Ministério de Minas e Energia
Eletrobrás
Diretoria de Operação de Sistemas

CEPEL
Centro de Pesquisas de Energia Elétrica

SHORT-TERM MEASURES TO MINIMIZE THE IMPACT OF EXTREME CONTINGENCIES IN THE BRAZILIAN POWER SYSTEM

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DESCRIPTION OF THE BRAZILIAN SYSTEM

INSTALLED CAPACITY (MW):

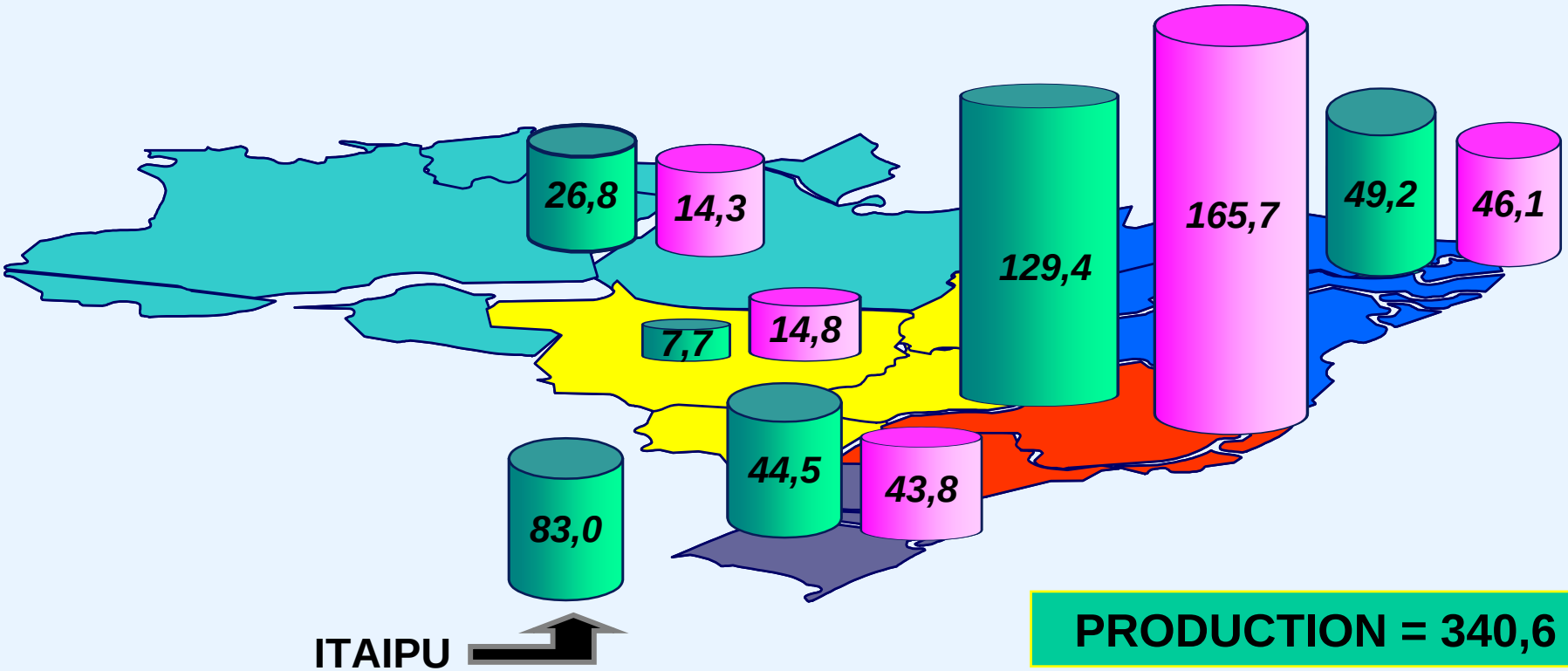
REGION	DECEMBER 1998	MAY 1999
SOUTHEAST	26.905	27.719
SOUTH	8.506	8.816
CENTER-WEST	2.517	2.702
NORTHEAST	10.371	10.371
NORTH	6.353	6.379
ITAIPU	6.300	6.300
BRAZIL	61.312	62.287

91,2% HYDRO

7,7% THERMAL

1,1% NUCLEAR

PRODUCTION AND CONSUMPTION PER REGION IN 1998 (TWh)



PRODUCTION = 340,6

CONSUMPTION = 284,7

BASIC CHARACTERISTICS:

- **Predominantly Hydro Generation**:

  - generation remote from load centers
  - long distance transmission
  - heavily dependent on hydro coordination

- **Small scale thermal generation**:

  - reduced availability of complementary thermal gen. close to load centers

Consequences:

- heavily loaded transmission lines
- need for heavy transfers due to hydro coordination
- sensitive to incidents that may cause chain reactions
- prone to voltage collapse
- severe frequency excursions

- **Significant number of extreme contingencies.**
- **Each type of extreme contingency calls for a specific remedial control action.**

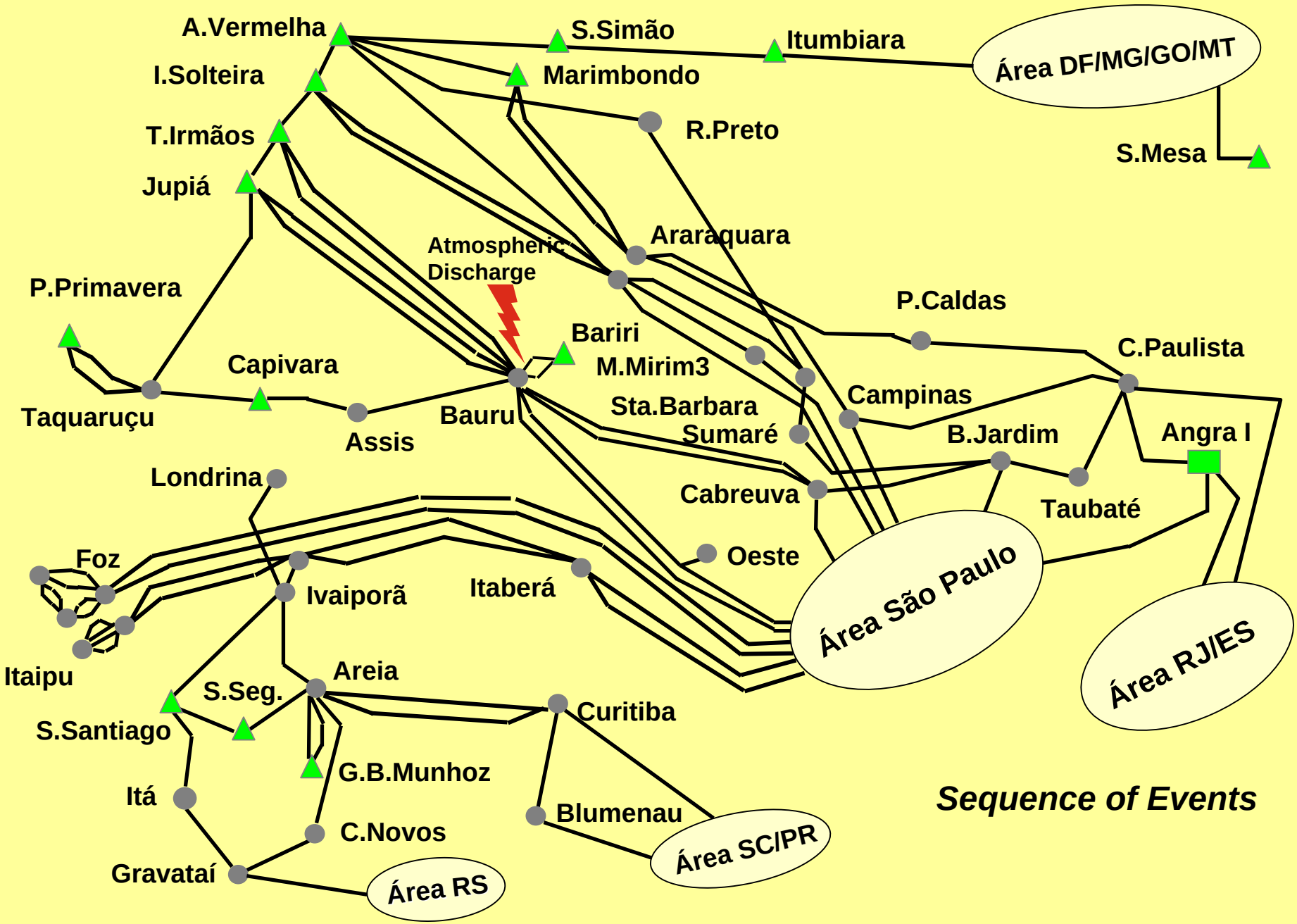
Examples:

- **load shedding (under-frequency; undervoltage)**
- **generation rejection**
- **islanding**
- **automatic switching of shunt elements (capacitors and reactors)**
- **combination of the above**

THE MARCH 11, 1999 BLACKOUT:

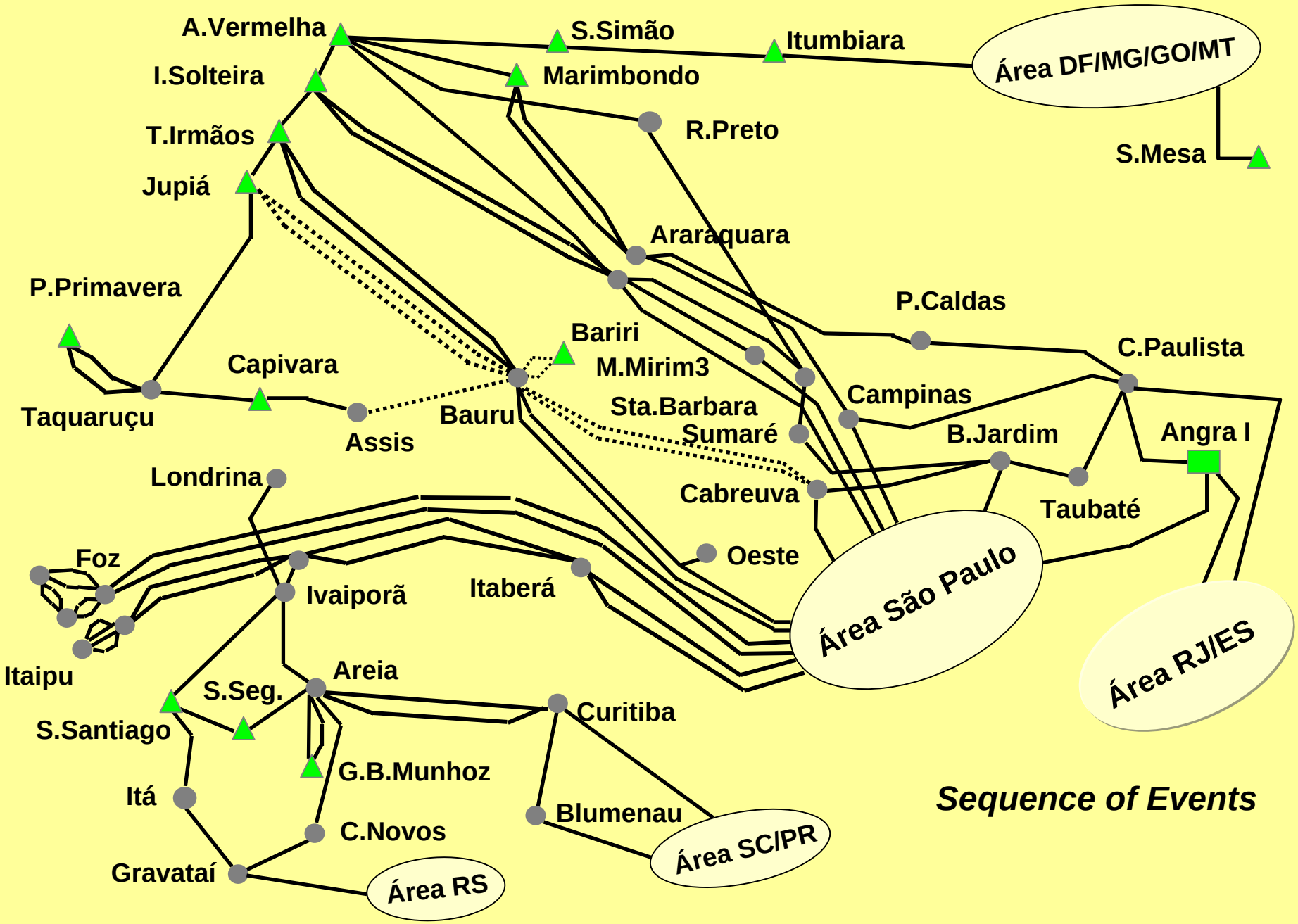
- Simultaneous loss of 5 lines (440 kV) following a fault at the Bauru substation.
- The tripping of a sixth 440 kV line (I. Solteira-Tres Irmãos) caused instability and collapse
- This tripping was due to 3rd. Zone relay misoperation.

Short- Circuit at Bauru Substation



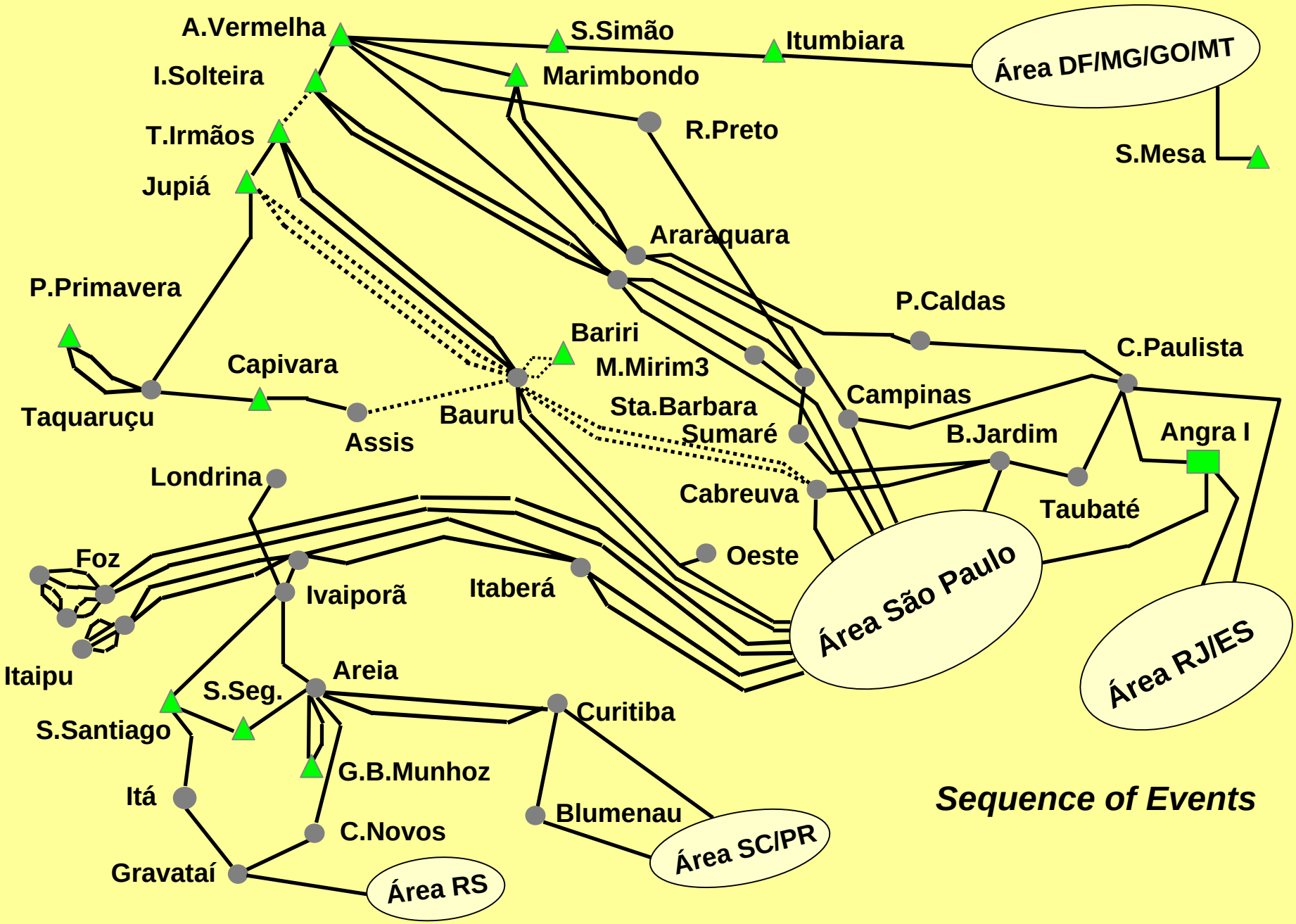
Sequence of Events

Loss of bus section and 5 lines (440 kV) at Bauru



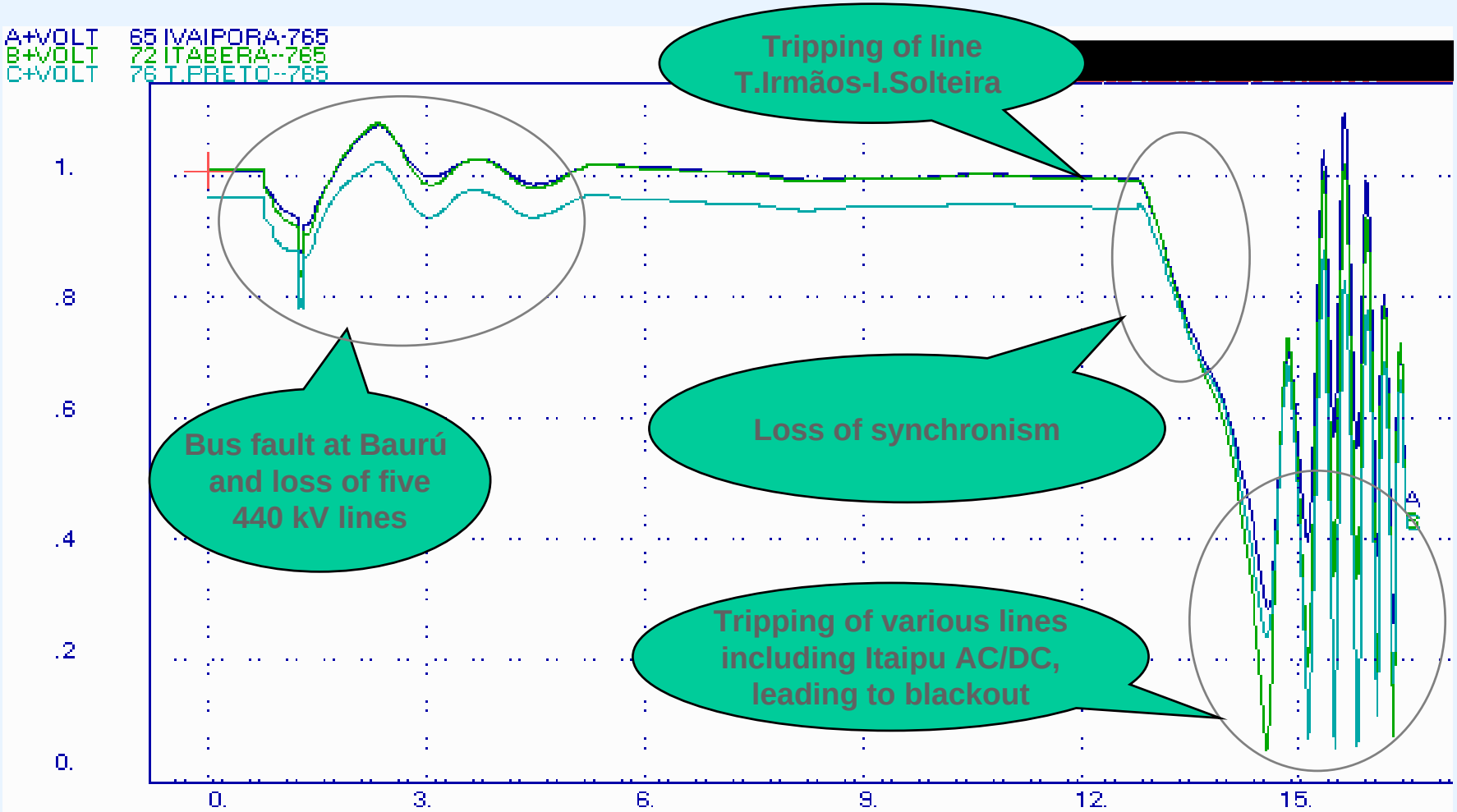
Sequence of Events

Tripping of Três Irmãos-Ilha Solteira 440 kV Line



Sequence of Events

Chain Reaction Leading to Blackout



Voltages at the Itaipu Transmission System

Minister for Energy Instructions:

- **Short and mid- term measures to detect and minimize the impact of extreme contingencies.**

Working Group ELETROBRÁS / CEPEL / GCOI / ONS to devise a Defense Plan against Extreme Contingencies

Improvements in substation layouts to reduce risk

SEVERAL TASK FORCES (SHORT AND MID-TERM) :

- **Analysis of substation layouts and proposal for most cost-effective changes and equipment additions.**
- **Assessment of existing Special Protection Schemes (SPS) and improvements.**
- **Implementation of fast action SPSs , PLC based, with direct detection of extreme contingencies.**
- **Reports by international experts**.
- **Review of restoration practices.**
- **Moderate-cost reinforcements that enhance security.**

Determining the Critical Substations

- **Substation ranking based on two viewpoints**

SYSTEM IMPACT VIEWPOINT

Which substations, when faulted, cause severe system instability or load loss?

SUBSTATION LAYOUT AND EQUIPMENT VIEWPOINT

Which substations have inadequate layouts or protection systems, that increase the chances of multiple outages?

Determining the Critical Substations

IMPACT TO THE EHV NETWORK

- **P_1** **Subestations where faults lead to extreme contingencies**

- **P_2** **Subestation where faults cause severe impact to the system, but not extreme contingencies**

- **P_3** **Subestations where faults cause a minor impact to the system**

Determining the Critical Substations

INTRINSIC SECURITY LEVEL OF SUBSTATION

Aspects considered: substation layout, bus protection utilized, major incoming lines and their characteristics (double-circuit tower, etc.)

- **S_1 substation presenting significant risk of outages.**
- **S_2 substations presenting some risk of outages.**
- **S_3 substations with layout and protection charateristics that make them secure, presenting very low risk of outages.**

The Network Security Matrix

- produced by the WG
- identifies the critical subestations

IMPACTO NO DESEMPENHO DO SISTEMA ↓ / NÍVEL DE PROTEÇÃO INTRÍNSECO →	S_1 nível de segurança reduzido	S_2 nível de segurança médio	S_3 nível de segurança bom	
P_1 Grande impacto no desempenho do sistema	Bauru 440 (CESP) Ilha Solteira 440 (CESP)	Adrianópolis 345 (FURNAS) Samambaia 345 (FURNAS) Bandeirantes 345 (FURNAS) Brasília Sul 345 (FURNAS) Itumbiara 345 (FURNAS) Grajaú 500 (FURNAS) B.Santista 345 (EPTE) Interlagos 345 (EPTE)	Ivaiporã 750 (FURNAS) Adrianópolis 500 (FURNAS) Angra 500 (FURNAS) C.Paulista 500 (FURNAS) Araraquara 440 (CESP) Itumbiara 500 (FURNAS) São José 500 (FURNAS) Ibiúna 345 (FURNAS) Jaguara 500 (CEMIG) Areia 500 (ELETROSUL) Curitiba 500 (ELETROSUL) Foz do Iguaçu 750 (FURNAS) Itaipu 500 (Itaipu)	Itaberá 750 (FURNAS) Tijuco Preto 750 (FURNAS) Tijuco Preto 500 (FURNAS) Samambaia 500 (FURNAS) Serra da Mesa 500 (FURNAS) Tijuco Preto 345 (FURNAS) Neves 500 (CEMIG) São Simão 500 (CEMIG) Água Vermelha 440 (CESP) Blumenau 500 (ELETROSUL) Gravataí 500 (ELETROSUL) Ivaiporã 500 (ELETROSUL) Emborcação 500 (CEMIG)
P_2 Impacto médio no desempenho do sistema	Cabreúva 440 (CESP) Jupiá 440 (CESP)	Guarulhos 345 (FURNAS) Nordeste 345 (EPTE) G.B.Munhoz 500 (COPEL) Furnas 345 (FURNAS) Poços 345 (FURNAS) Estreito 345 (FURNAS) Campinas 345 (FURNAS) Jaguara 345 (CEMIG) Pimenta 345 (CEMIG) Jacarepaguá 345 (FURNAS)	Araraquara 500 (FURNAS) Itá 500 (ELETROSUL) Campinas 500 (FURNAS) C. Novos 500 (ELETROSUL) Água Vermelha 500 (CESP) S.Santiago 500 (ELETROSUL) Marimbondo 500 (FURNAS) Taubaté 500 (CESP)	Assis 440 (CESP) Embuguaçu 440 (CESP) Poços 500 (FURNAS) Mesquita 500 (CEMIG) Salto Segredo 500 (COPEL) Santa Bárbara 440 (CESP) Santo Ângelo 440 (CESP)
P_3 Impacto reduzido no desempenho do sistema		Itapeti 345 (EPTE) V.Grande 345 (CEMIG) Barreiro 345 (CEMIG) Taquaril 345 (CEMIG) Capivara 440 (CESP) Corumbá 345 (FURNAS) P.Colômbia 345 (FURNAS)	Embuguaçu 345 (CESP) Nova Ponte 500 (CEMIG) Neves 345 (CEMIG) Salto Caxias 525 (ELETROSUL) Bom Jardim 440 (CESP) Taubaté 440 (CESP) Três Irmãos 440 (CESP)	Sumaré 440 (CESP) São Gotardo 500 (CEMIG)

The Network Security Matrix

- **crítical matrix blocks**

NÍVEL DE PROTEÇÃO INTRÍNSECO → / IMPACTO NO DESEMPENHO DO SISTEMA ↓	S_1 nível de segurança reduzido	S_2 nível de segurança médio
P_1 Grande impacto no desempenho do sistema	Bauru 440 (CESP) Ilha Solteira 440 (CESP)	Adrianópolis 345 (FURNAS) Samambaia 345 (FURNAS) Bandeirantes 345 (FURNAS) Brasília Sul 345 (FURNAS) Itumbiara 345 (FURNAS) Grajaú 500 (FURNAS) B.Santista 345 (EPTE) Interlagos 345 (EPTE)
P_2 Impacto médio no desempenho do sistema	Cabreúva 440 (CESP) Jupiá 440 (CESP)	Guarulhos 345 (FURNAS) Nordeste 345 (EPTE) G.B.Munhoz 500 (COPEL) Furnas 345 (FURNAS) Poços 345 (FURNAS) Estreito 345 (FURNAS) Campinas 345 (FURNAS) Jaguara 345 (CEMIG) Pimenta 345 (CEMIG) Jacarepaguá 345 (FURNAS)

ENHANCING NETWORK SECURITY

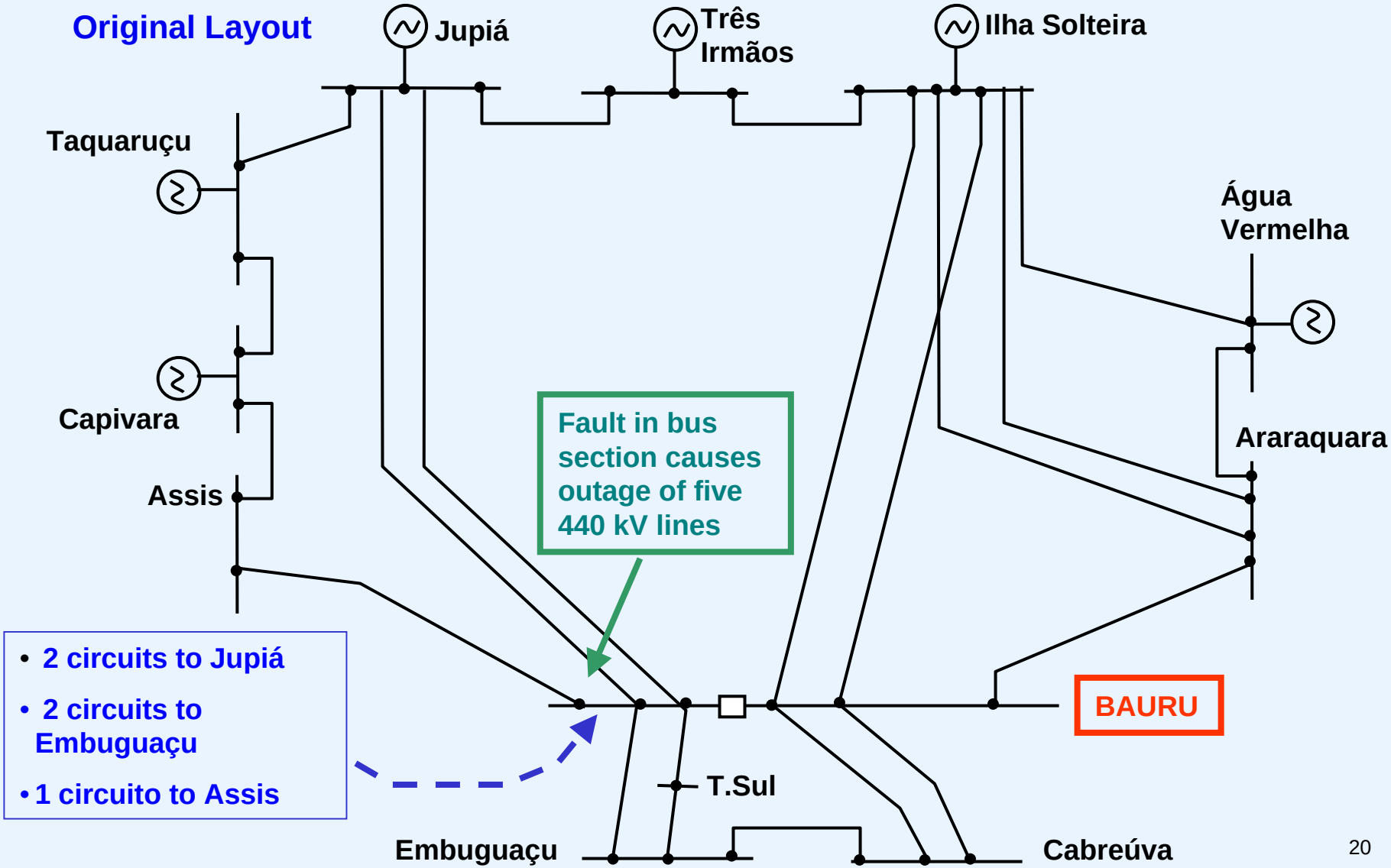
- **SPSs will be installed to detect and confine extreme contingencies associated with substations located in the RED zone of the matrix**

- **Short-term changes to layouts, improvements in intrinsic protection and addition of critical equipment to substations ranked as S_1 e S_2**

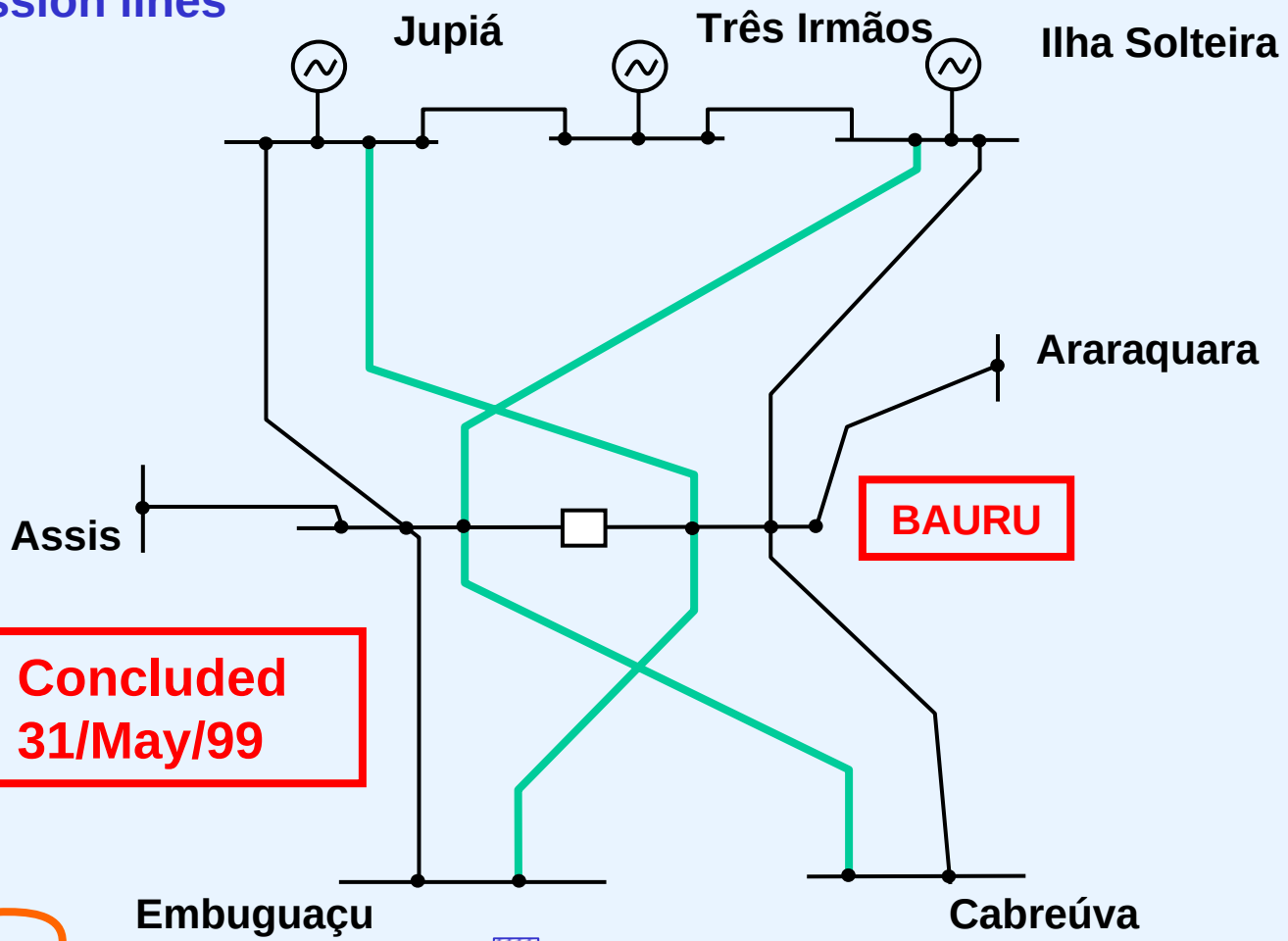
- **These actions will move the substations away from the RED zone (hopefully into the GREEN zone)**

IMMEDIATE MEASURES:

Layout changes in Bauru Substation



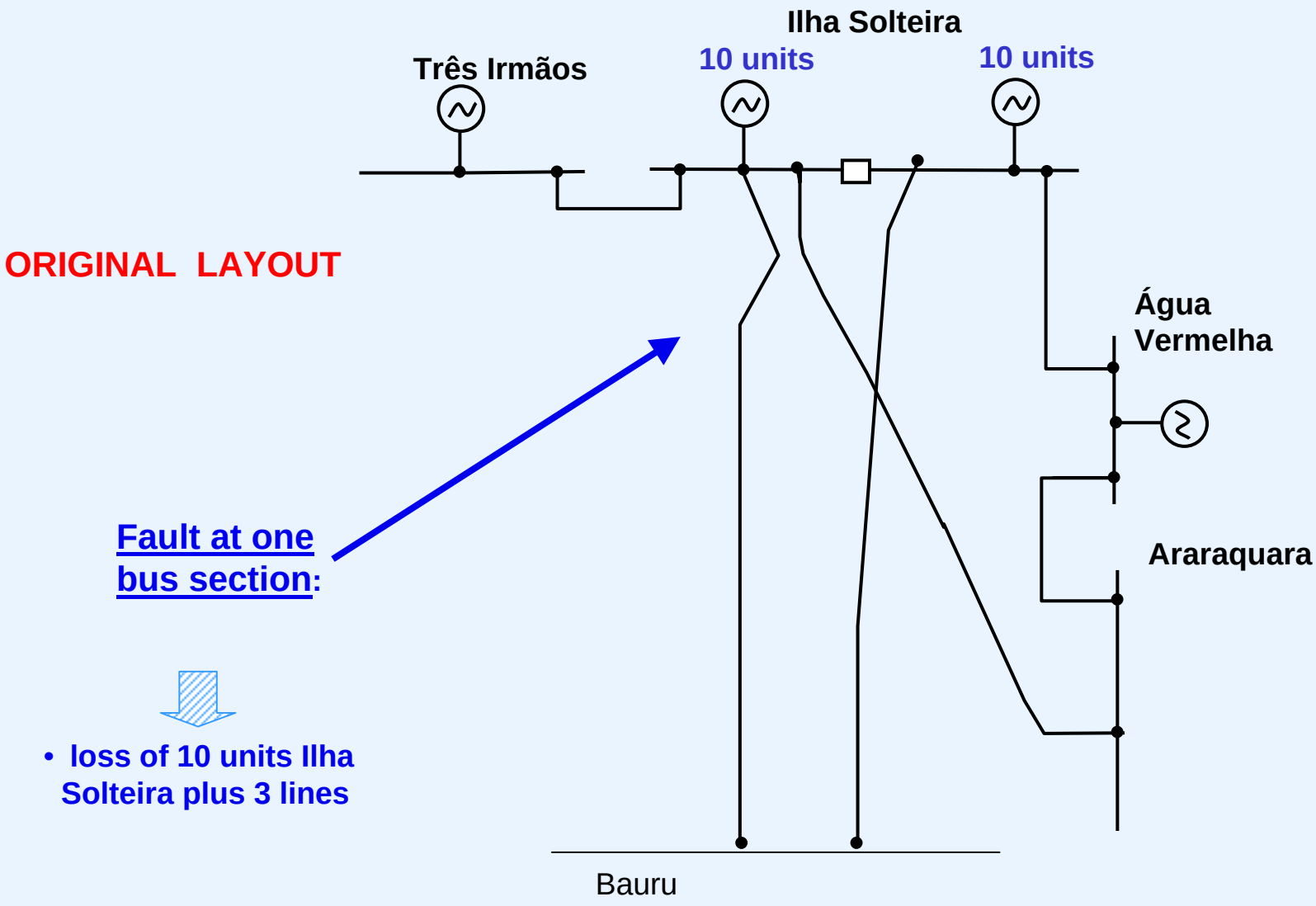
1st. Stage: Transposition of incoming transmission lines

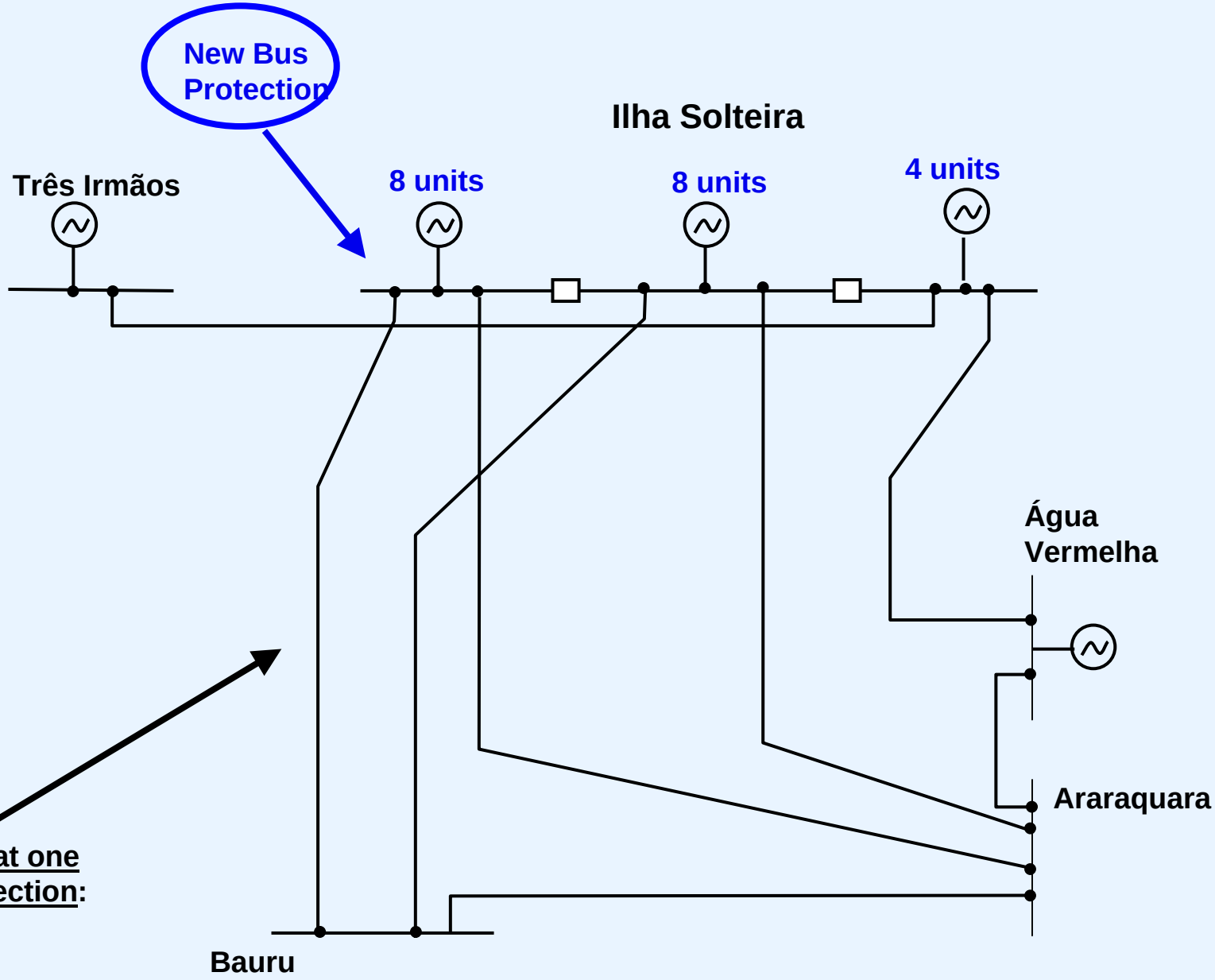


Fault in bus section of Bauru substation

- One circuit Jupiá - Bauru remains connected
- One circuit Bauru - Embuguaçu remains connected

Layout Changes at Ilha Solteira 440 kV Substation





- loss of either 8 or 4 units and 2 transmission lines

Concluded 31/Aug/99

CURRENT STATUS OF WG WORK

Concluded

- Report on improvements in substation layouts, etc.
- Reports by international experts
- Some substation layout improvements and equipment additions
- Some changes to existing SPSs

Under development

- Dynamic studies to define new SPS logics
- Acquisition of PLCs and needed communication links
- Work on dynamic system monitors, P.S. restoration, reinforcements, etc.