Analysis of the Connection of Ignitor to the Rondissone Substation of the European Electrical Grid

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Introduction (1)

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1. During 2001, GRTN, the Italian Independent Power System Operator (ISO), studied the effects of the connection of the Ignitor machine to the Italian EHV Power System and, more comprehensively, on the European interconnected system (UCTE, Union for the Coordination of Transmission of Electricity).

2. The study in the dynamic regime of the possible interferences induced by the Ignitor load on the power system was carried out taking into account two typical extreme conditions of the grid, namely at maximum load (winter configuration) and at minimum load (summer configuration).

3. All the simulations were run using realistic grid configurations that can be regarded as representative of most of the normal states of operation. The worst machine-operating scenario in terms of real and reactive power requirements has been conservatively assumed as the reference scenario.

Introduction (2)

4. We studied the connection of the Ignitor machine to two different nodes that both guarantee a high level of tri-phase short-circuit power and attractive logistic solutions:

   - the 420 kV Rondissone electric node

   - the 400 kV Caorso electric node

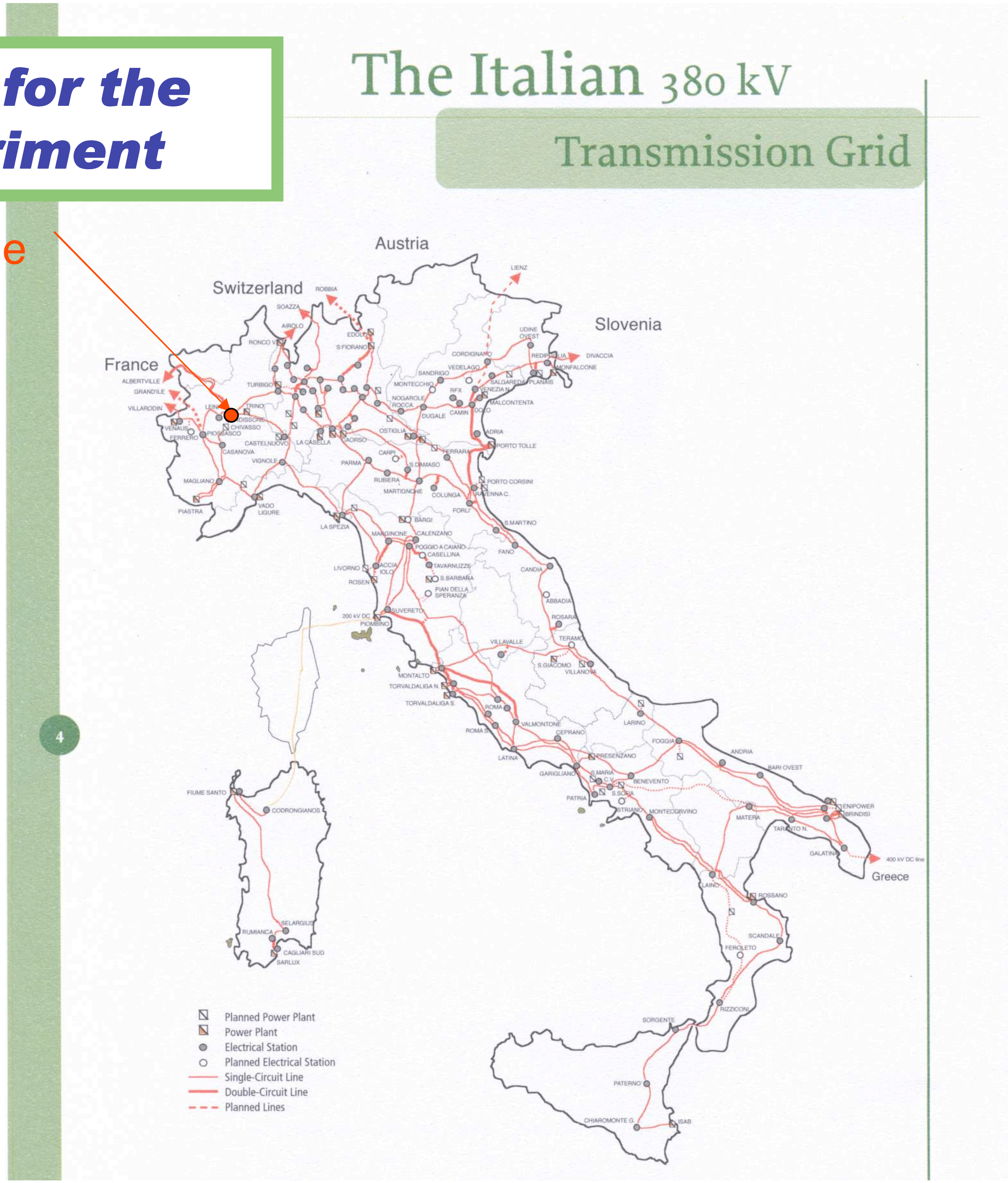
5. In terms of connection to the national network, all the analyses performed show the substation of Rondissone to be the most suitable to host the Ignitor experiment.

6. Given the Ignitor's demand of real and reactive power, we analyzed in detail the presence of possible disturbances induced into the network by the fast variation of active power demanded by the generator groups located nearby the Rondissone site.

7. In principle, the Ignitor's connection to the Rondissone site can affect the voltage of nearby electric nodes and the frequency of both near and distant electric nodes.

Selected site for the Ignitor experiment

Rondissone



Characteristics of the site:

The Rondissone substation is one of the most powerful in North-West Italy and is directly connected to the European transmission grid at the 420 kV voltage level.

The site hosts also the CESI laboratories for testing of very large power system components.

The Rondissone Site (1)

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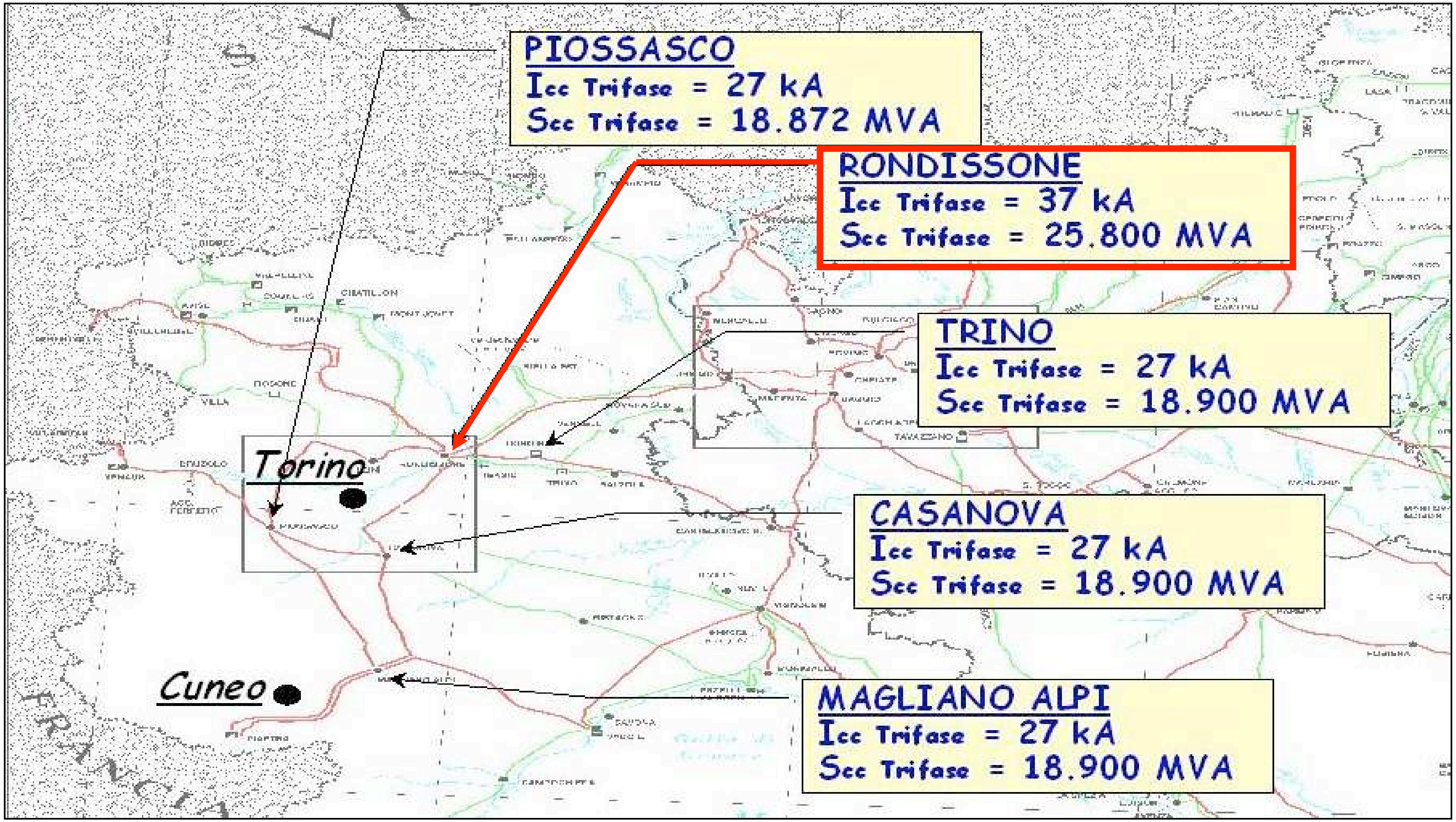

The Rondissone Site (2)

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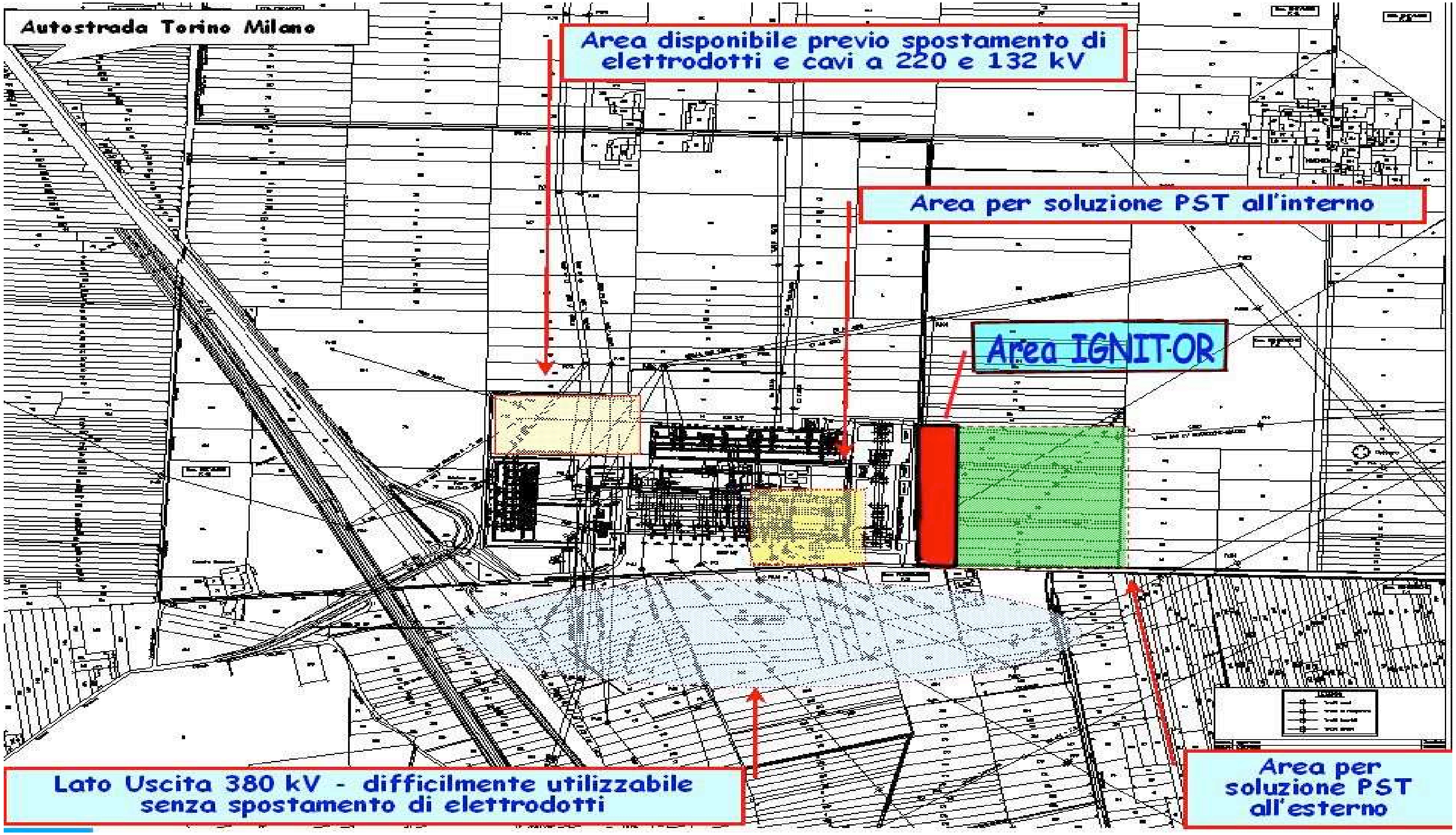

View of the Rondissone Site (3)

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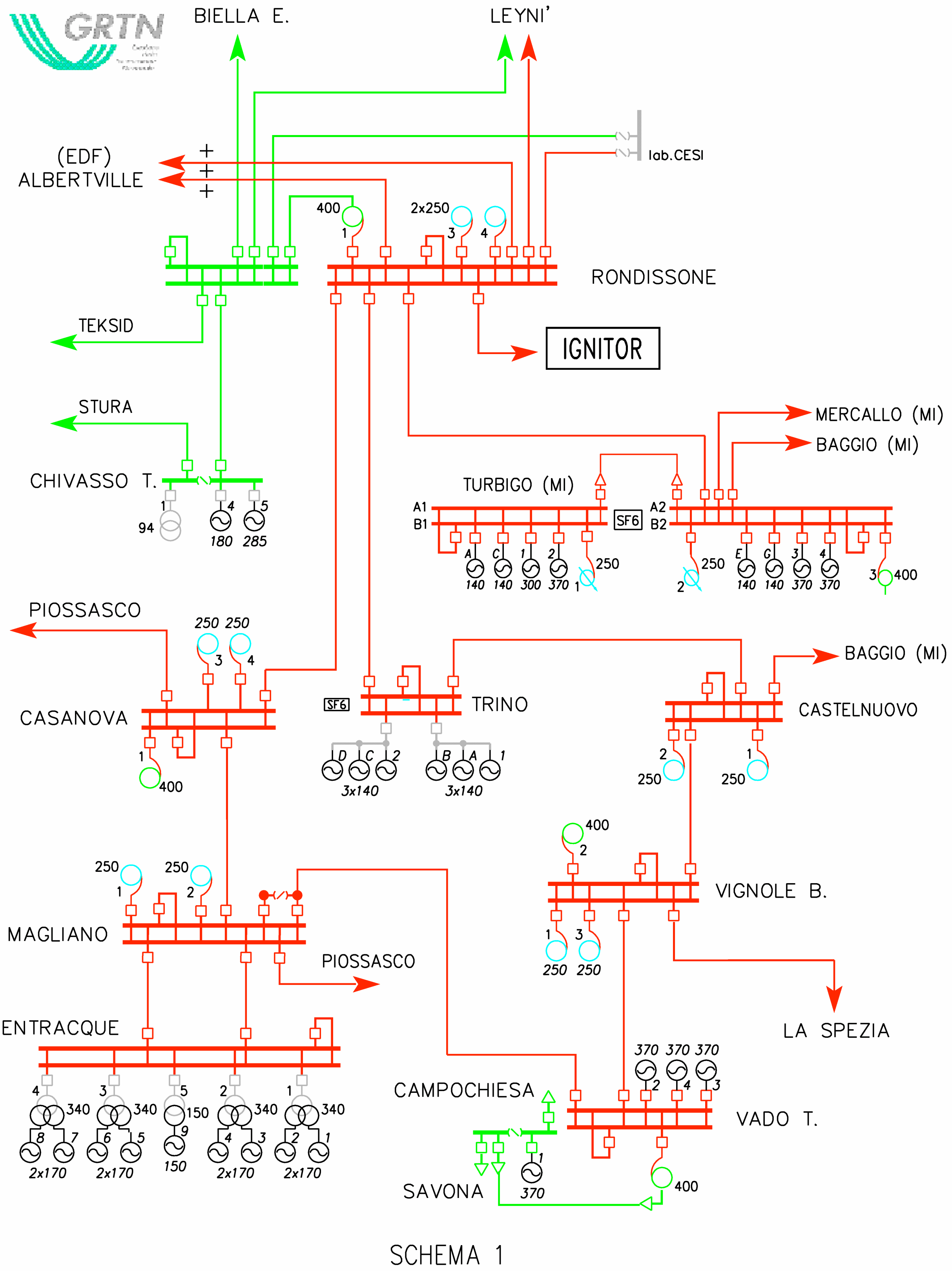
Electric scheme showing the connection of the Ignitor machine to the 420-245 kV substation of Rondissone (TO)-Italy



European and Italian EHV Power Systems

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The rated voltage of the UCTE transmission grid in Europe is 400 kV and the frequency is 50 Hz. Recorded voltage and frequency variations are within ±5% and ±0.1%, respectively, during normal operation.

The Rondissone substation was chosen because is one of the most powerful nodes in the North-West Italy, and it is directly connected to the European transmission grid at 420 kV voltage level.

In 2003 the nominal rotating power of the Italian grid (45,000 MW) is about 1/5 of the nominal power of the entire UCTE grid. Additionally, Italy imports almost 6500 MW from abroad to supply a peak load of more than 52 MW. The mean voltage values in the area surrounding Turin are 402 kV and 230 kV.

In our model the Italian Extremely High Voltage (EHV) network is simulated by taking into account both 420 kV and 245 kV and comprehends the passive grid, synchrony and asynchrony machines, primary and secondary regulators of frequency and voltage, on-load tap changers, and Static Var Compensators (SVC). The passive European grid at the same voltage levels is modeled by simulating up to 3 electric nodes outside the Italian border and by introducing generation equivalents to model the remaining network.

Power System Simulation Tools

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Two power system simulators are used:

- CRESO for steady state and
- SICRE for dynamic state [5].

Both simulators were developed during the past 20 years to model the peculiarities of the Italian network.

SICRE is a very comprehensive tool that simulates the following behaviors:

1) the short term dynamics (STD) of the grid with time periods on the order of a few seconds and integration steps of tenths of ms, and

2) the long term dynamics (LTD) with time periods on the order of a few minutes (5-10 minutes with integration steps of 500 ms).

The short term behavior is driven by the electromechanical transient phenomena typically experienced in the power system and by fast and local regulations.

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Elevation View of the Ignitor Machine

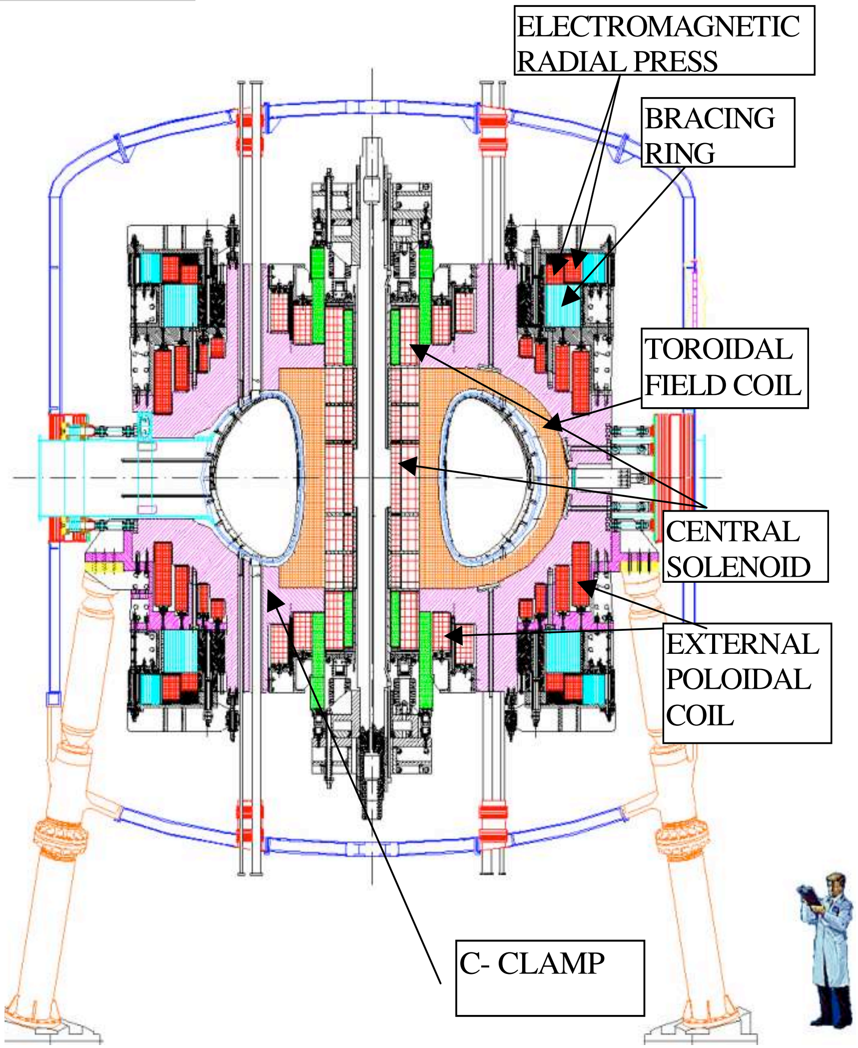


TABLE I: EXAMPLE OF PLASMA PARAMETERS WHEN IGNITION IS REACHED (JETTO CODE)

Toroidal Plasma Current I_p	11 MA
Toroidal Field B_T	13 T
Central Electron Temperature T_{e0}	11.5 ke
Central Ion Temperature T_{i0}	10.5 keV
Central Electron Density n_{e0}	9.5×10^{20} m
Central Plasma Pressure p_0	3.3 MPa
Alpha Density Parameter n_α^*	1.2×10^{18} m-
Average Alpha Density $\langle n_\alpha \rangle$	1.1×10^{17} m-
Fusion Alpha Power P_α	19.2 MW
Plasma Stored Energy W	11.9 MJ
Ohmic Power P_{OH}	11.2 MW
ICRF Power P_{ICRH}	0
Bremsstrahlung Power Loss P_{brem}	3.9 MW
Poloidal Beta $\langle \beta_p \rangle$	0.20
Toroidal Beta $\langle \beta_T \rangle$	1.2 %
Central "safety factor" q_0	1.1
Edge safety factor $q_\psi = q_\psi(a)$	3.5
Bootstrap Current I_{bs}	0.86 MA
Poloidal Plasma Current	8.4 MA
Energy Replacement Time τ_E	0.62 sec
Alpha Slowing Down Time $\tau_{\alpha,sd}$	0.05 sec
Average Effective Charge $\langle Z_{eff} \rangle$	1.2

$$n_\alpha^* \equiv n_D n_T \langle \sigma v \rangle \tau_{\alpha,sd}$$

$$\tau_{\alpha,sd} \equiv 0.012\, T_{e0}^{3/2}(\mathrm{keV})/n_{e0}\ (10^{20}\ \mathrm{m}^{-3})$$

Power Demand According to Different Scenarios

The worst operating scenario in terms of power consumption, i.e., Scenario C, has been assumed to be the reference scenario.

Scenario C is characterized by an impulsive history of the active and reactive powers, and it generates peak power consumption of about 1095 MW and 860 Mvar, as well as a peak power delivery of 430 MW.

Every pulse is assumed to have an overall duration of 14 s, a pulse separation period of at least 4 hrs, and a maximum number of 250 repetitions per year.

Ignitor Power Demand according to different Scenarios.

Scenario	0	A	B	C
B_T [T]	5	9	11	13
I_p [MA]	5	7	10	12
P_{max} [MW]	415	600	880	1095
Q_{max} [MVAR]	300	550	610	861
Flattop [s]	-	6	5	4
$\|\Delta P\|$ [MW]	-	~500	~1000	~1325
Pulse/hr	3	1	0.5	0.25

Ignitor Reference Pulse and Power Requirements (1)

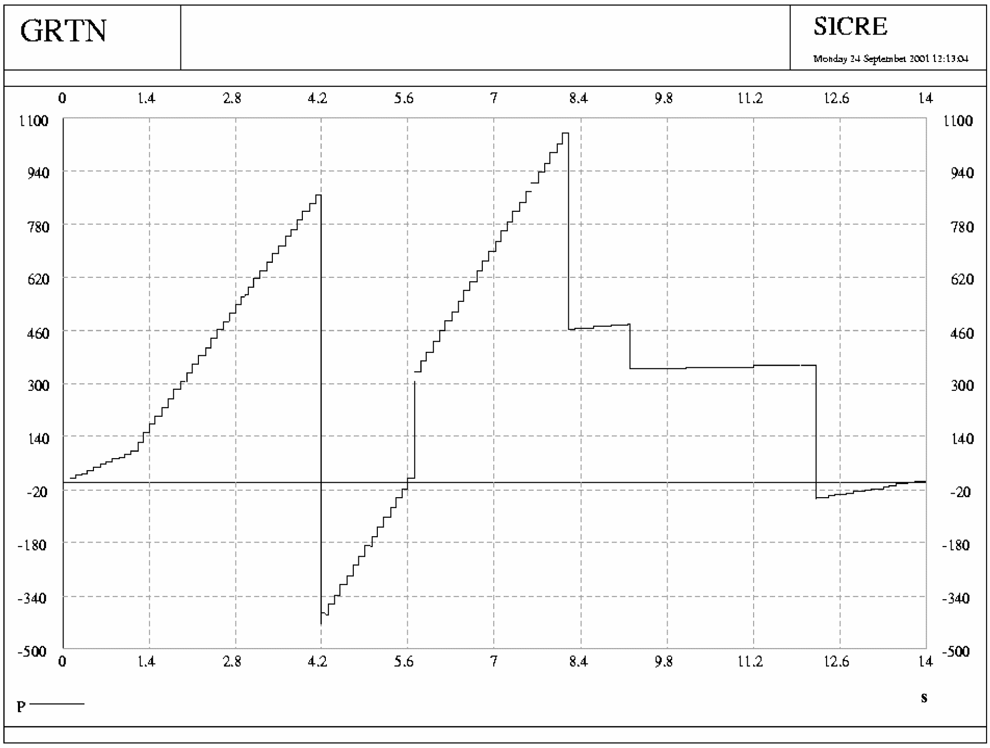
The reference case we assumed in running the simulations refers to the following conditions:

(a)Chopper Toroidal Magnets with GTO discharge resistance and Thyristor Poloidal Coils with GTO discharge resistance,

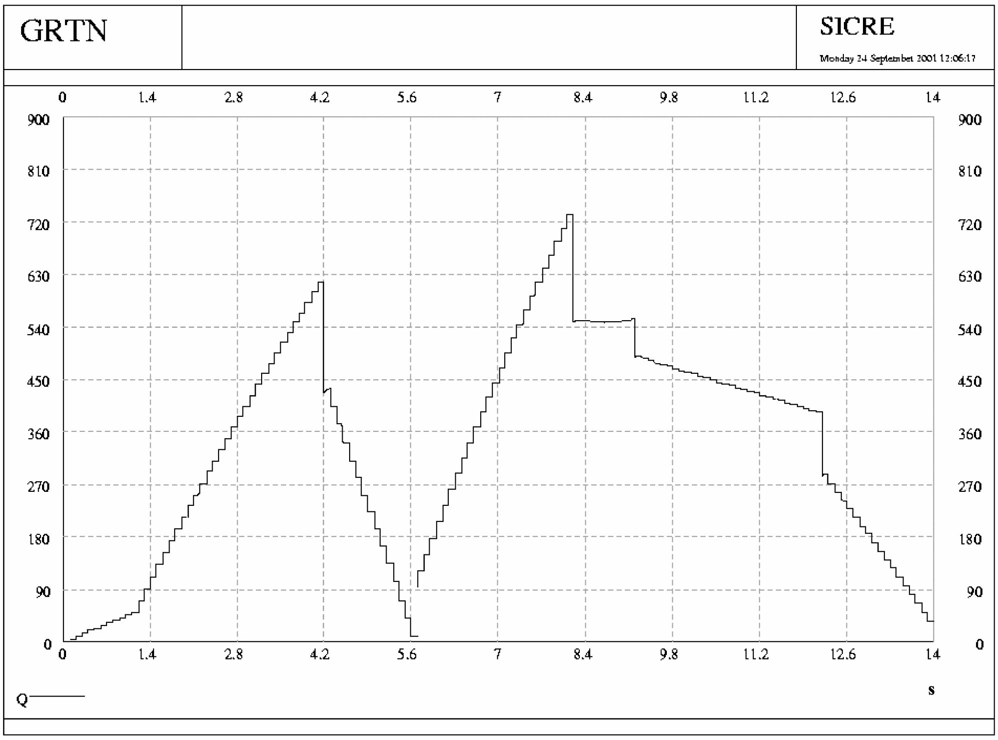
(b) all power provided by the transmission grid and

(c) absorption of active electrical power (*P*) and reactive electrical power (*Q*) in accordance with the charts produced by ENEA/Consorzio Ignitor (as shown in the next slide).

Real and reactive power demand of the Ignitor machine



Real power demand *P* [MW] of the Ignitor machine



Reactive Power demand *Q* [Mvar] of the Ignitor machine

Ignitor Reference Pulse and Power Requirements (2)

The study of the possible interferences induced by the Ignitor load on the transmission grid in the dynamic regime was carried out considering two typical extreme conditions, namely at:

- *MAXIMUM WINTER LOAD*:

  - National peak load of 47 GW

  - High short circuited tri-phase power of the Rondissone substation:

    25.8 GVA

  - Very large loading on the grid and a large number of generators in operation with all the network components in service

- *MINIMUM SUMMER LOAD*:

  - National peak load of 21 GW

  - Short circuited tri-phase power of the Rondissone substation approaching the annual lowest value of about 18.2 GVA

  - Lowest loading on the grid, characterized by a high number of network components out of service because of maintenance. Few generators in operation, namely half the number of the winter scenario

Evaluation of the Interferences on the Grid:
Winter Configuration (1)

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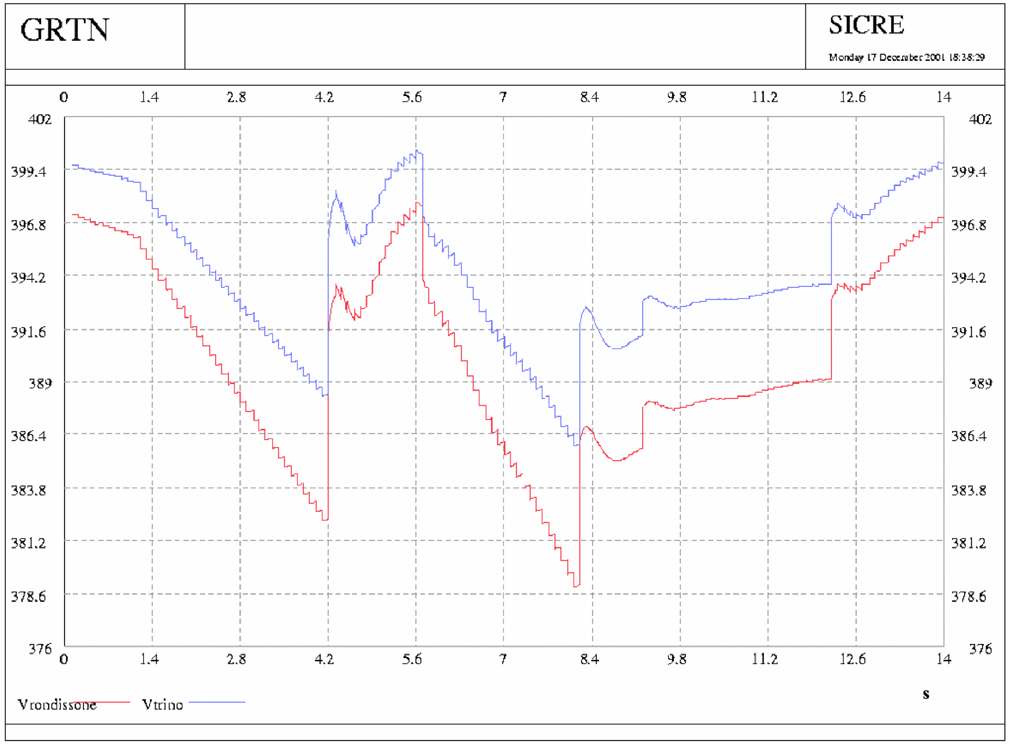
- The maximum voltage drop is within 5% of the reference value of 400 kV at the Rondissone substation.

-During the most severe transient phase, a voltage drop ΔV = 19 kV, from 398 kV to 379 kV, is experienced.

-The peak-to-peak variation in frequency is 0.03 Hz with a maximum relative variation of -0.02 Hz relative to the rated value of 50 Hz.

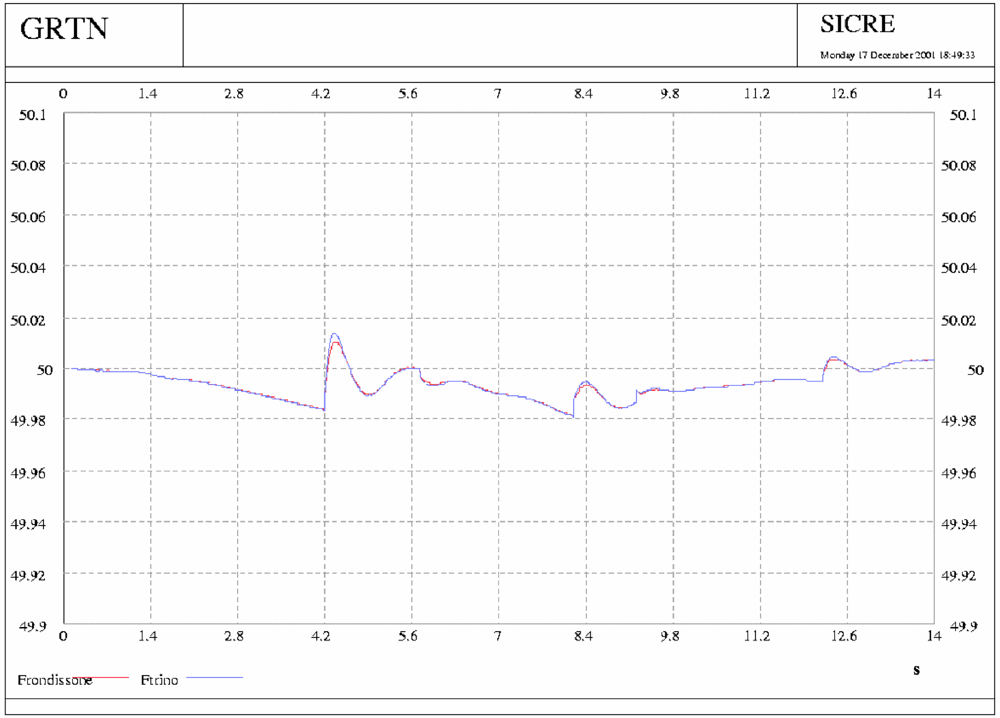


Voltage trends [kV] at the nodes of Rondissone and Trino when the Ignitor load is supplied.

Evaluation of the Interferences on the Grid: Winter Configuration (2)

-During the peak of the real power, about 2/3 of the overall power absorbed by Ignitor is imported from abroad, i.e., 740 MW out of 1095 MW. In particular, the variation of the power transit coming from France along the 420 kV lines Rondissone-Albertville is only 250 MW. This corresponds to an instantaneous increase of power drawing from the grid of about 12.5%.

-In any case, the Italian grid is robustly connected to the power systems abroad and can easily stand demand steps (when limited to a few seconds in duration).



Frequency trends [Hz] at the nodes of Rondissone and Trino when the Ignitor load is supplied.

Evaluation of the Interferences on the Grid: Summer Configuration – Lowest load (1)

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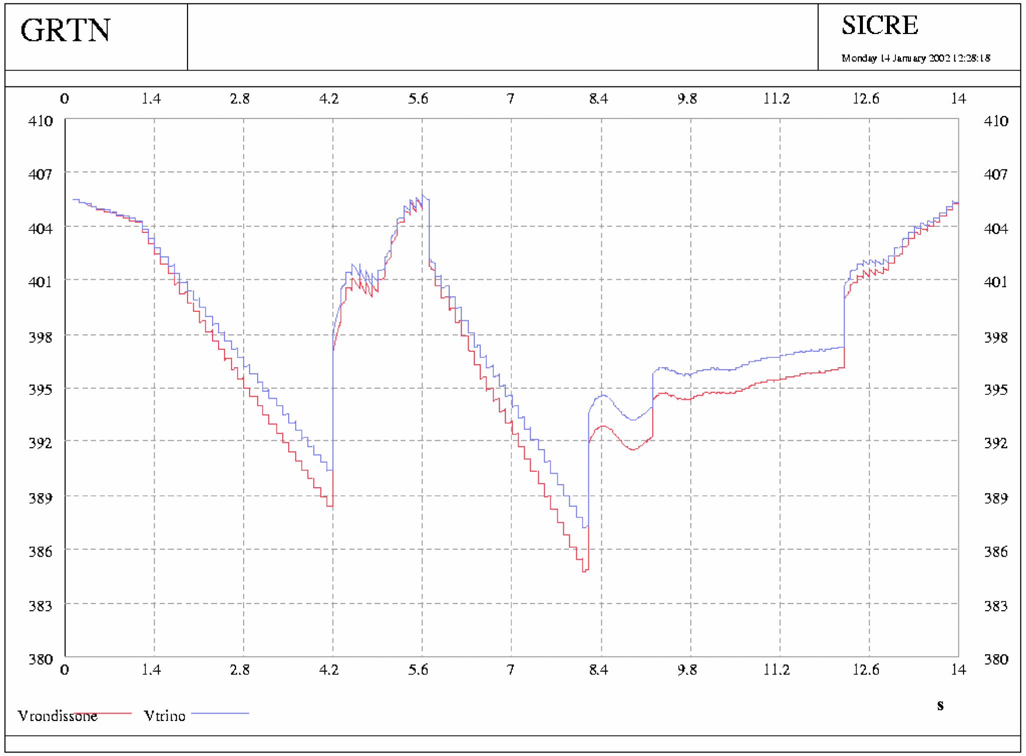
-The highest voltage drop at the Rondissone substation is -5.5% of the 400 kV reference value.

- The absolute variation of voltage is 22kV, ranging from 406 kV to 384 kV.

- The peak-to-peak variation in frequency is 0.035 Hz, with a maximum relative variation of -0.025 Hz.

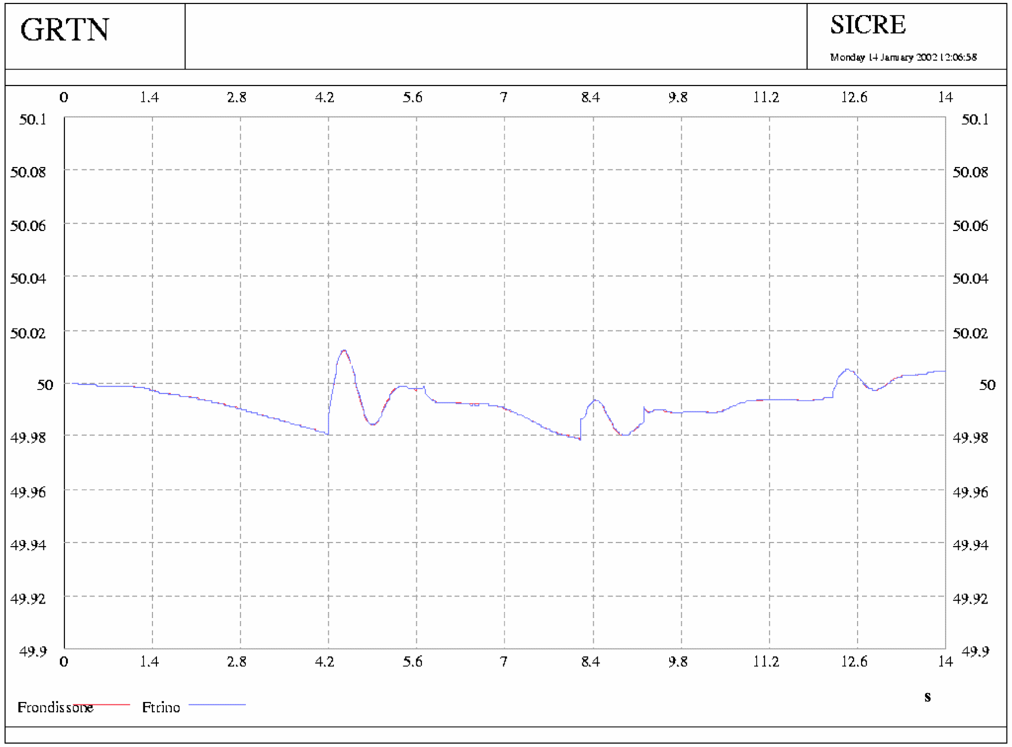


Voltage trends [kV] at the nodes of Rondissone and Trino when the Ignitor load is supplied.

Evaluation of the Interferences on the Grid: Summer Configuration – Lowest load (2)

The variation of the real power flow from abroad reaches 910 MW, about 85% of the whole power required by the Ignitor machine. About 1/3 of that power comes from the Rondissone-Albertville lines.

During the early hours of a mid-August day, a normal period of vacation in Italy, the network supplies few sensible loads. Thus, the consequences of the possible disturbances of the Ignitor machine on the network are quite limited.



Frequency trends [Hz] at the nodes of Rondissone and Trino when the Ignitor load is supplied.

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Evaluation of the Interferences on the Grid

All the results obtained refer to specific diagrams of power absorption and to a specific cycle of the Ignitor machine. At the moment, our study does not take into account the disturbances of the Ignitor load on a network in temporary degraded conditions.

The disturbances in frequency introduced by the Ignitor machine into the network do not exceed the limit set for the normal grid operating conditions, i.e., 49.9-50.1 Hz.

In all the configurations we tested, the prescribed RTN limit over the voltage variation (400 kV +/-5%) is slightly exceeded.

Disturbances in frequency are propagated along the entire network and the most affected electric nodes are those located in the Sicilian area.

Conclusions (1)

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All the simulations performed with realistic grid scenarios (representative of the Italian normal power system operation) showed that the Rondissone substation is the most suitable candidate to supply the Ignitor power demand.

Simulations relative to the variation in frequency at various electric nodes of the grid showed that the Ignitor load, operating in normal conditions, does not introduce significant disturbances neither in Italy, nor in the neighboring European countries.

The frequency variations are within the UCTE prescriptions.

The disturbances induced by the Ignitor machine slightly exceeds the permissible voltage range because of the large impulsive behavior of the Ignitor load that absorbs up to about 860 Mvar.

Conclusions (2)

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The generated interference of voltage at the substation of Rondissone could become critical when the grid configuration is in a low short-circuited power condition (off-load periods). At present, the most suitable technique to solve the problem consists in the installation of local systems of reactive power compensation (SVC).

The influence of the introduction of current harmonics into the grid by the Ignitor load was not in the scope of this study. However, adequate filtering systems are envisaged to limit the Total Harmonic Distortion (THD) at the Rondissone substation within 1.5%, as requested by the GRTN grid code.

Recent developments of the Ignitor Magnet Systems showed the possibility to obtain the same plasma parameters by using a reduced amount of real and reactive power. Even though these new hypotheses require additional assessments, it is expected that the overall load influence on the network will be reduced with the additional advantage of a network capable of providing a better power service to the Ignitor load.