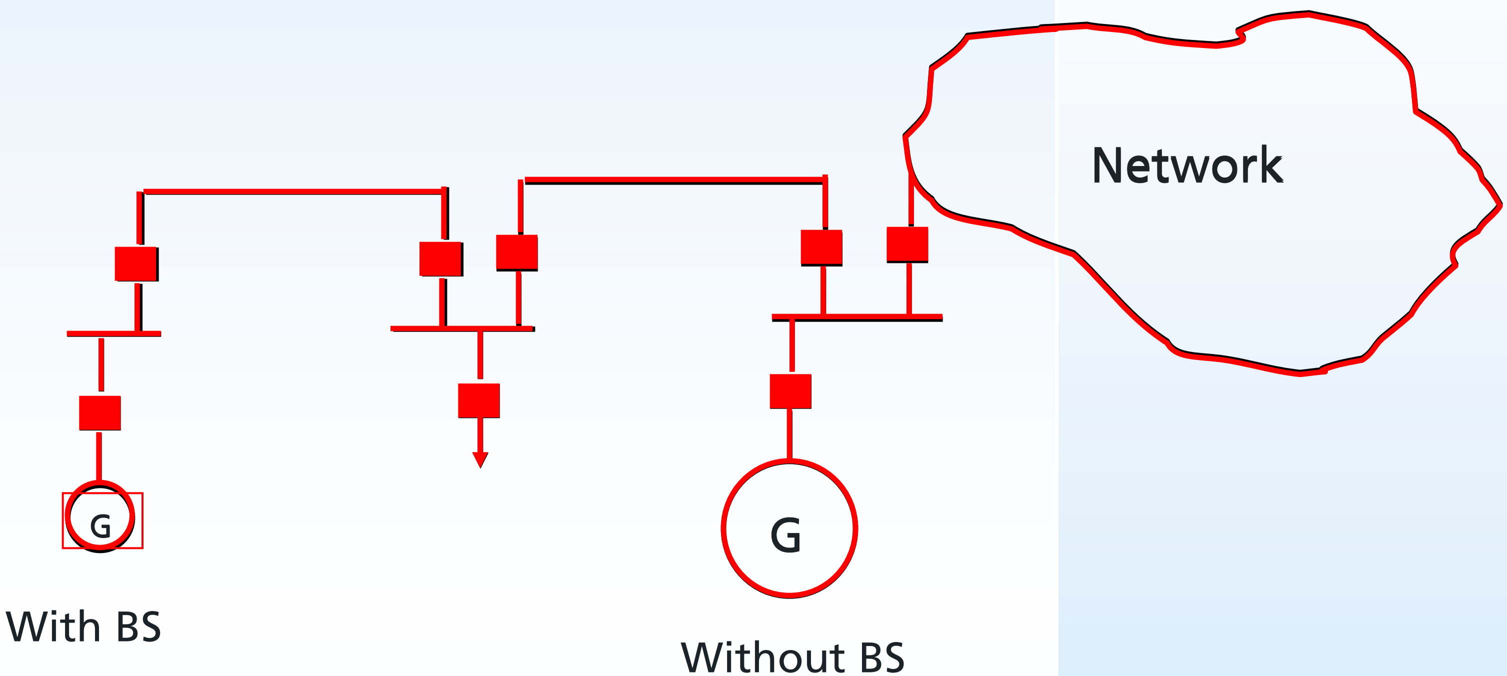
QUESTIONNAIRE SURVEY

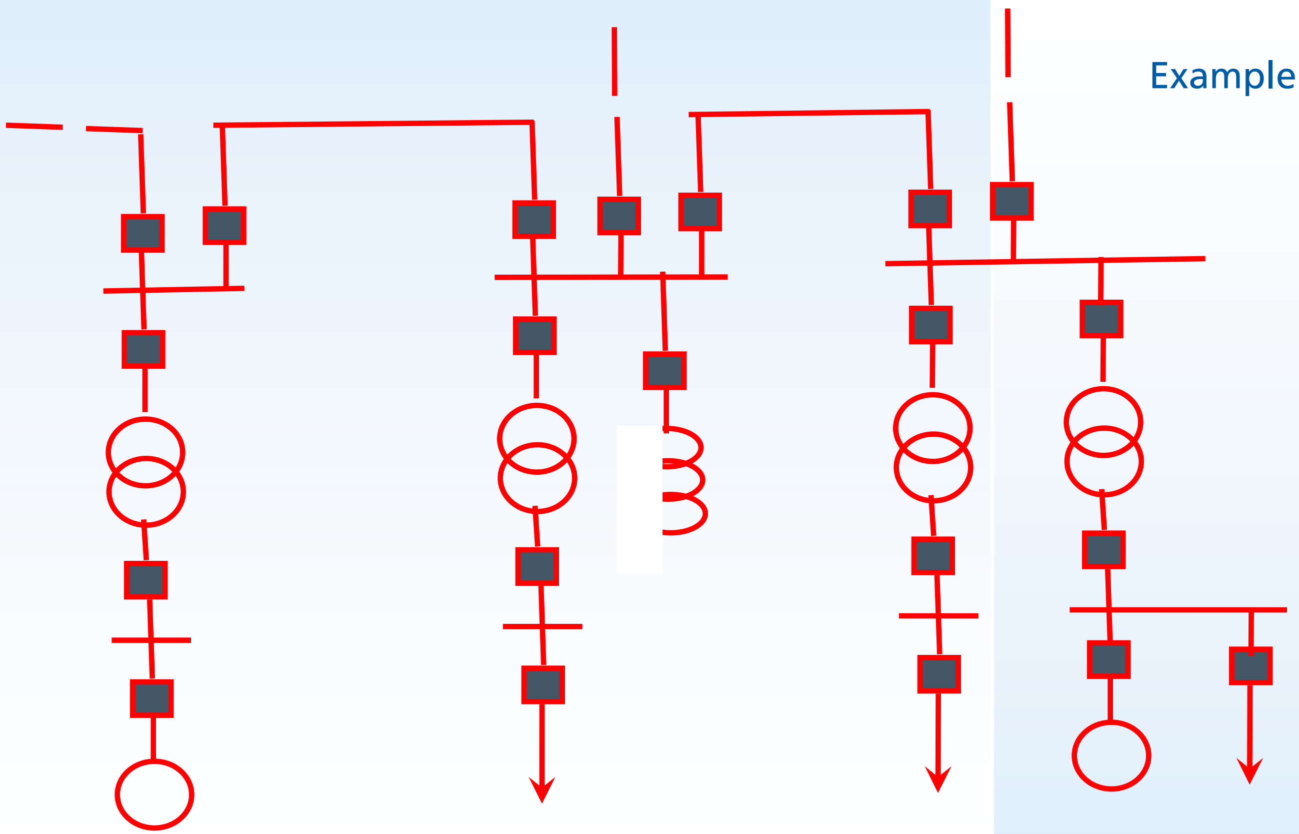
Objectives of Defense & Restoration Plans

Example

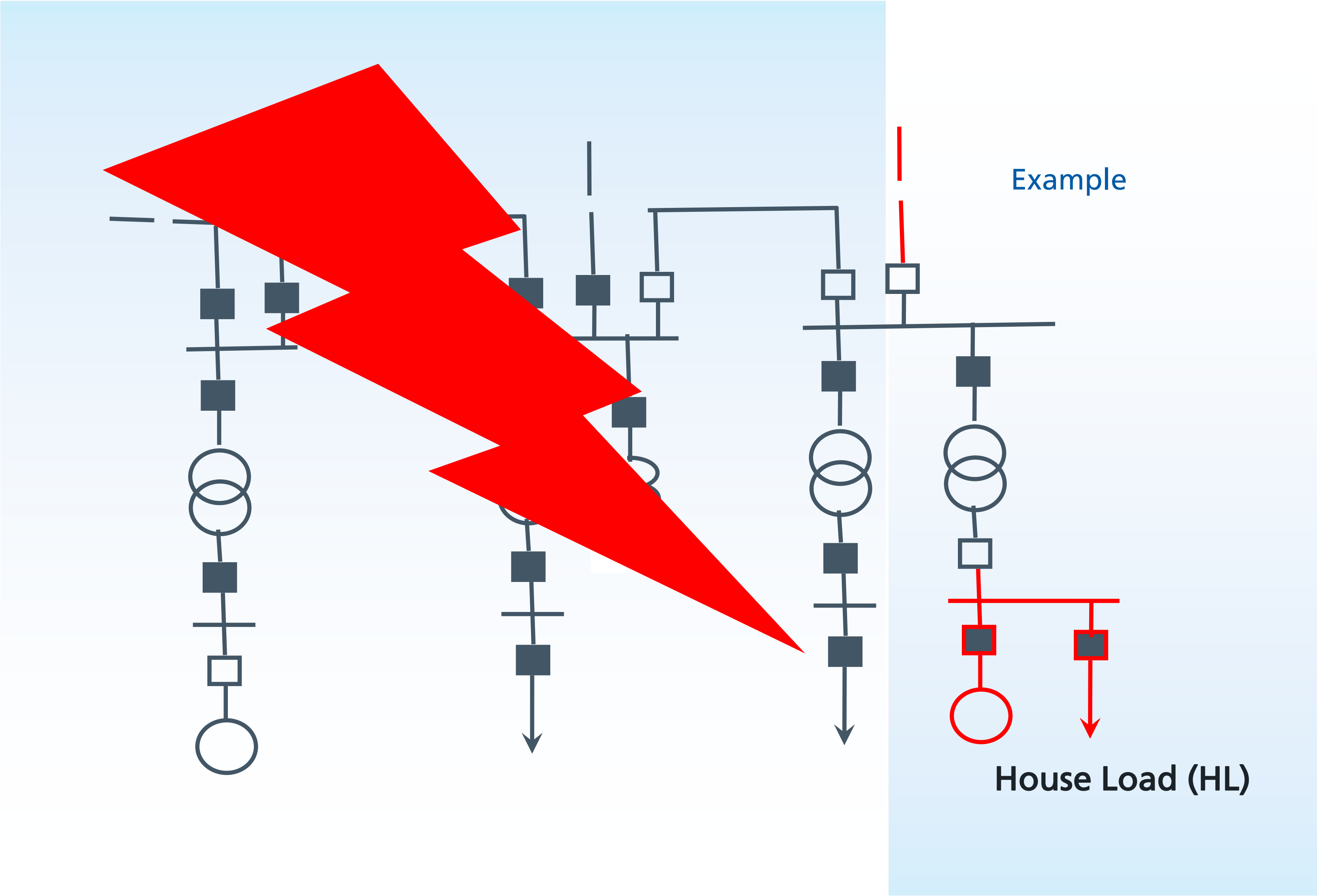


Objectives of Defense & Restoration Plans

Example



Objectives of Defense & Restoration Plans



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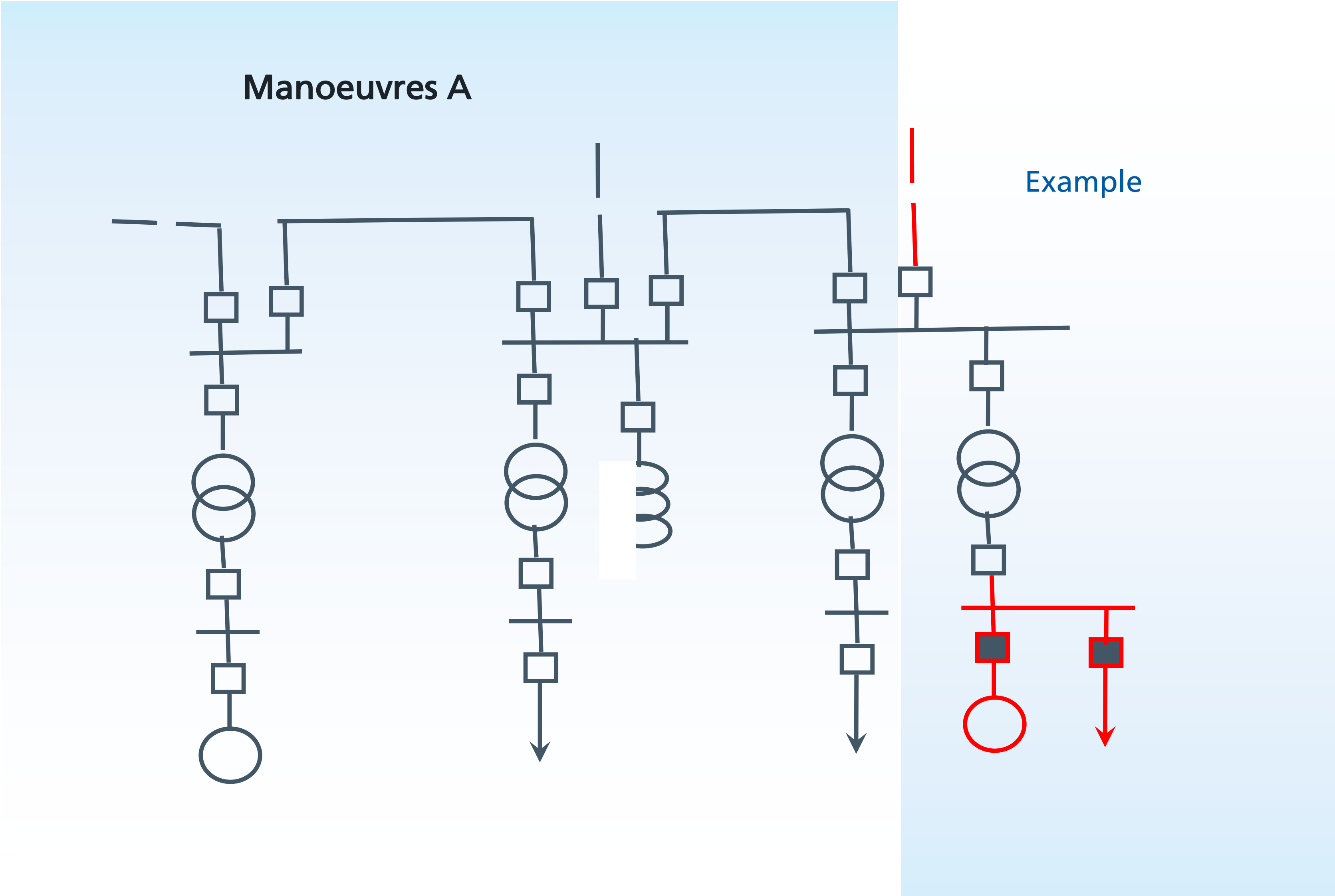
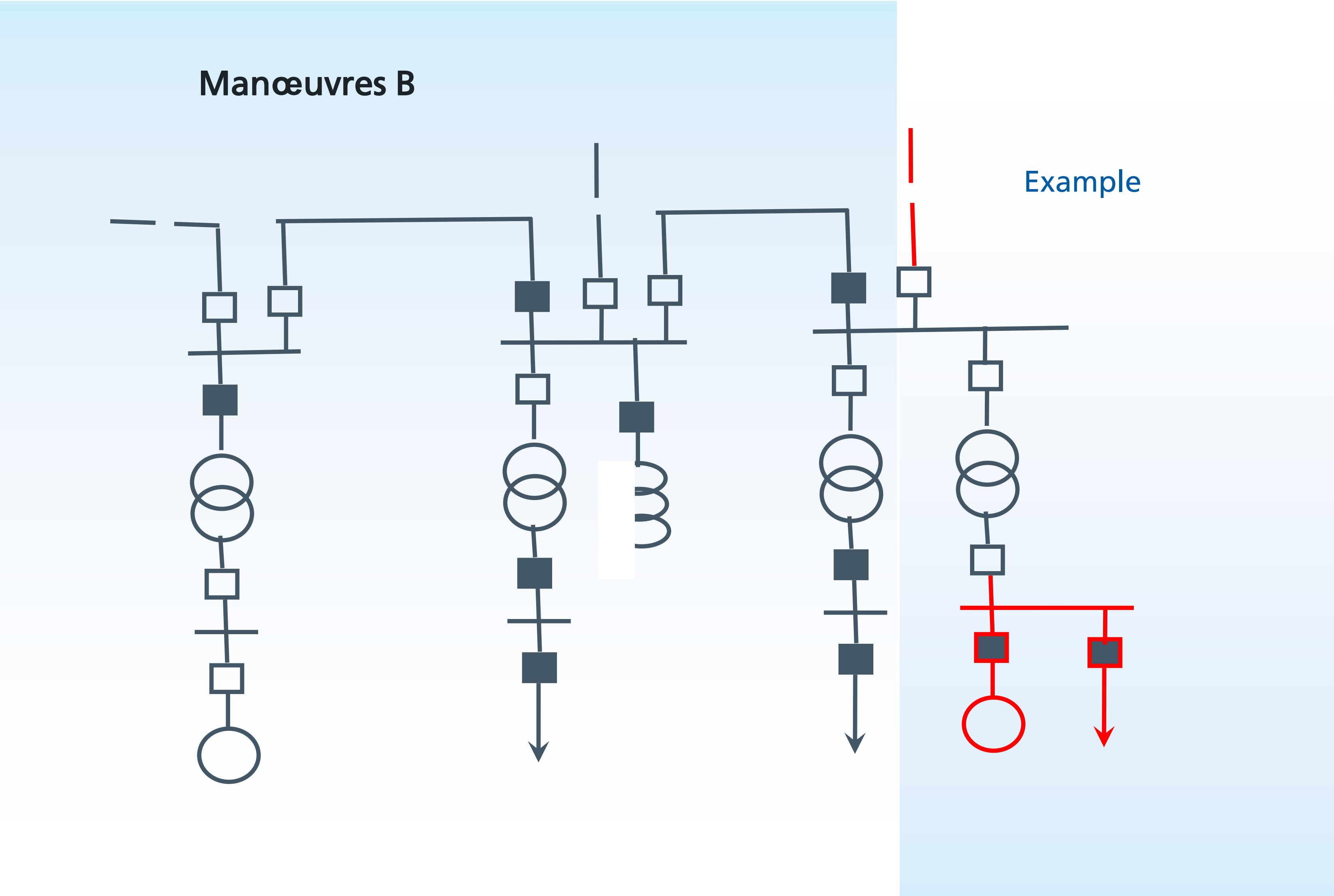
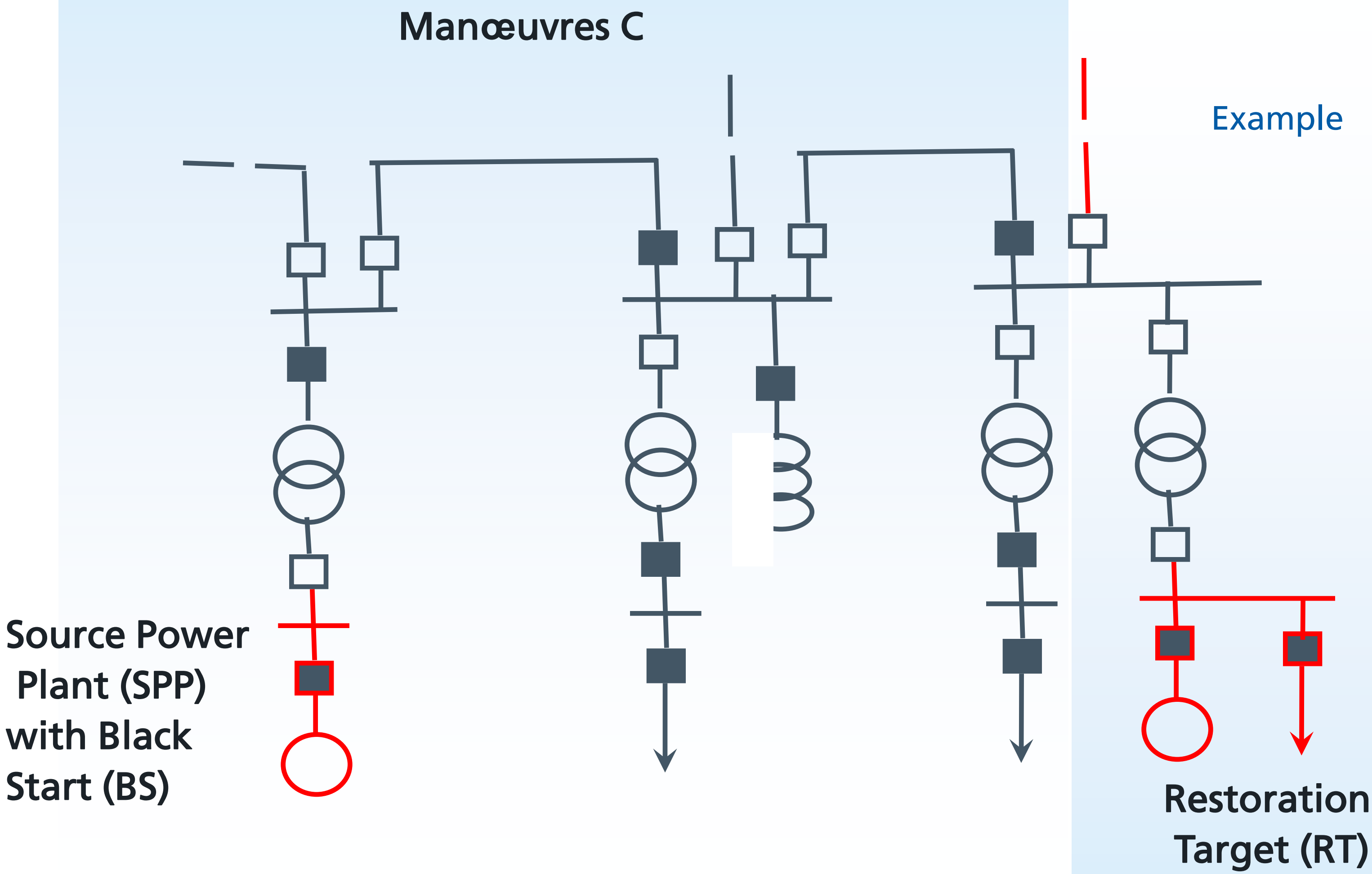


Objectives of Defense & Restoration Plans



International Common and Best Practices



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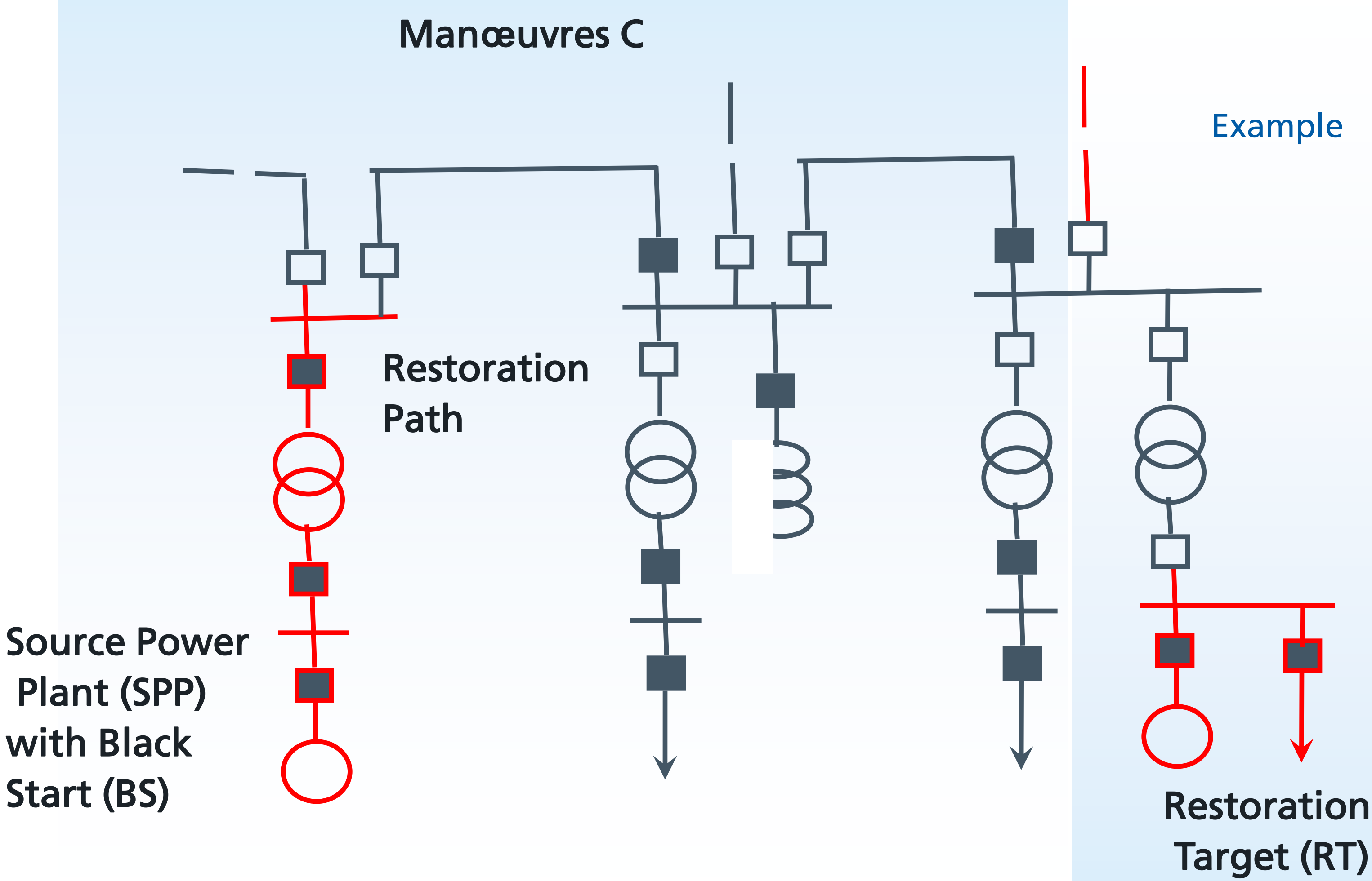

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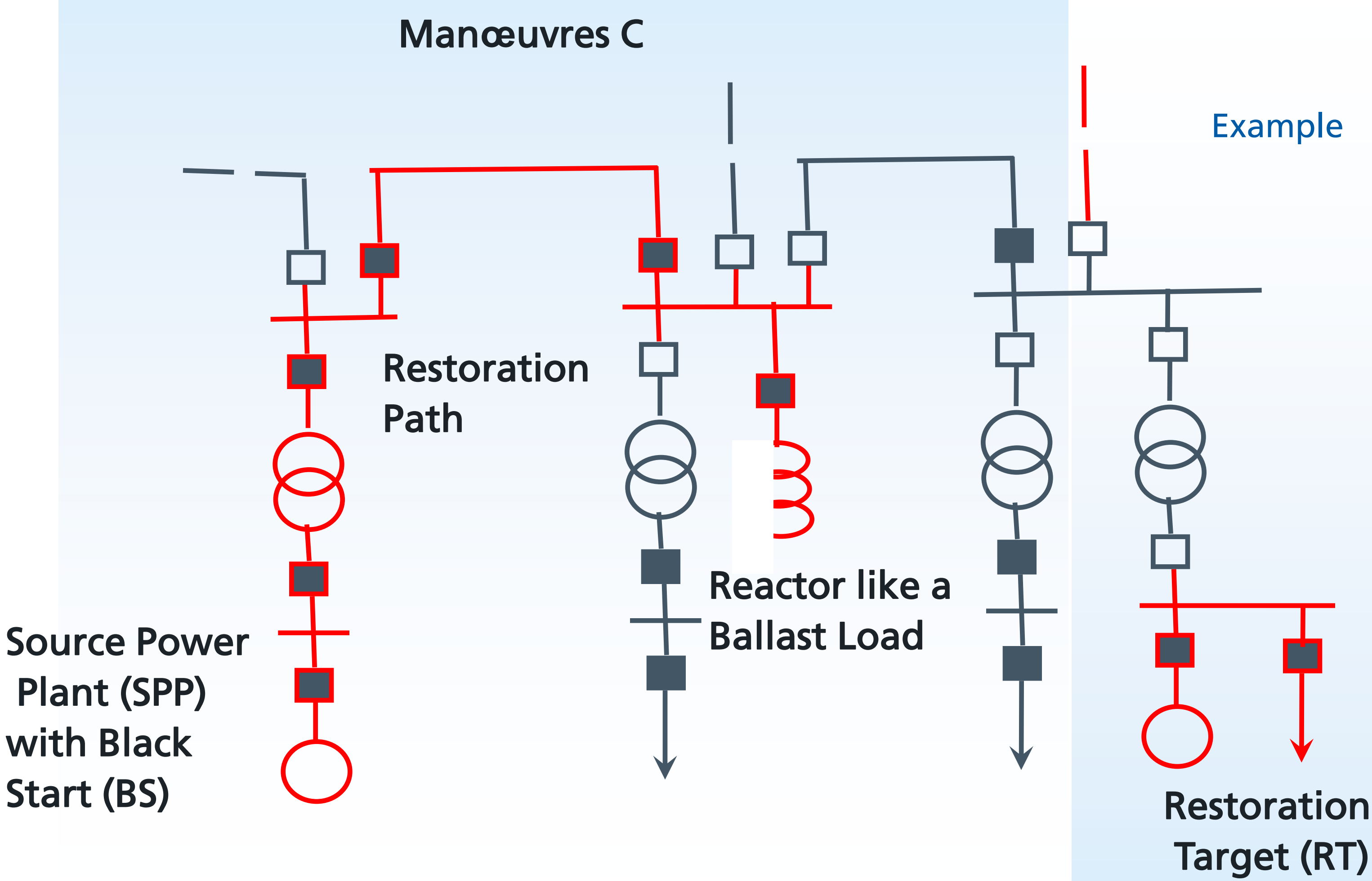
International Common and Best Practices



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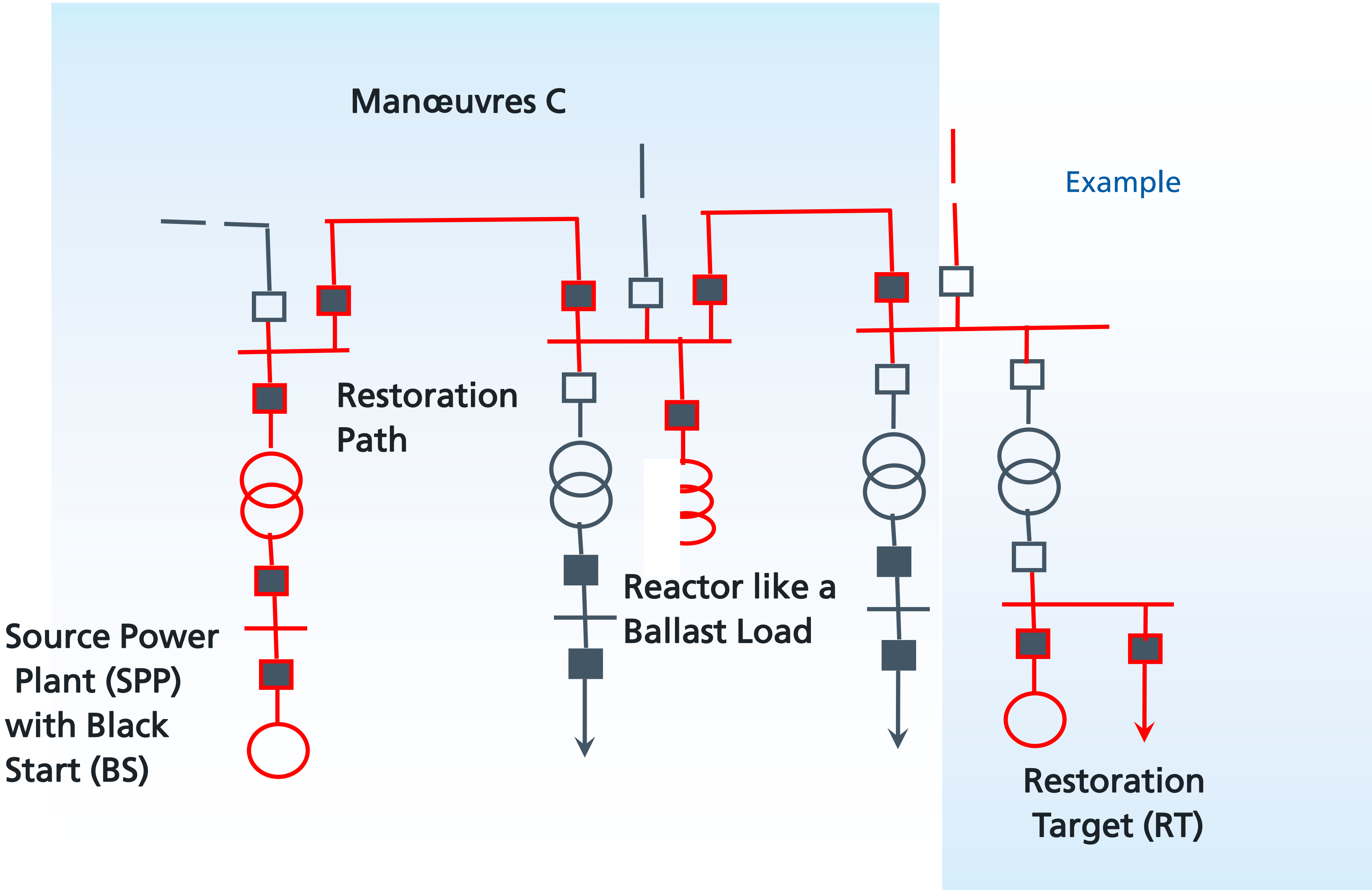

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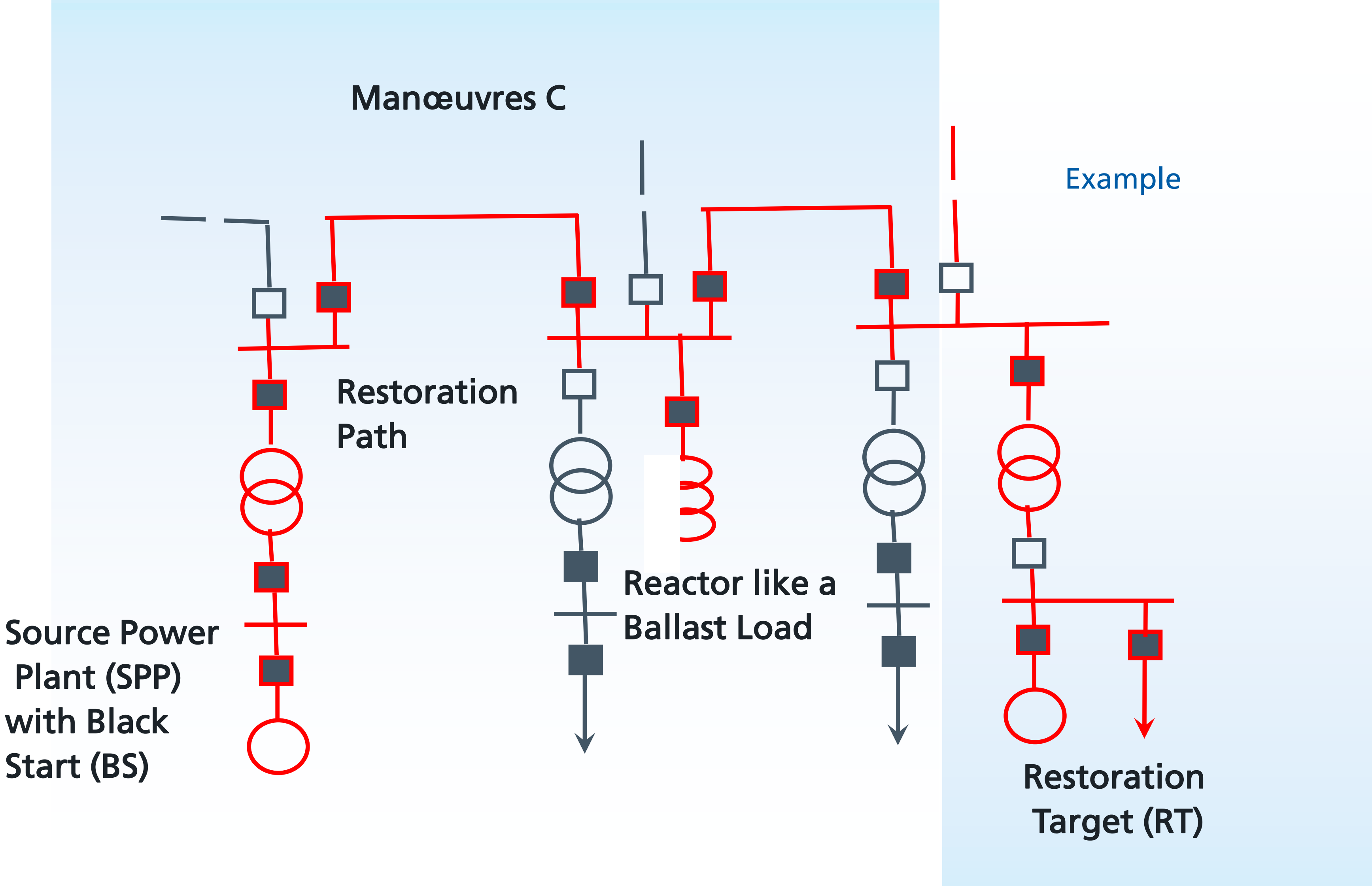

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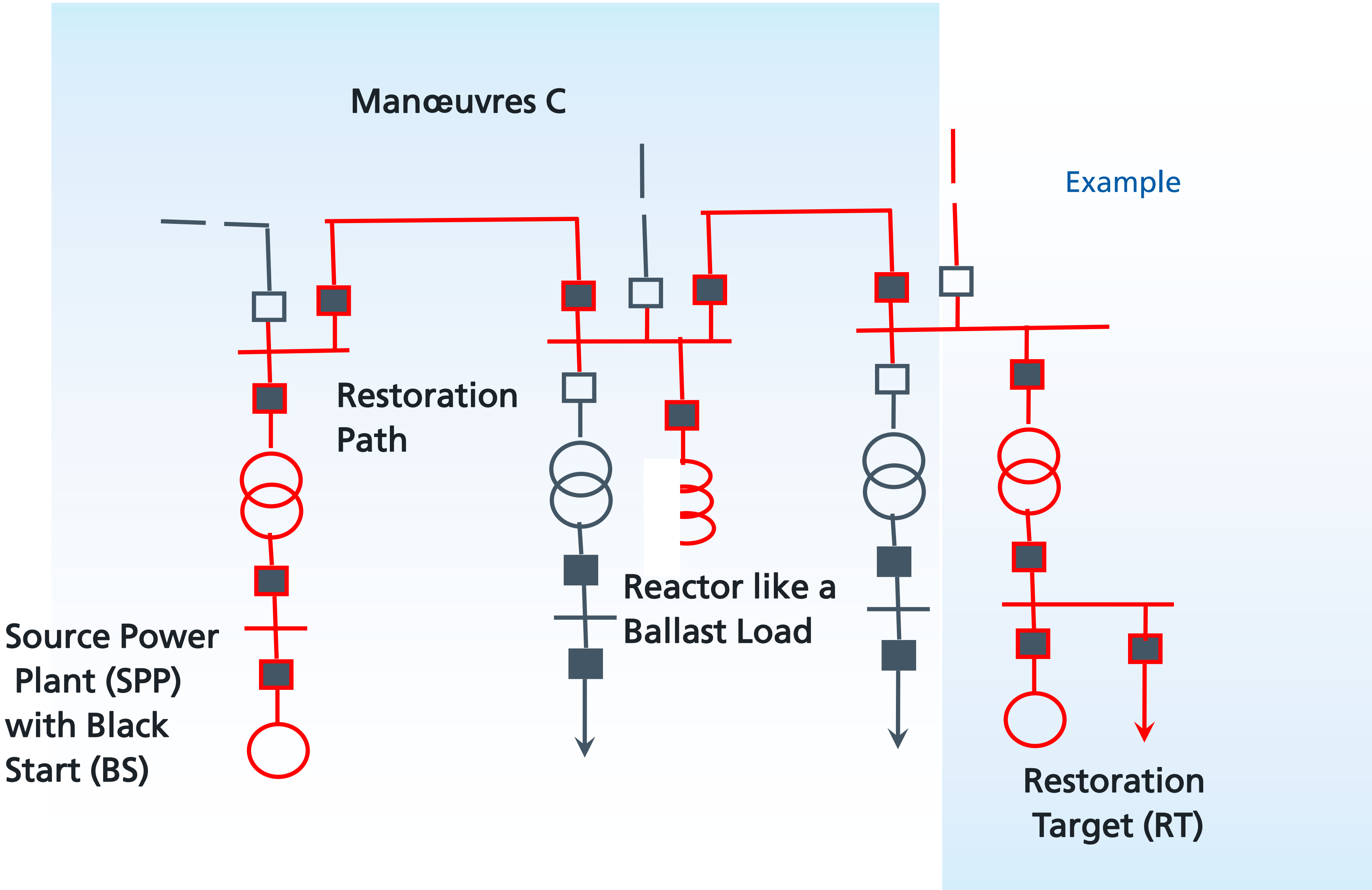

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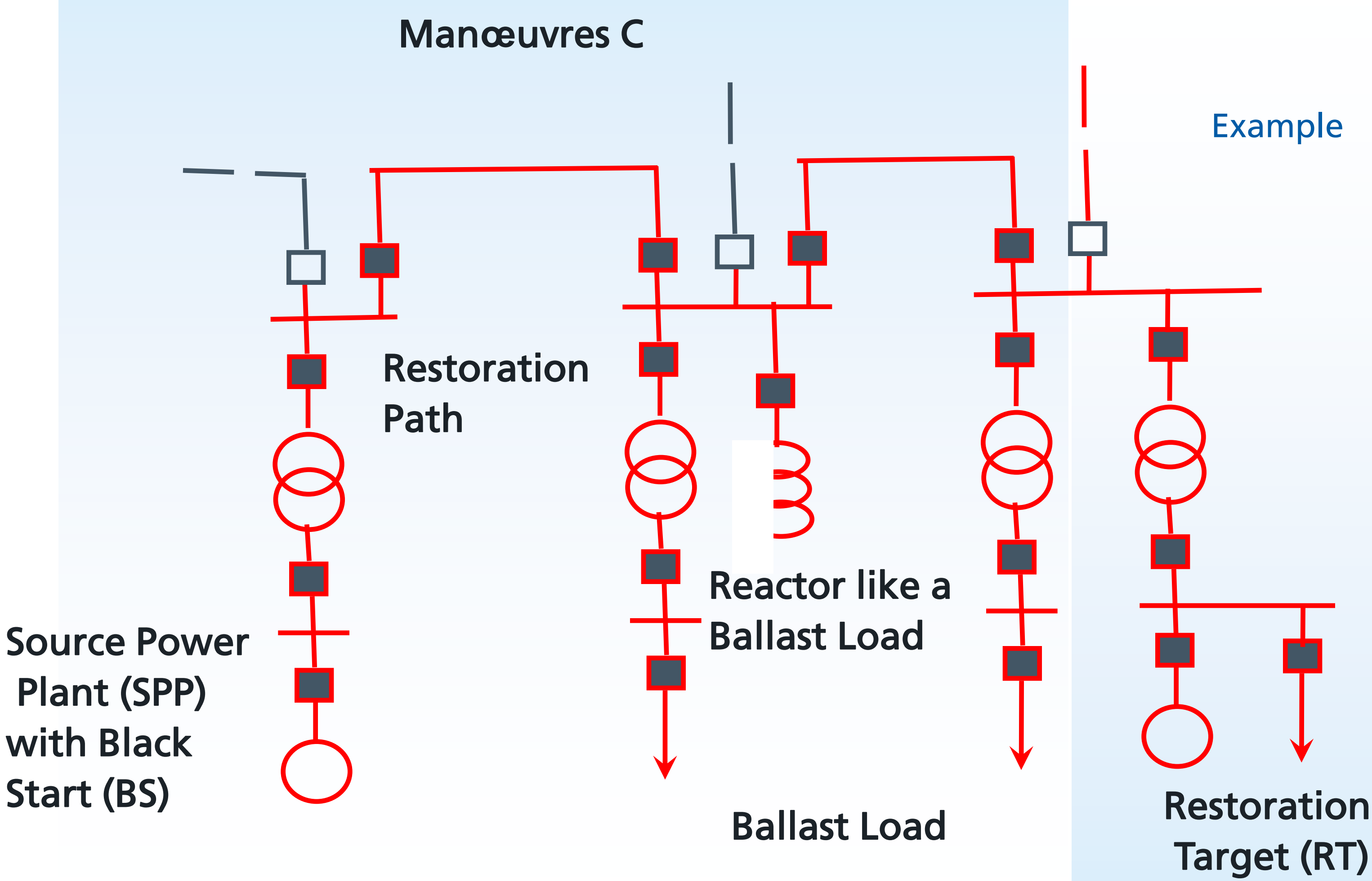
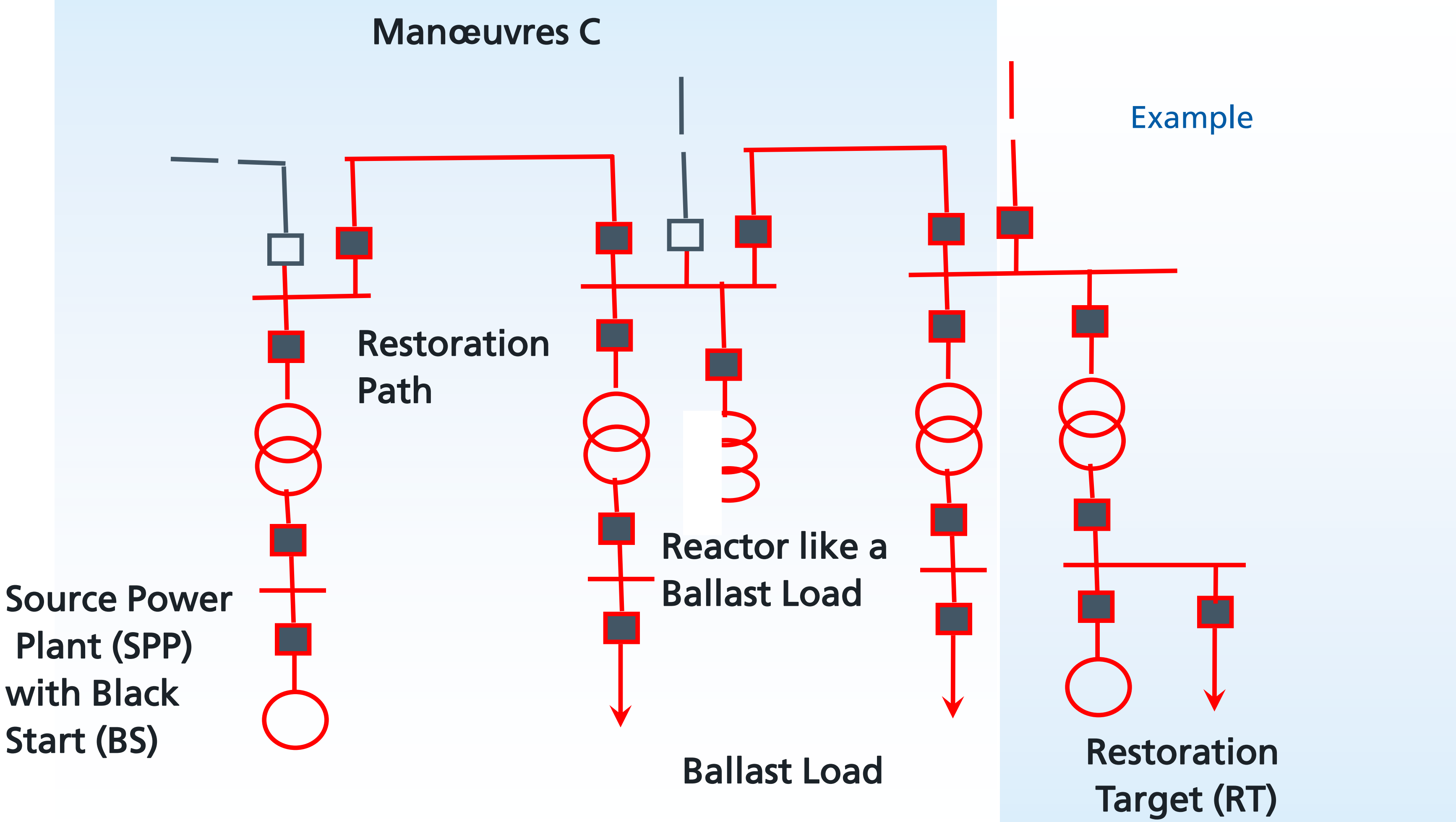


Objectives of Defense & Restoration Plans



Summary

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2. Defense & Restoration Plans & Practices in Italy
3. Critical Aspects in presence of large amount of VRE
4. Case Studies from other TSOs

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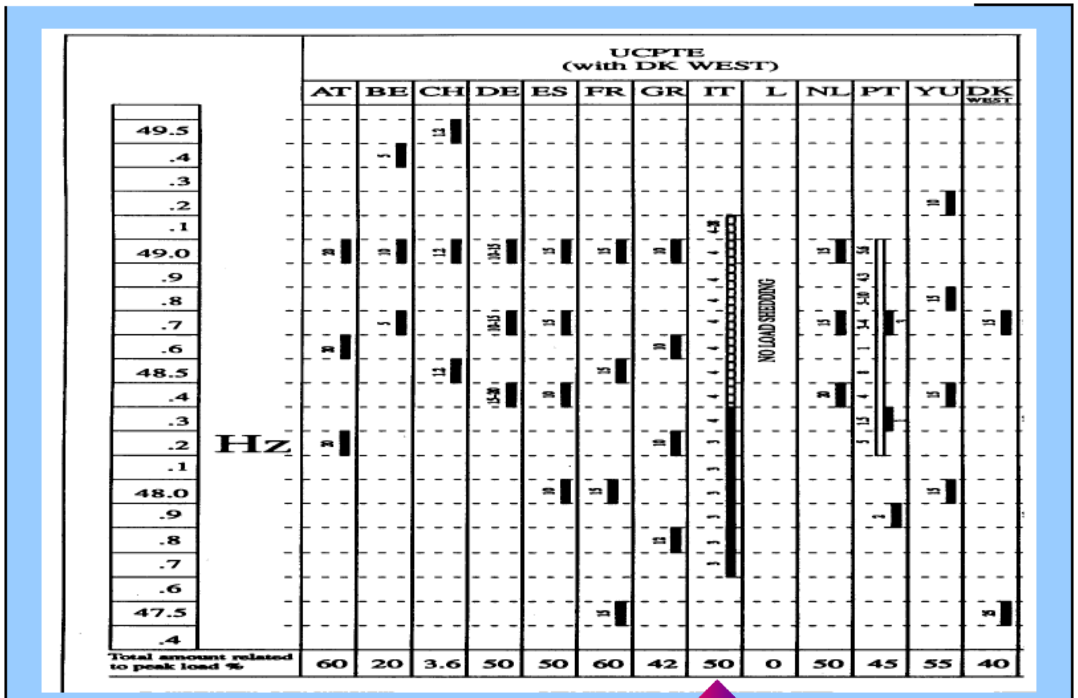
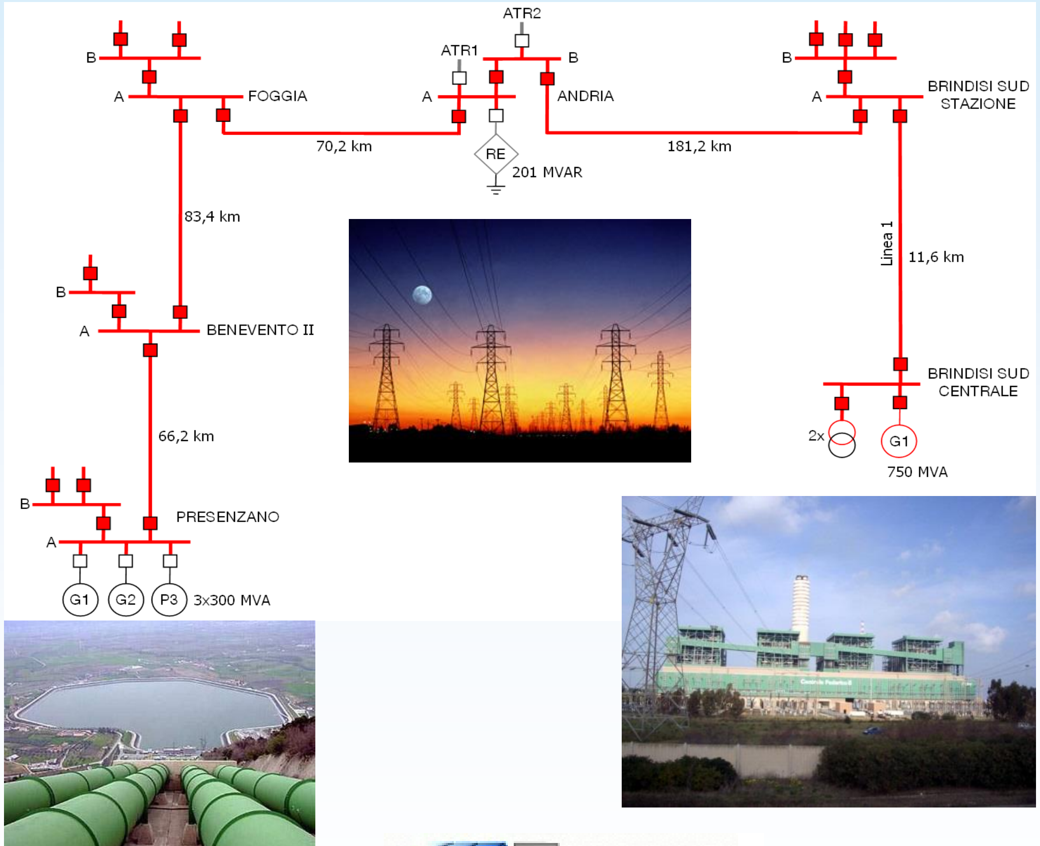
Defense & Restoration Plans & Practices in Italy



Defence Plans

- The Italian Defence Plan is based on a mix of Event-based and Phenomenon-based strategies;
- Automatic frequency load shedding (threshold and derivate);
- Automatic frequency pumps shedding (threshold)
- SPS with automatic tripping device for units;
- SPS with automatic tripping device for loads;
- Manual disconnection of dedicated loads;

Defense & Restoration Plans & Practices in Italy



Terna
Rete Elettrica Nazionale

Restoration Plans

- The Italian Restoration Plan is based on a list of restoration paths from Source Power Plants (units with black start, islanded areas and neighbors grid) to Strategic Restoration Targets (big thermal units in house load, priority load).
- The Italian Restoration paths are split in high and low priority paths

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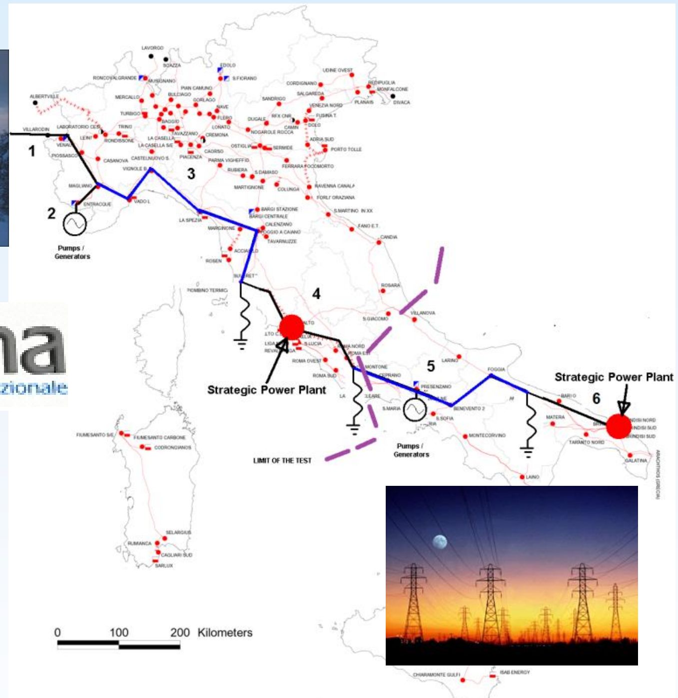
Defense & Restoration Plans & Practices in Italy



1 NCC National Control Center

8 RCC Regional Control Center

Restoration Plans

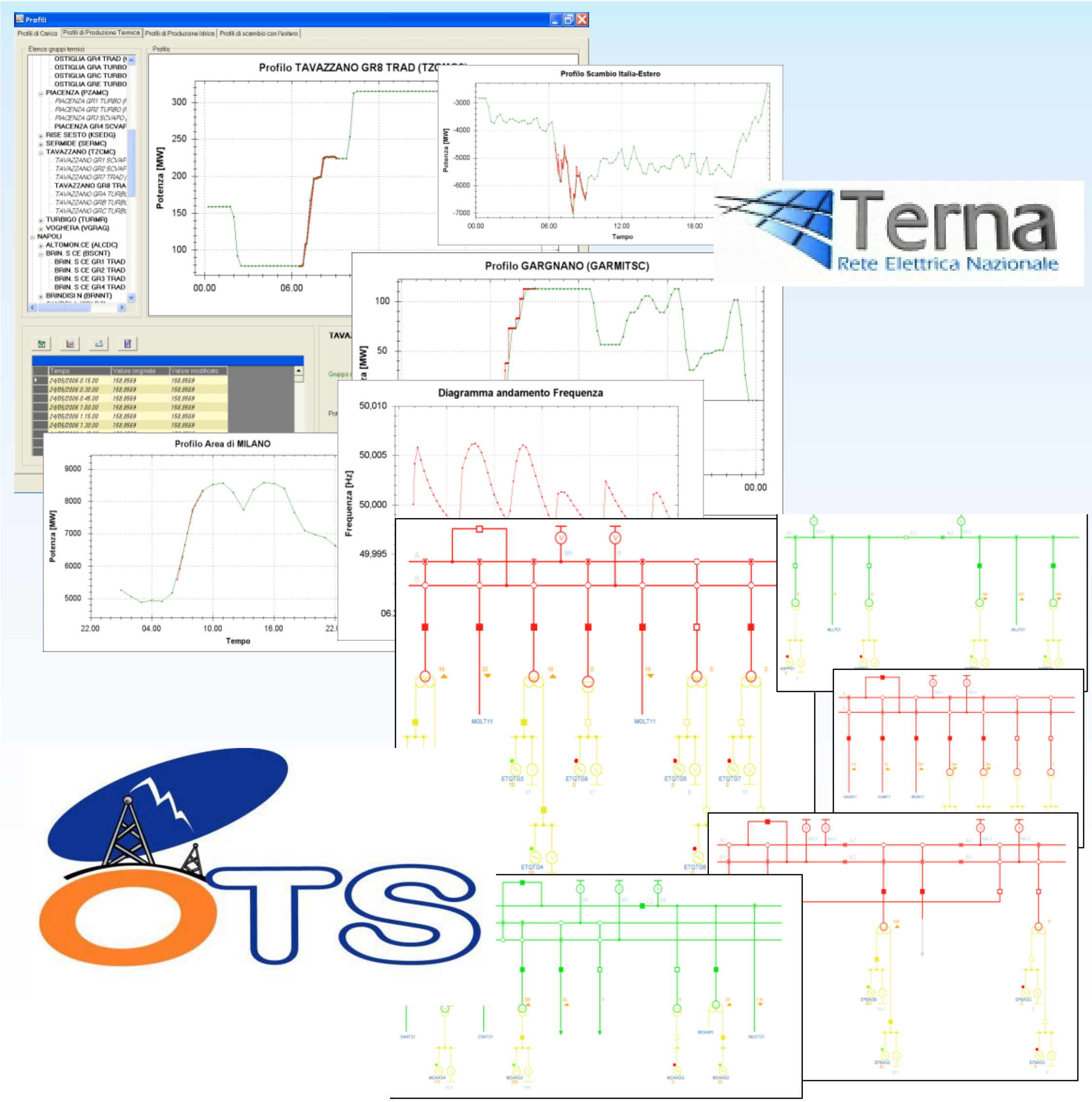
- National Priority - Restoration from neighbours grid;
- National Priority - Restoration from islanding network;
- Regional Priority - Restoration from neighbours regional grid;
- Regional Priority - Restoration from Black Start-up;
- Regional Priority - Restoration from islanding network;

Defense & Restoration Plans & Practices in Italy

- Acceleration of the Restoration procedures with close coordination with bordering TSOs;
- Simplification and acceleration of the identification of the black-out condition and of its extension by means of the Wide Area Measurement System (WAMS) measurements;
- Creation of 380 kV Restoration Back-bones from bordering systems (ENTSOE network).
- Installation of shunt reactors in 380 kV nodes crucial for operation and restoration. The aim is the acceleration of the Center and South Italy restoration;
- Islanding criteria (restart cores).
- Increase of number and reliability of the Black Start-up (BS) units (or Source Power Plants), as well as of their uniform distribution in the network;
- Increase of reliability of Load Rejection (LR) procedures, mainly for relevant units (Strategic Power Plants), as much as possible distributed in the grid;
- Telecommunications and telecontrol strategy revision and improvement;
- Accomplishment of periodical restoration tests of entire restoration paths.

Restoration Plans Update, New strategies and simulation tools

Defense & Restoration Plans & Practices in Italy



Restoration Plans Update,

New strategies and simulation tools

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Defense & Restoration Plans & Practices in Italy

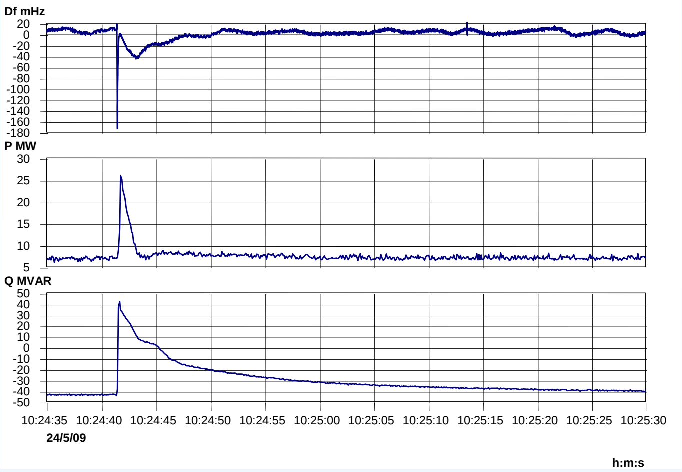
- TERNA conduct, with the support of CESI, the real restoration tests in order to evaluate:
  - ✓ The effectiveness of the test and performance;
  - ✓ Eventual critical aspects or unfeasibility of some manoeuvres, unexpected malfunctions;
  - ✓ Adequacy and identification of dynamic models;
  - ✓ Updating on human resources training;
  - ✓ General feedback from of regulation, protection and command systems;
  - ✓ Load Rejection house load and Black Start-up modalities of generators;
  - ✓ Interaction with defence systems and substation automation systems;
  - ✓ Performance and reactions of involved people;
  - ✓ Adequacy of the Control System and MMI;
  - ✓ Improvements.
  - ✓ Accomplishment of periodical restoration tests of entire restoration paths.

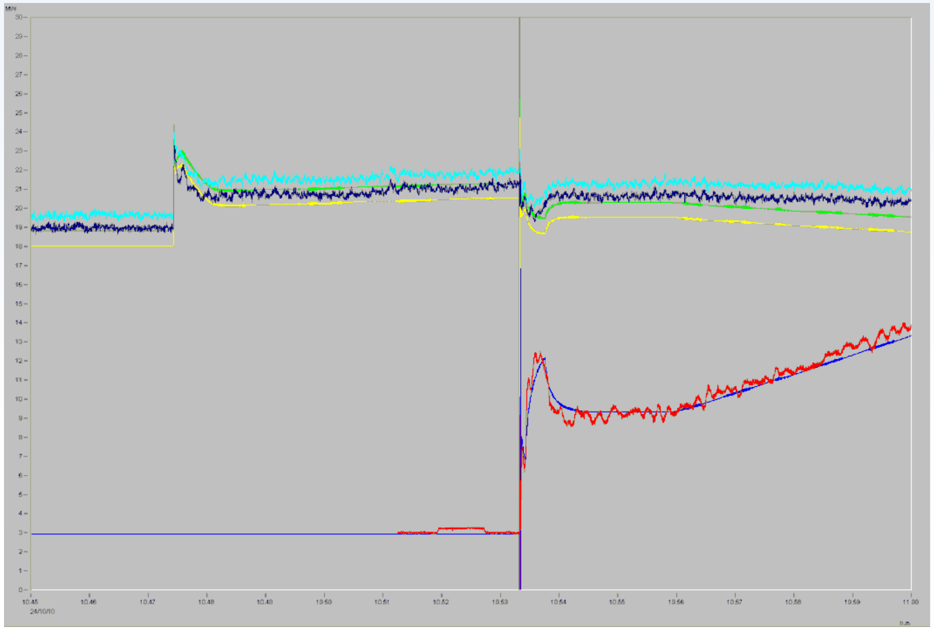
The real Restoration Tests

Defense & Restoration Plans & Practices in Italy

- Model's Tuning, e.g. Ballast Load Model from statistical analysis of measures

- Real measures (active power) vs simulation behavior





The real Restoration Tests

Summary

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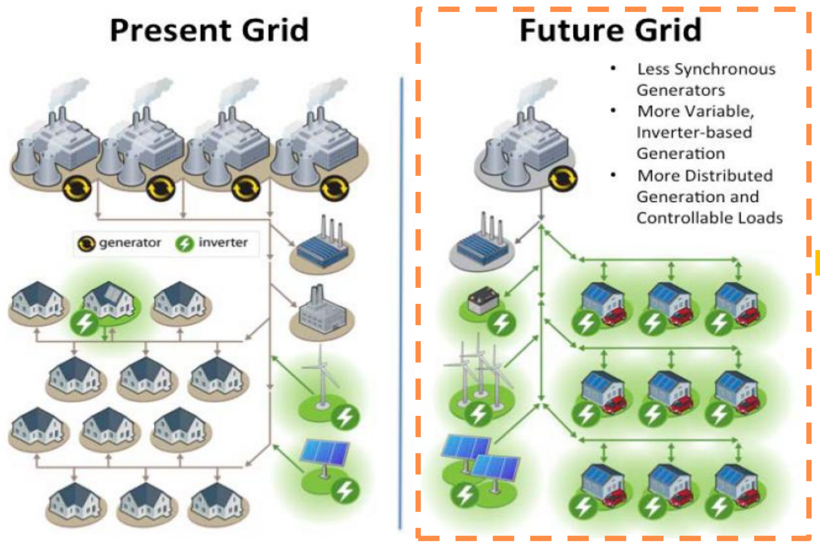
3. **Critical Aspects in presence of large amount of VRE**
4. Case Studies from other TSOs

Renewable Energy (RE) generation & Distributed Energy Resources (DER)
Impact on the grid and issues

GRID DEVELOPEMENT



Reduced transient and dynamic system stability

- Need to implement the control facilities of RE and DER in the network operation
- Need to update the **defense plans** in order to be effective in the changed network conditions

ISSUES

Variability and uncertainty of the generation

- ❑ Difficulty in forecasting short-term generation variations related to wind speed and solar irradiation changes
- ❑ Inadequate total system primary reserves

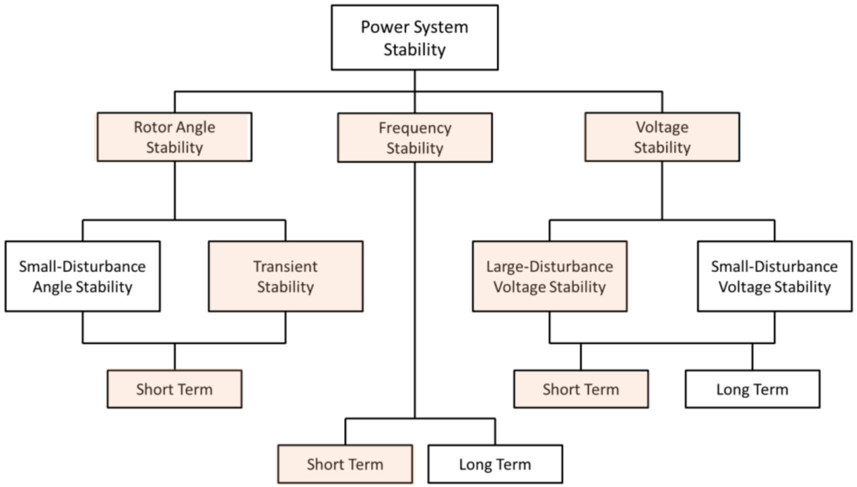
Ancillary services and operational rules

- ❑ Nowadays trend of grid codes is to define the connection rules and regulation requirements of the RE and DER generation
- ❑ Operational guidelines and rules still need to be implemented in the real system
- ❑ Reduced control of system frequency and voltages

System behaviour

- ❑ Reduction of the system inertia
- ❑ High voltage line loading due to DER generation
- ❑ RoCoF (Rate of Change of Frequency) increment and larger frequency excursions
- ❑ Risk of over-voltage control difficulties

Dynamic phenomena affected by RE generation and DER
Involved phenomena and related Defense Plan components



Defense Plan Components

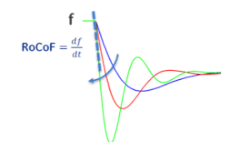
Frequency Stability
- ❑ Under-frequency load shedding - UFLS (under-frequency)
- ❑ Generation disconnection (for over-frequency)
- ❑ Controlled opening of interconnections
- ❑ HVDC fast power changes and special controls
- ❑ Special protection schemes

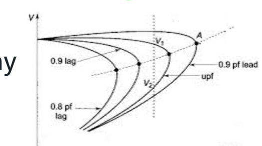
Voltage Stability
- ❑ Under-voltage load shedding - UVLS (under-frequency)
- ❑ HVDC fast power changes and special controls
- ❑ Automatic shunt switching
- ❑ Special protection schemes

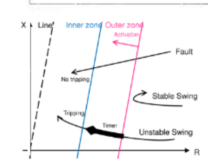
Rotor Angle Stability
- ❑ OST protections
- ❑ Controlled opening of interconnections
- ❑ Special protection schemes

Examples of Defense Plan components affected by the growth of RE and DER

UFLS	❑ Considering the reduction of system inertia and the reduction of the system ability to control the frequency, UFLS stages should be reviewed and UFLS sensible to the RoCoF adopted where necessary (2).
UVLS	❑ Considering the reduction of the system ability to control the voltages, UVLS settings and relay location should be reviewed or implemented where necessary (2)
Protections	❑ The loss of high short circuit current may affect protection settings; a review of the setting is required
OST protection	❑ The reduction of the system inertia affects the dynamic behavior of the apparent impedance. This requires the protections OST functions settings to be updated







(1) SPSs should use the latest technologies available (e.g. PMU and WAMS in order to operate on the basis of an extended view of the system)
(2) The choice of the feeders to disconnect should consider the presence of underlying DER. Feeders injecting power into the grid should not be disconnected. Advanced applications may dynamically select the feeders to be disconnected in real time.

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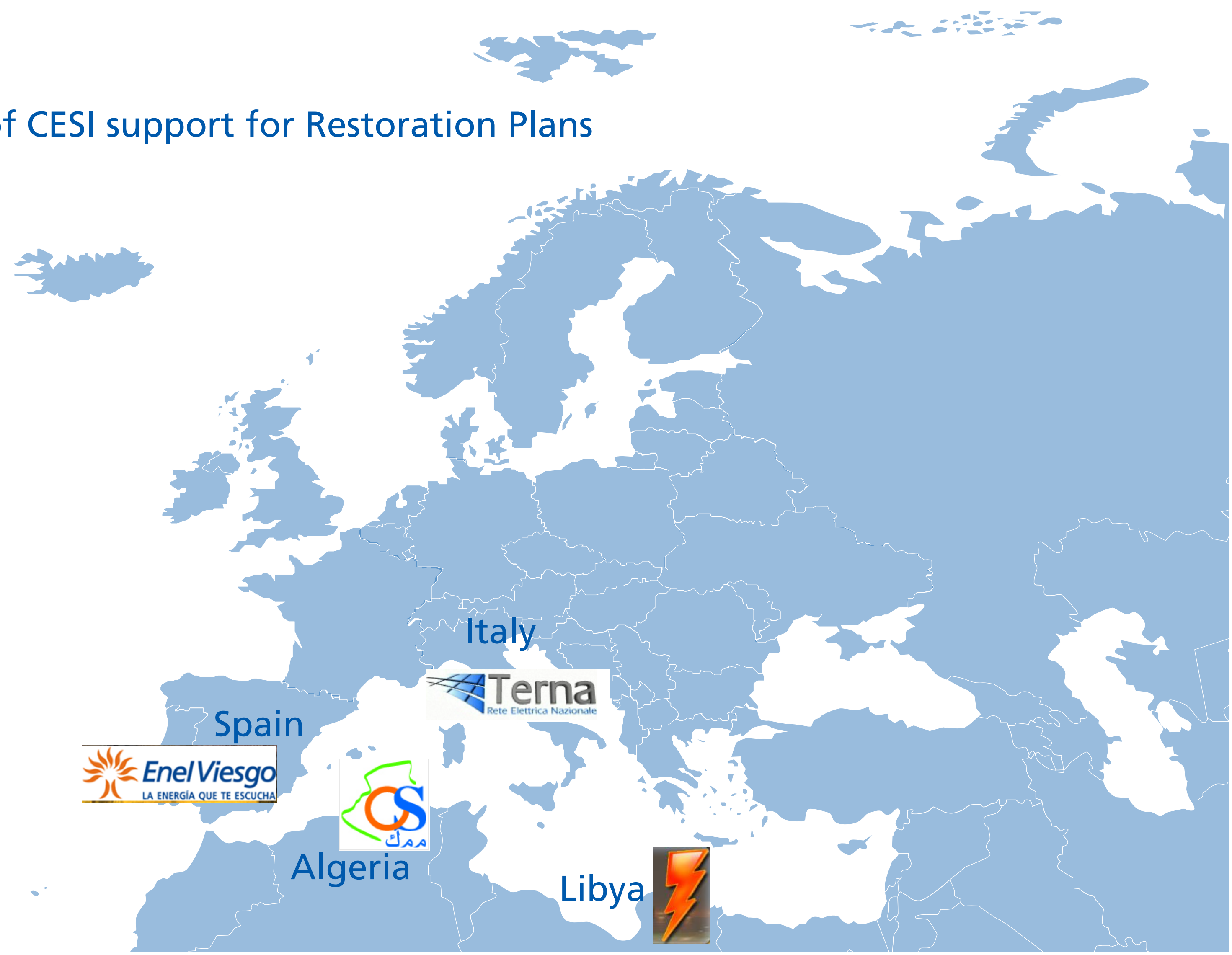
Case Studies from other TSOs

Example of CESI support for Restoration Plans



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Case Studies from other TSOs

Client: **Opérateur Système Electrique – OS-Sonelgaz**

Year: **2009/2010**

Country: **Algeria**

Project Description

Aim of the project is the preparation of Restoration Plan for Algerian Power Network.

The main tasks of the activity are:

- Power Network data collection for dynamic simulations;
- Preparation of Power Network scenarios for dynamic simulations;
- Data collection of present restoration procedure and control room operators experience;
- Dynamic simulations of different hypothesis;
- Identification of best strategies;
- Identification of critical issues and possible solutions;
- Control room operator training on methodologies.

Case Studies from other TSOs

Client: **GECOL**

Year: **2007/2010**

Country: **Libya**

Project Description

Aim of the project is the preparation off Restoration Plan for Libyan Power Network.

The main tasks of the activity are:

- Power Network data collection for dynamic simulations;
- Preparation of Power Network scenarios for dynamic simulations;
- Data collection of present restoration procedure and control room operators experience;
- Dynamic simulations of different hypothesis;
- Identification of best strategies;
- Identification of critical issues and possible solutions;
- Control room operator training on methodologies.

Case Studies from other TSOs

Client: **ENEL Viesgo**

Year: **2006**

Country: **Spain - Italy**

Project Description

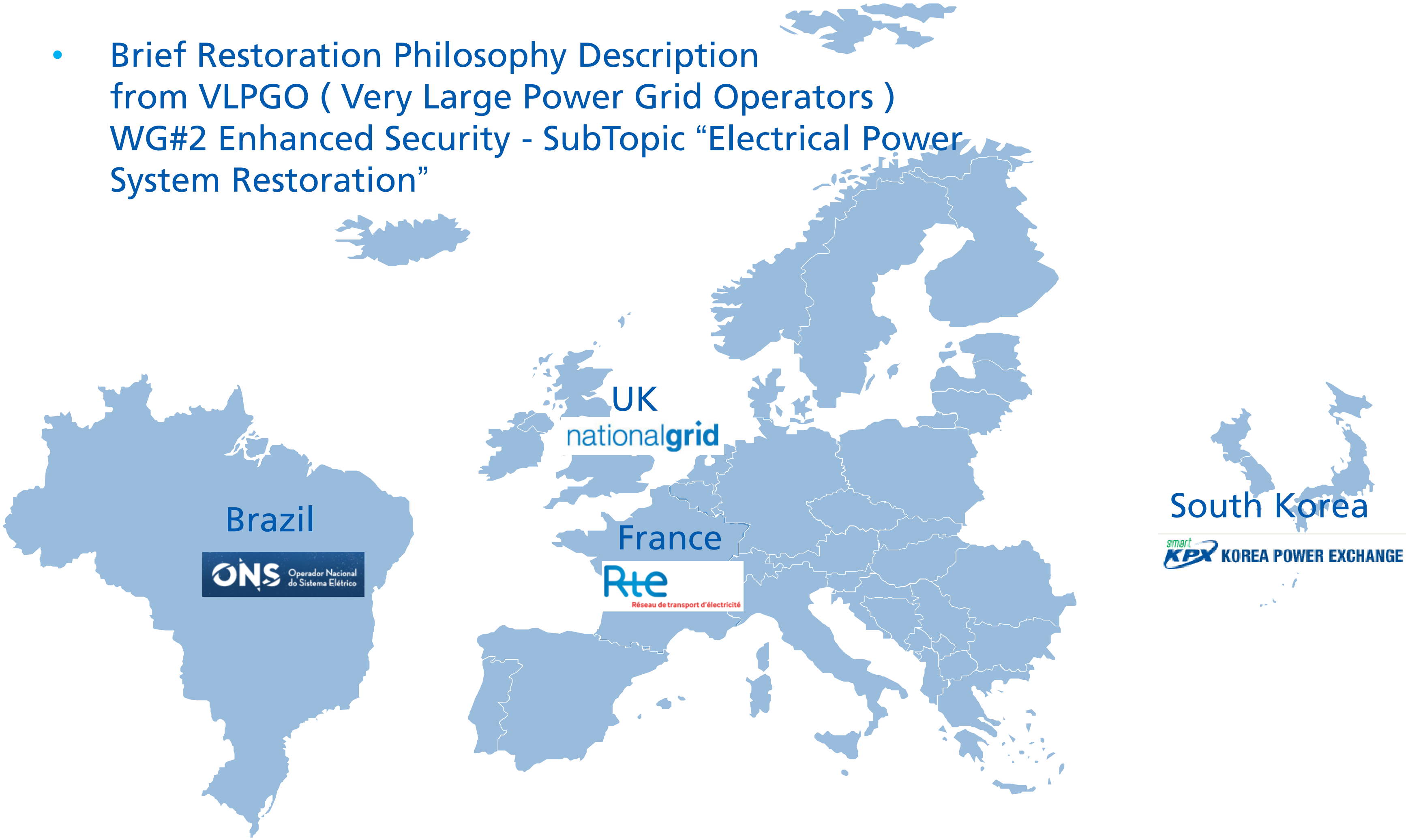
Aim of the project is the support to ENEL Viesgo, to analyze the characteristics of three Hydroelectric power plants to permit the restoration, as request by the Spain TSO RED ELECTRICA.

The main tasks of the activity are:

- Technical analysis of power plants characteristics with focus on restoration;
- Technical analysis of TSO requests;
- Dynamic simulations of different hypothesis;
- Identification of critical points;
- Identification of solutions.

Case Studies from other TSOs

- Brief Restoration Philosophy Description from VLPGO (Very Large Power Grid Operators) WG#2 Enhanced Security - SubTopic “Electrical Power System Restoration”



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Defense & Restoration Plans & Practices in Italy

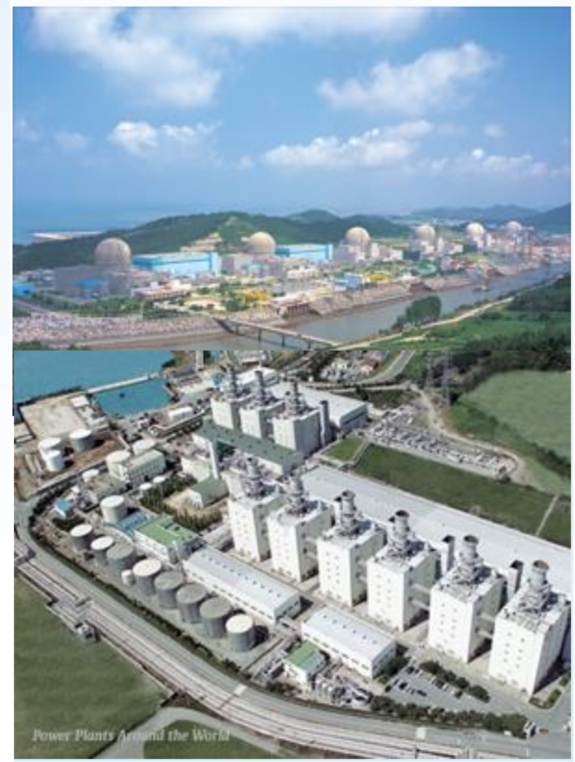
- In Brazil, restoration is based on a two-stage process:
  - ✓ fluent PP restoration;
  - ✓ coordinated restoration.
- The first stage is begun 5 minutes after the identification of the black out state, at the hydro plants with black-start capacity with the identification of the minimum configuration of the preferential restoration corridors. Priority load are restored utilizing a minimum telephone communication between the operators of the hydro plants and substations involved, according to pre-established procedures. The process is managed without any interference from the Operation Control Centers, except in presence of problems;
- In the second stage, the Operation Control Centers coordinate the synchronization and the system rebuilding;
- The Brazilian power system is divided into four geo-electrical regions. The RP includes 34 fluent restoration areas (3 in the North, 6 in the Northeast, 16 in the Southeast and 9 in the South);
- ONS periodically updates the RP of National Interconnected System.

ONS Brazil

Defense & Restoration Plans & Practices in Italy

- The aim of KPX RP is the re-meshing and the stabilization of 7 regions. Each region has two paths, main and backup. Each path can be energized by hydro units or gas turbine units with black start.
- The restoration process is begun immediately after the identification of the blackout state. Strategic Restoration Targets are the thermal power plant units, by predefined corridors which are energized by black-start units or islanded areas (around Nuclear Power Plants) of the system still in operation.
- After the blackout state detection, all the regional control centers with central control center start the creation of the restoration paths, aimed to reach the HV busbars of thermal power units in the fastest possible way. The restoration paths are stabilized, in terms of voltage and frequency, by the ballast loads which are connected to them and by the automatic control systems of black-start units.

KPX South Korea



Defense & Restoration Plans & Practices in Italy

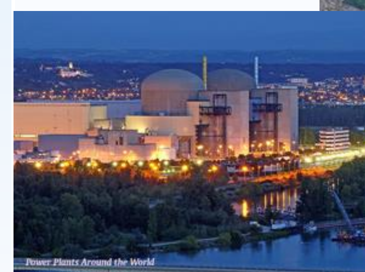
- The main criteria in restoring the GB Transmission system is the restoration of the interconnected 400kV and 275kV networks (includes 132kV in Scotland). This will facilitate restoration of supplies to stations which do not have Black Start capability. Restoration of load is not in itself a priority. Restoration of load will follow from the restoration of the GB Transmission system and selected demands will provide stability to the generation which has been restored. The aim is to charge the 400/275 kV network in 12 to 24 hours.
- Selected Generating Stations are contracted to have a Black Start Capability. That is the ability to start a main generating unit from its own internal resources, batteries, diesel and gas turbine generators, without any external supply.
- A power island will be established around the Generating Station which will be expanded and linked to adjacent power islands to form zonal/regional islands. The zonal regional islands will be linked to eventually re-establish a charged and functioning GB Transmission system. As further generation becomes available demand will be restored. There is no autonomous restoration procedure.

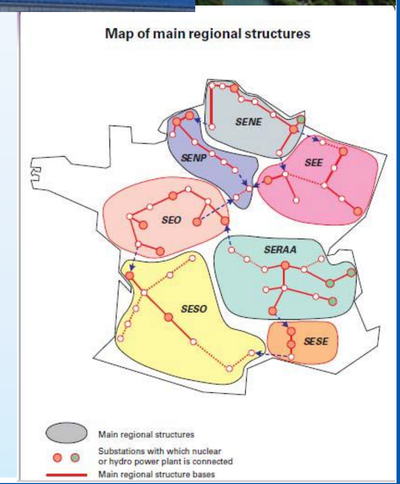
National Grid UK

Defense & Restoration Plans & Practices in Italy

- Network restoration is based on a succession of complex and delicate operations which should be studied and prepared beforehand. RTE periodically updates the RP and checks the elements;
- If a sufficiently powerful network is available, service restoration gets under way using that network. Otherwise, or as a supplement (if it serves to speed up service restoration in zones remote from the network in question), RTE undertakes network restoration by main regional structures;
- The principle is based on the independent and simultaneous constitution, in each of the seven regions, of predetermined 400 kV structures called "main regional structures". These structures are designed so as to link, at each regional hub level, the nuclear units and a number of large hydro generation sites to the supply substations of the major load areas;
- Under the supervision of the regional dispatching center, each regional structure is re-energized step by step by means of nuclear generation units which had tripped to house load and, if necessary, by using pre-established "load pockets". These pockets must be large enough to ensure voltage control under steady and transient operating conditions, while remaining compatible with the load restoration capacity of the generation units connected to the main structure;
- Once these regional structures have been re-energized, after any partial load restoration, they are connected with one another or/and with foreign networks on the initiative of the national dispatching center.

RTE France





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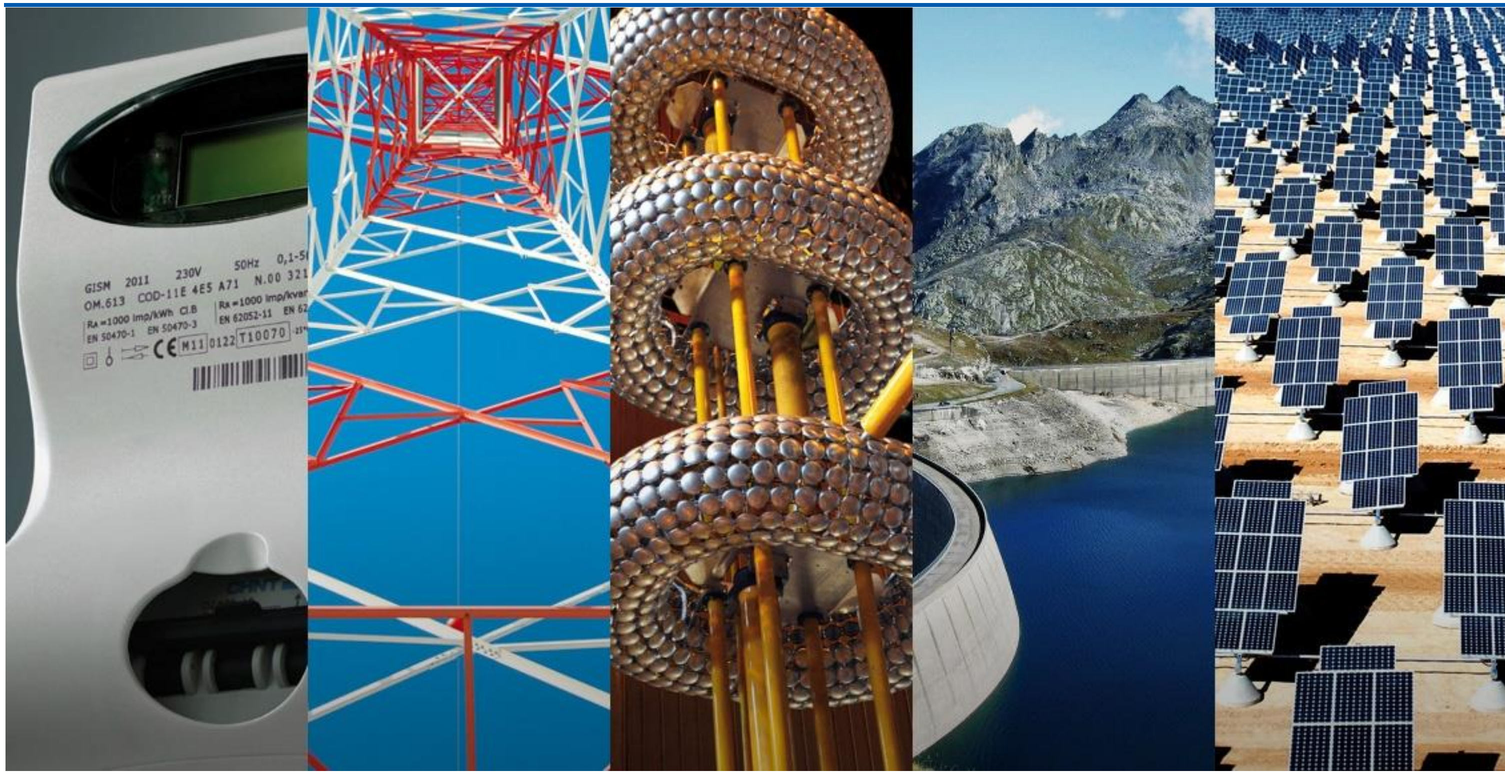

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