Appendix

Appendix 1.A

Explanatory Materials
for Technical Assistance
on System Planning
(UHV Transmission Line)

1100kV AC Transmission Project in Japan

April 21, 2010

TEPCO

TOKYO ELECTRIC POWER COMPANY

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1. Research and Development of UHV in Japan

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Why Did Japan Start UHV R&D?

- Steady expected growth of power demand.
- Distance between large scale power stations and load centers expected to become greater.

↓

- Larger capacity and longer distance transmission technology.

↓

- Next voltage level above 550kV.

↓

- UHV R&D started in Japan in 1973.

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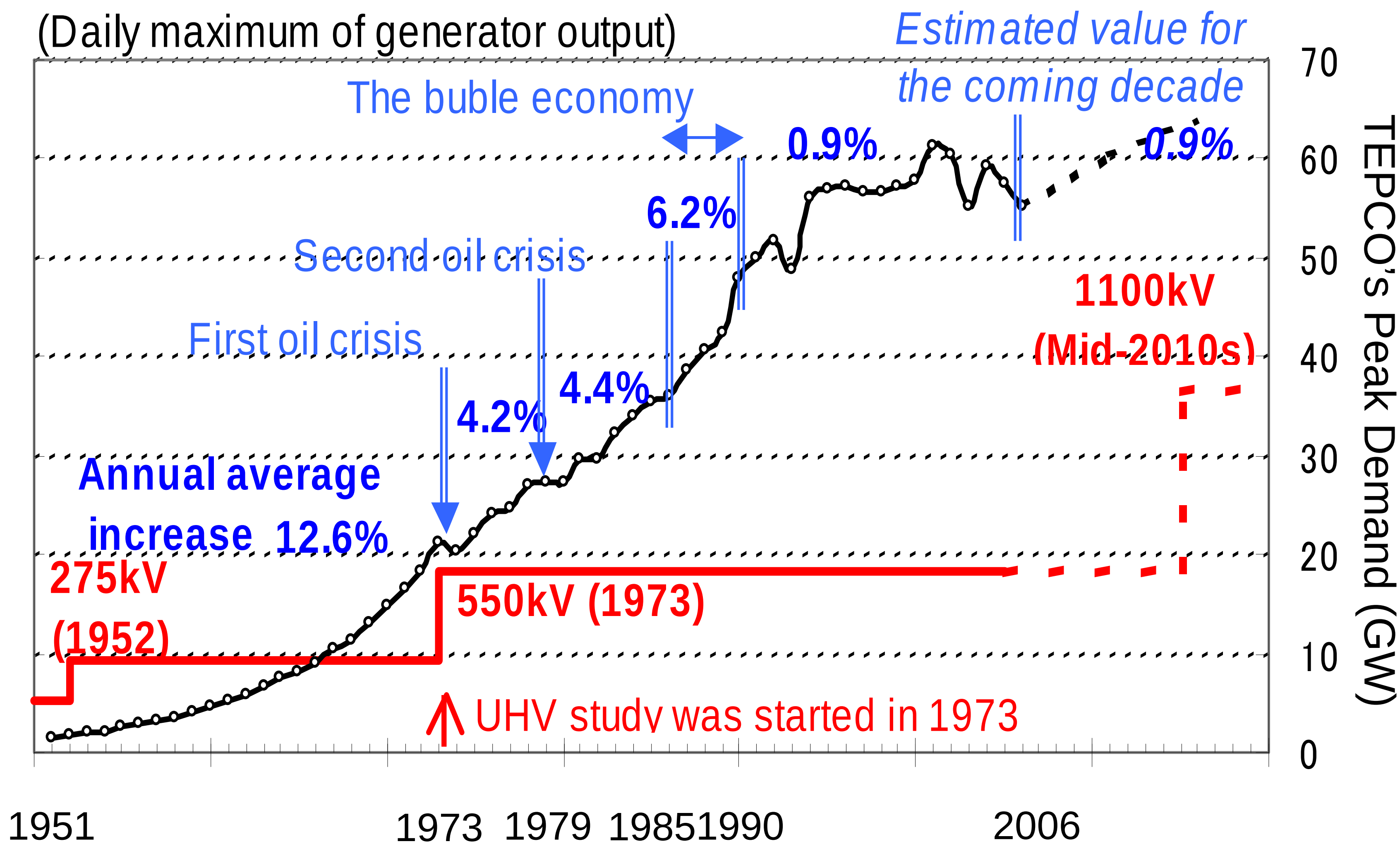
AC Voltage History & Peak Demand



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R&D Conducted by Organizations Nationwide

First Step

- "The central electric power council", 1973 - 1978
- 9 Utilities and CRIEPI
- Basic research and conceptual design

Second Step

- "The nation-wide study committee for UHV transmission", 1978 - 1982
- 9 Utilities, CRIEPI, Academia and Manufacturers

- 1100kV was designated Highest AC voltage.
- Prospect of realizing reliable UHV system was attained.

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Study of the Highest AC Voltage of UHV in Japan

- Studies were conducted on the 10GW, 600km transmission model to meet future needs.
- Candidates for the highest voltage were 800, 1100, 1200, and 1500kV.
  - 800kV transmission has not enough capability.
  - 1500kV transmission was not estimated to be technically feasible.

→1100kV and 1200kV remained

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Why 1100kV was selected as the Highest Voltage of UHV in Japan

- Double circuit towres must be used even for UHV transmission.

  ←The acquisition of ROW is difficult in a country where land space is narrow.
- UHV transmission lines go through mountainous areas.

⇩

- A more compact tower is more advantageous.

  →1100kV was preferred.
- 1100kV was also estimated to have an economic advantage.

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Adoption of 1100kV as The Highest AC Voltage

Highest Voltage (kV)	800	**1100**	1200	1500
Number of Circuits per Route × Number of Routes	2 × 4	**2 × 2**	2 × 2	1 × 2
Technical Feasibility	Easy	**Feasible**	Feasible	Difficult
Total Construction Cost	1.06	**1.00**	1.19	1.09
Tower Height（m）	91	**110**	123	125

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Comparison with DC Transmission (1)

- If the part of the meshed main grid is composed of DC link
  - System reliability can not be guaranteed easily
    - Forced Outage Rate of DC link – 1.64 %/yr （average of CIGRE survey）
  - Since multi-terminal DC link is necessary, the flexibility becomes lower for system expansion
    - Economic efficiency gets worse due to the multi-terminal DC link
    - Reverse of power flow in some terminals requires mechanical switching of the main circuit.

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Comparison with DC Transmission (2)

- Application to long distance power transmission
  - The transmission distance in Japan is about 600km, not so long as that in other countries, as a result, the economic efficiency of DC is comparatively low.
  - The shutoff recovery sequence of HVDC due to AC system faults (including the frequent faults such as single phase grounding fault) impacts on system stability.
  - If HVDC is applied to nuclear power transmission instead of hydro power, the following subjects should be carefully studied regarding interaction of nuclear power generator and DC system:
    - Coordinated control in normal operation and DC system fault
    - Possibility of SSTI (Sub-synchronous Torsional Interaction)

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UHV Testing Facilities in Japan (1)

- Full scale tower for switching impulse testing.
  - Shiobara, CRIEPI
  - 2 phases
  - Maximum voltage : (1st phase)2.6MV, (2nd)2.3MV

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UHV Testing Facilities in Japan (2)

- Full scale conductor bundle for testing corona noise.
  - Shiobara, CRIEPI
  - Size of Cage;
    8m × 8m × 24m
  - Maximum voltage;
    up to 1,200kV

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UHV Testing Facilities in Japan (3)

- Full scale tower & lines for corona noise test.
  - Akagi, CRIEPI
  - Length : 600m
  - Number of Towers : 3

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Prototype Development

- Prototype UHV transformer
  - Half unit of a single-phase transformer

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3. TEPCO's UHV Project

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Introduction of UHV System for Future Development by TEPCO

- Steady growth of peak demand
- Increase of power flow from remote power plants

⇩

- Land acquisition problems anticipated with future 550kV system expansion:
  - Necessity of many transmission routes.

⇩

- TEPCO decided to introduce 1100kV transmission.

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Current State of TEPCO's UHV

1100kV Transmission Lines

- 430km UHV designed transmission lines had been constructed, and they are operated at 550kV.

1100kV Substation Equipment

- All necessary substation equipment has been energized in a field test yard since 1996.

Upgrading to 1100kV

- Planned for mid-2010s.

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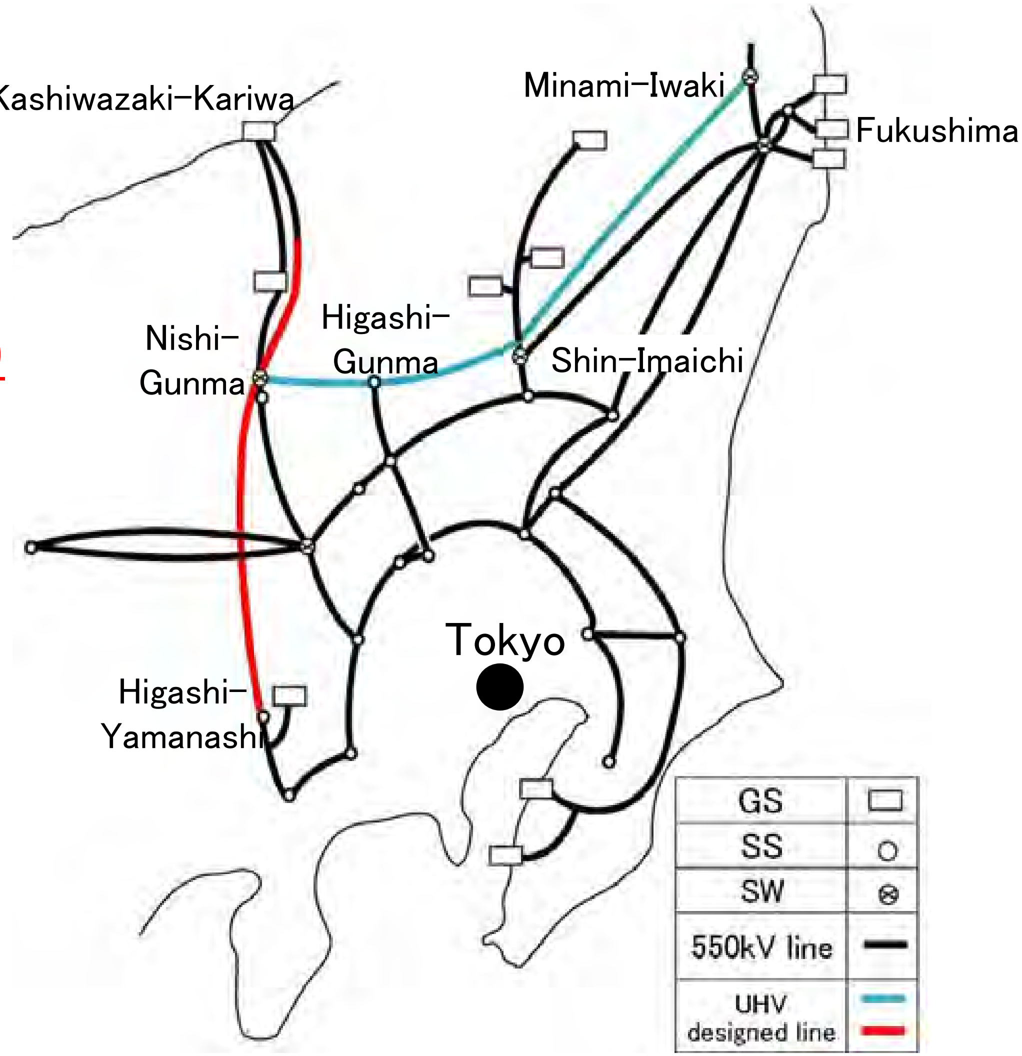
Construction of UHV Designed Transmission Lines



North-South route (190km)

- Construction by 1993

East-West route(240km)

- Construction by 1999

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UHV Transmission Tower and Line

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Downsizing of Transmission Tower

- It is essential to make transmission towers smaller for cost reduction and environmental consideration.

- The overvoltage level is suppressed for downsizing.

  ←Tower size depends on its insulation level, or overvoltage level.

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1100kV Double-Circuit Tower Design

- Typical tower height is reduced to 110m by suppressing switching overvoltage level to 1.6-1.7PU.

(143m for 2.0PU overvoltage level)

- Electromagnetic field strength is the same level as that of the 550kV tower.

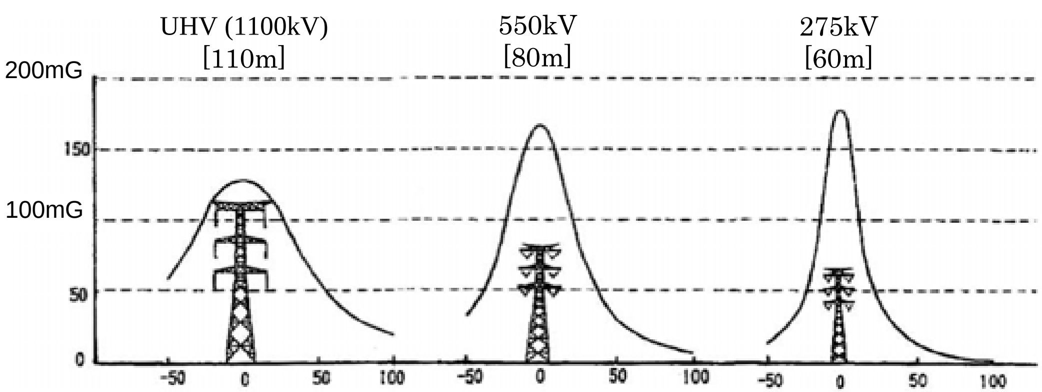
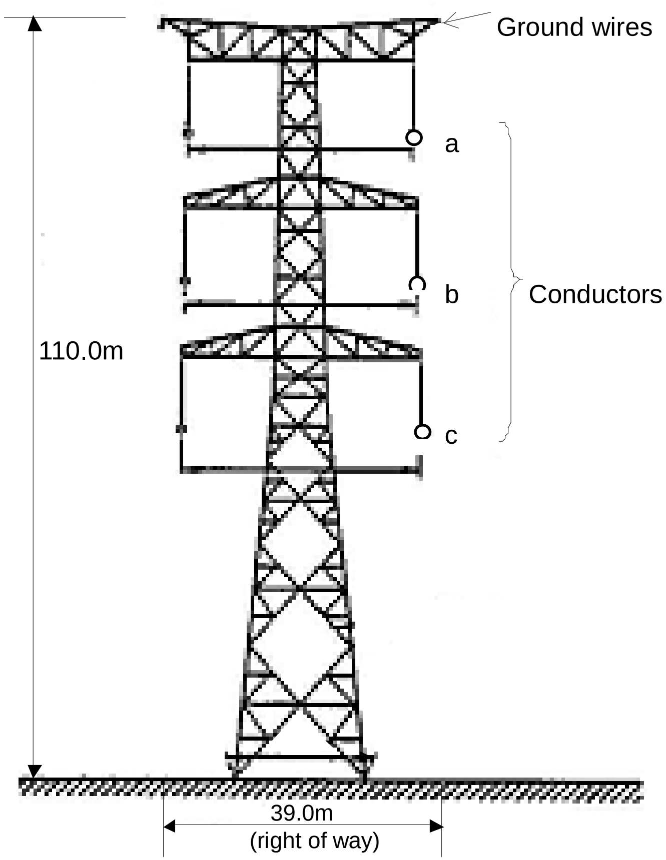


Figure 7: Magnetic field (mG)



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UHV Substation Equipment Test Site

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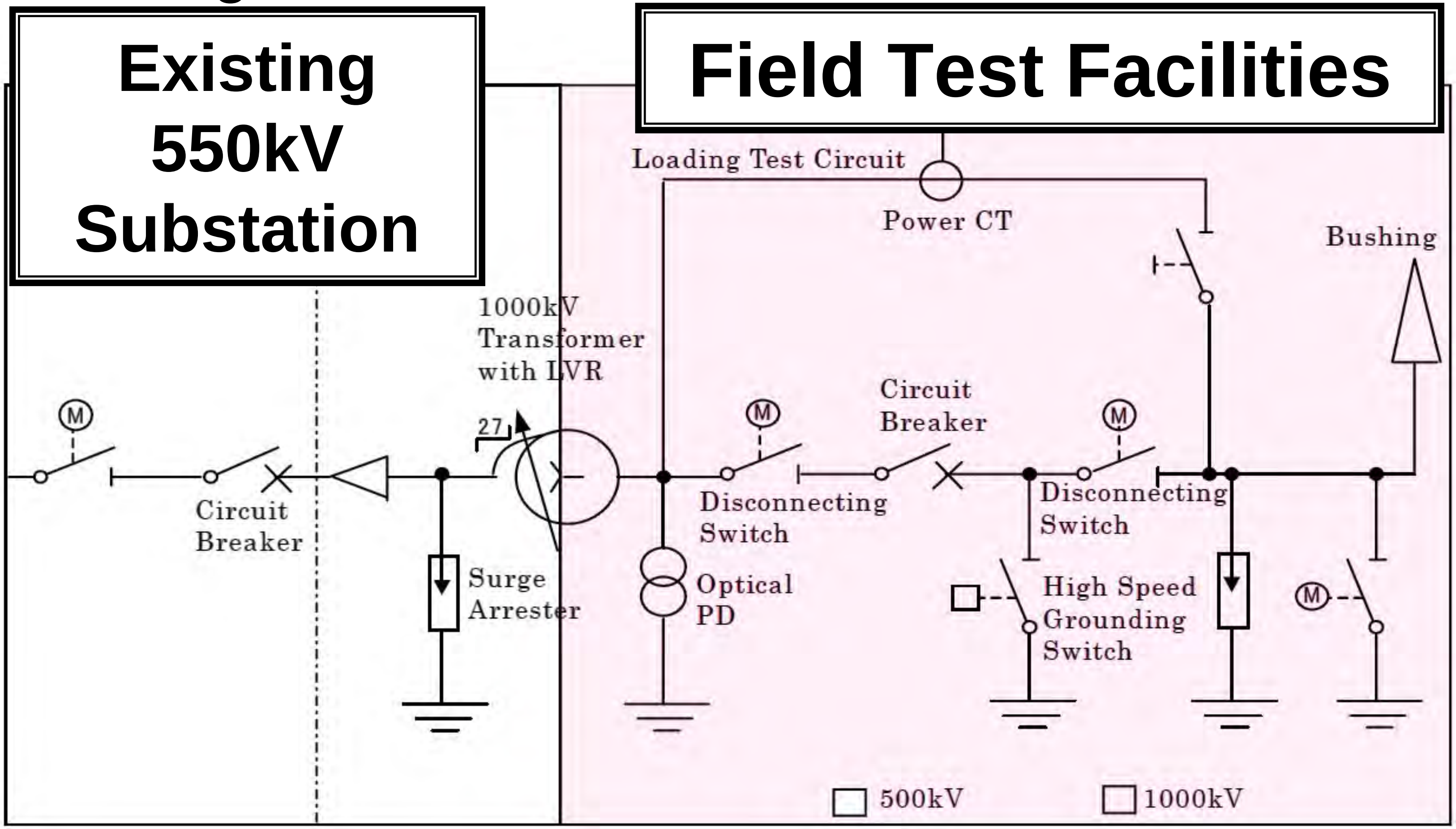
Substation Equipment Field Test

- One set of substation equipment has been energized since 1996.



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4. Conclusion

- The highest adopted UHV voltage in Japan is 1100kV.

- TEPCO constructed more than 400km of 1100kV designed transmission lines, which are currently operated at 550kV.
- For substation technology, the equipment has been energized in the test yard since 1996.

→ UHV technology has been established.

- TEPCO will upgrade the lines to 1100kV in 10 years time.

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JICA Technical Assistance for Power Development Plan 7 in Vietnam

Methods of Bulk Power Transmission from Nuclear PPs & Coal TPPs in South Eastern Vietnam

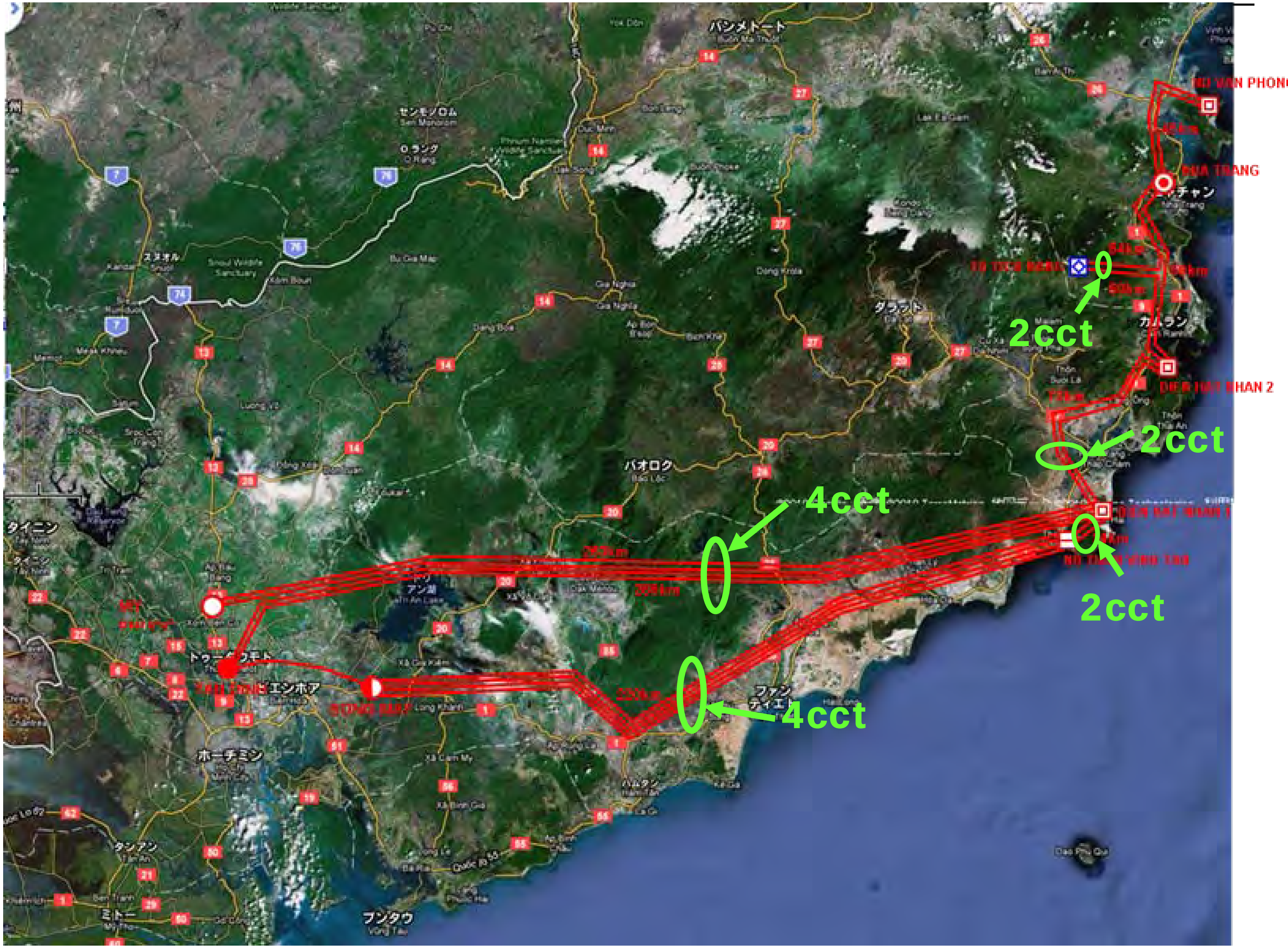
March 3rd, 2010

JICA Technical Assistance Team

Power Generation

- Nuclear Power Plants
  - Dien Hat Nhan 1: 4,000MW
  - Dien Hat Nhan 2: 4,000MW
- Coal Thermal Power Plants
  - ND Than Vinh Tan: 4,400MW
  - ND Van Phong: 2,400MW
- Pumpted Strage Power Plant
  - TD Tich Nang: 1,200MW
- Total 16,000MW

Present Plan



Power Flow Analysis

- Assumption
  - Integrate the whole system of Ho Chi Minh area
    - Background power system: behind My Phuoc, Tan Dinh, and Song May
  - Capacity of the background system: 35,000MVA
    - Maximum power demand in 2020: 51,000MW
    - Power flow from NPP, CTPP, and PSPP: 16,000MW

Power Flow Analysis

- 500kV Transmission Line
  - Line Constants (ACSR330x4,100MVA Base)
    - R: 0.00001pu/km
    - X: 0.000112pu/km
    - B: 0.010025pu/km
  - Thermal Rating
    - 2,400MVA/cct
- Step-up Transformer
  - Impedance b/w Primary and Secondary Sides
    - 14% (Machine Base)
  - Rated Capacity
    - Generator capacity/power factor (0.85) →nearest 50s

Power Flow Analysis

- Generators
  - Pmax (MW/unit)
    - Nuclear Power Plant: 1,000
    - Coal Thermal Power Plant: 500 and 600
    - Pumped Storage Power Plant: 600
  - Mbase
    - Pmax/0.85
  - Power Factor
    - Leading 0.85 – Lagging 0.90

Stability Analysis

- Assumptions
  - Generator Model
    - Nuclear Power Plants and Coal Thermal Power Plants
      - GENROU

T'do	T''do	T'qo	T''qo	H	D	Xd
5.2	0.015	1	0.015	4.76	0	1.74
Xq	X'd	X'q	X''d = X''q	Xl	S(1.0)	S(1.2)
1.72	0.29	0.29	0.2	0.168	0.1	0.4

    - Pumped Storage Power Plant
      - GENSAL

T'do	T''do	T''qo	H	D	Xd
6.27	0.041	0.047	4.01	0	0.93
Xq	X'd	X''d = X''q	Xl	S(1.0)	S(1.2)
0.61	0.31	0.2	0.13	0.1	0.37

    - Slack (Ho Chi Minh System)
      - GEN CLS

H	D
5.00	0

Stability Analysis

- Assumptions
  - Exciter Model
    - SEXS

T_A/T_B	T_B	K	T_E	E_{MIN}	E_{MAX}
0.1	10	100	0.1	0	5.0

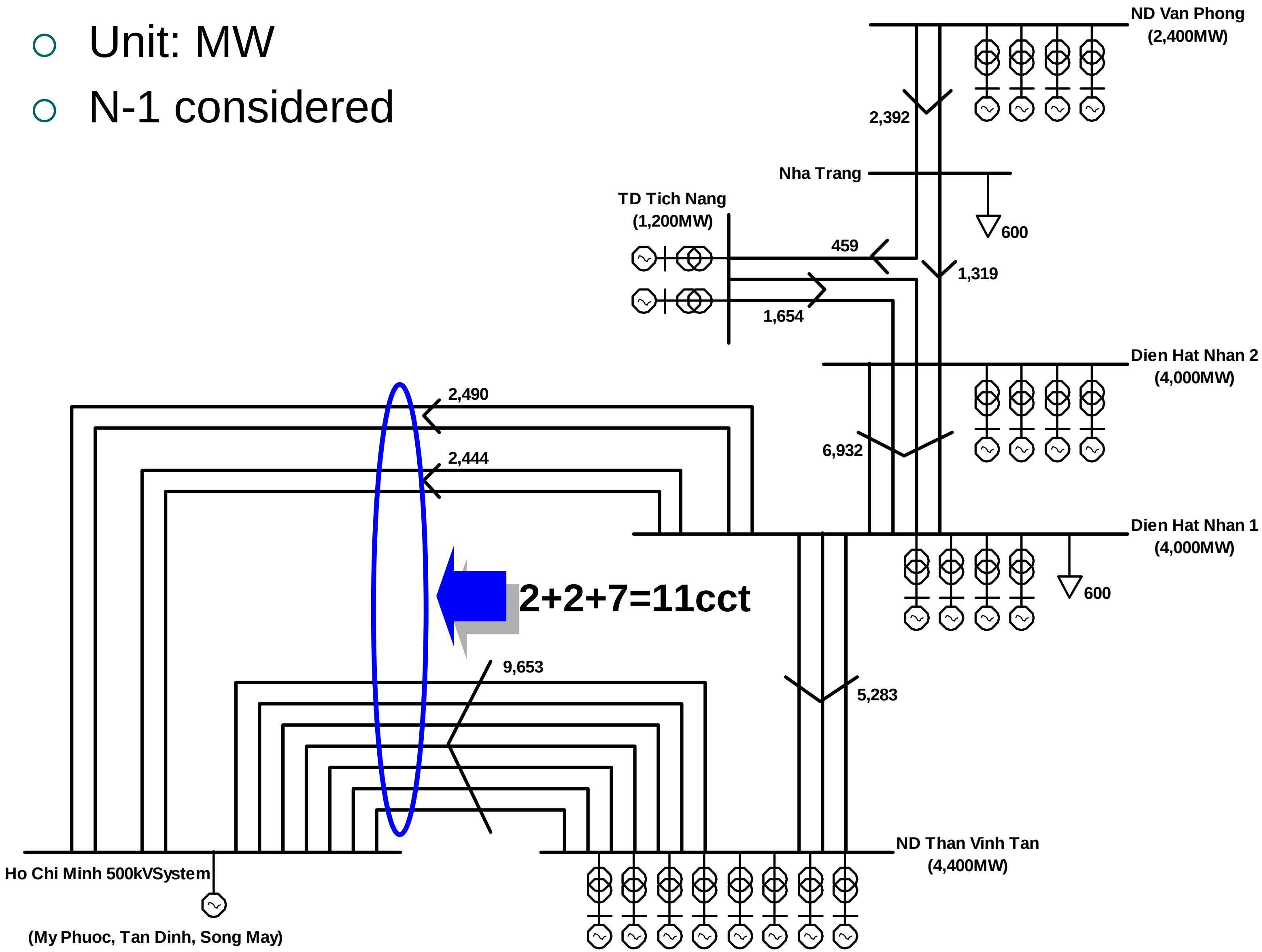
  - Governor
    - N/A
  - Fault Clearing Time
    - 80msec

Stability Analysis

- Analysis Case
  - Fault Section (1cct)
    - Dien Hat Nhan 1 P/S – Ho Chi Minh 500kV Slack
  - Fault Sequence
    - 0msec: Single Circuit Three-phase Short Circuit Fault
    - 80msec: Fault Clearance (1cct open)
    - 10sec: End of Calculation
  - Phase Angle Difference
    - Ho Chi Minh – ND Than Vinh Tan: **Green**
    - Ho Chi Minh – Dien Hat Nhan 1 : **Blue**
    - Ho Chi Minh – Dien Hat Nhan 2 : **Light Blue**
    - Ho Chi Minh – ND Van Phong : **Pink**
    - Ho Chi Minh – TD Tich Nang : **Yellow**

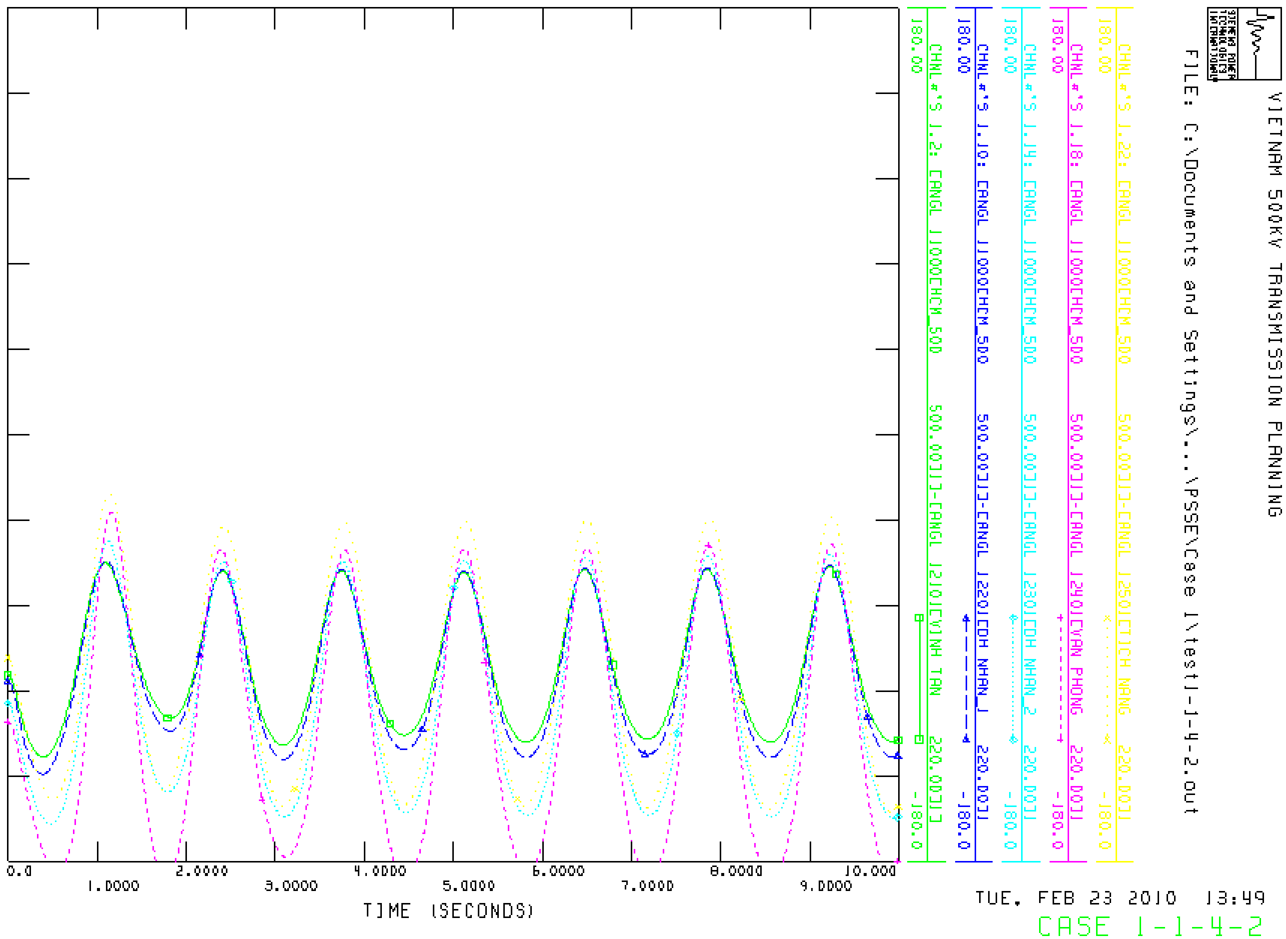
Stability Analysis
- System Configuration #1

- Unit: MW
- N-1 considered



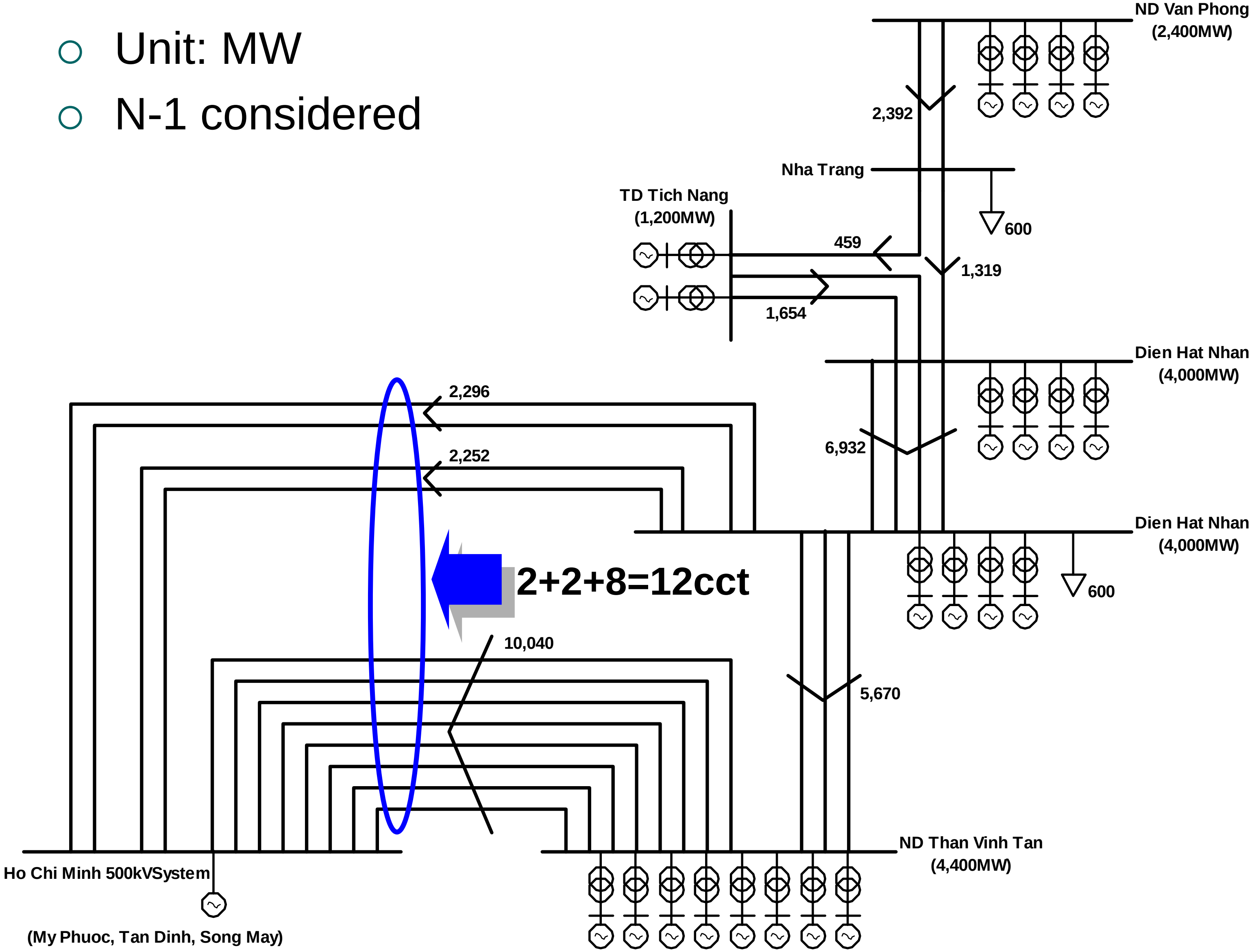
Stability Analysis
- System Configuration #1

- Analysis Result
  - **Unstable**



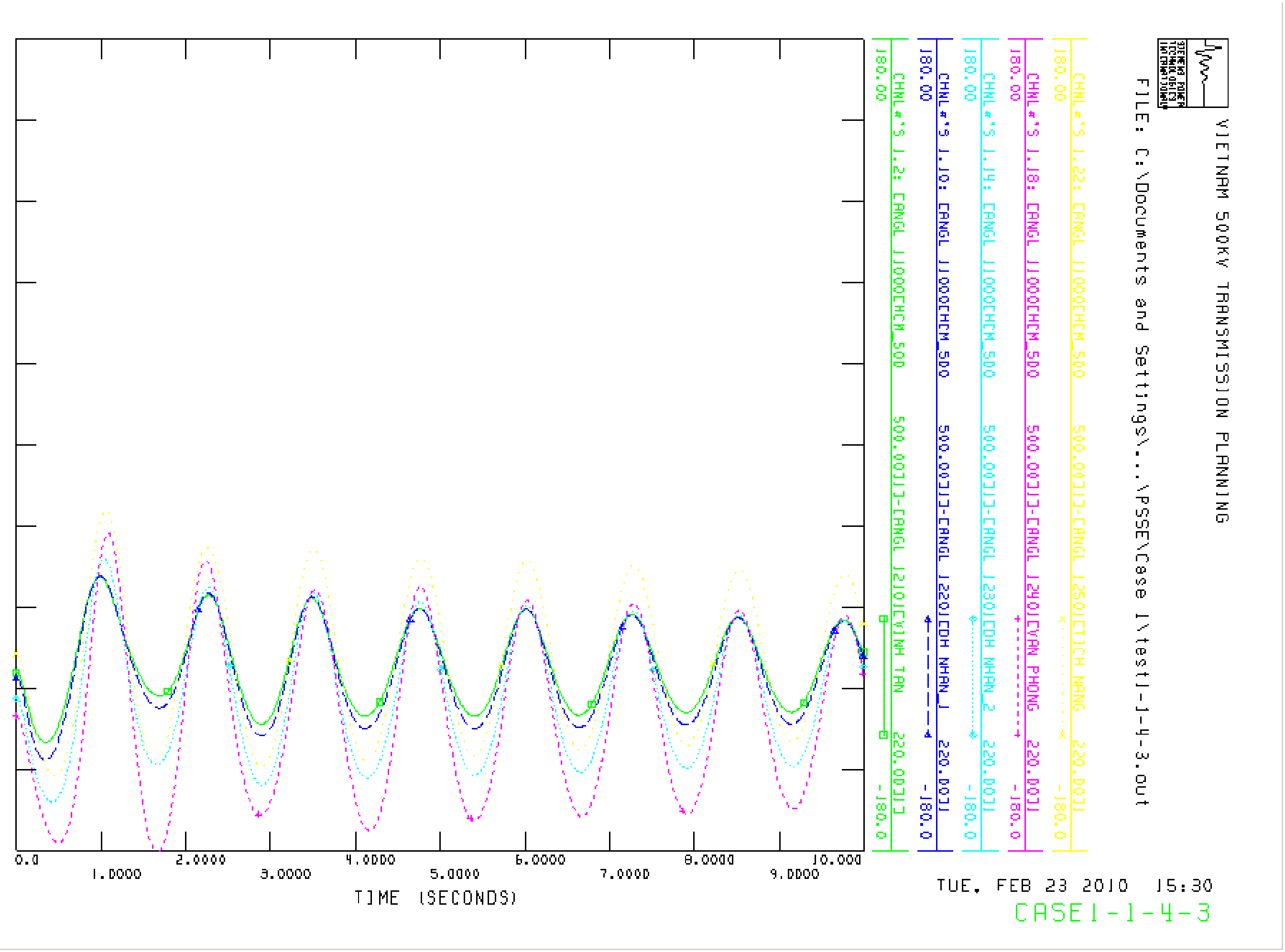
Stability Analysis
- System Configuration #2

- Unit: MW
- N-1 considered

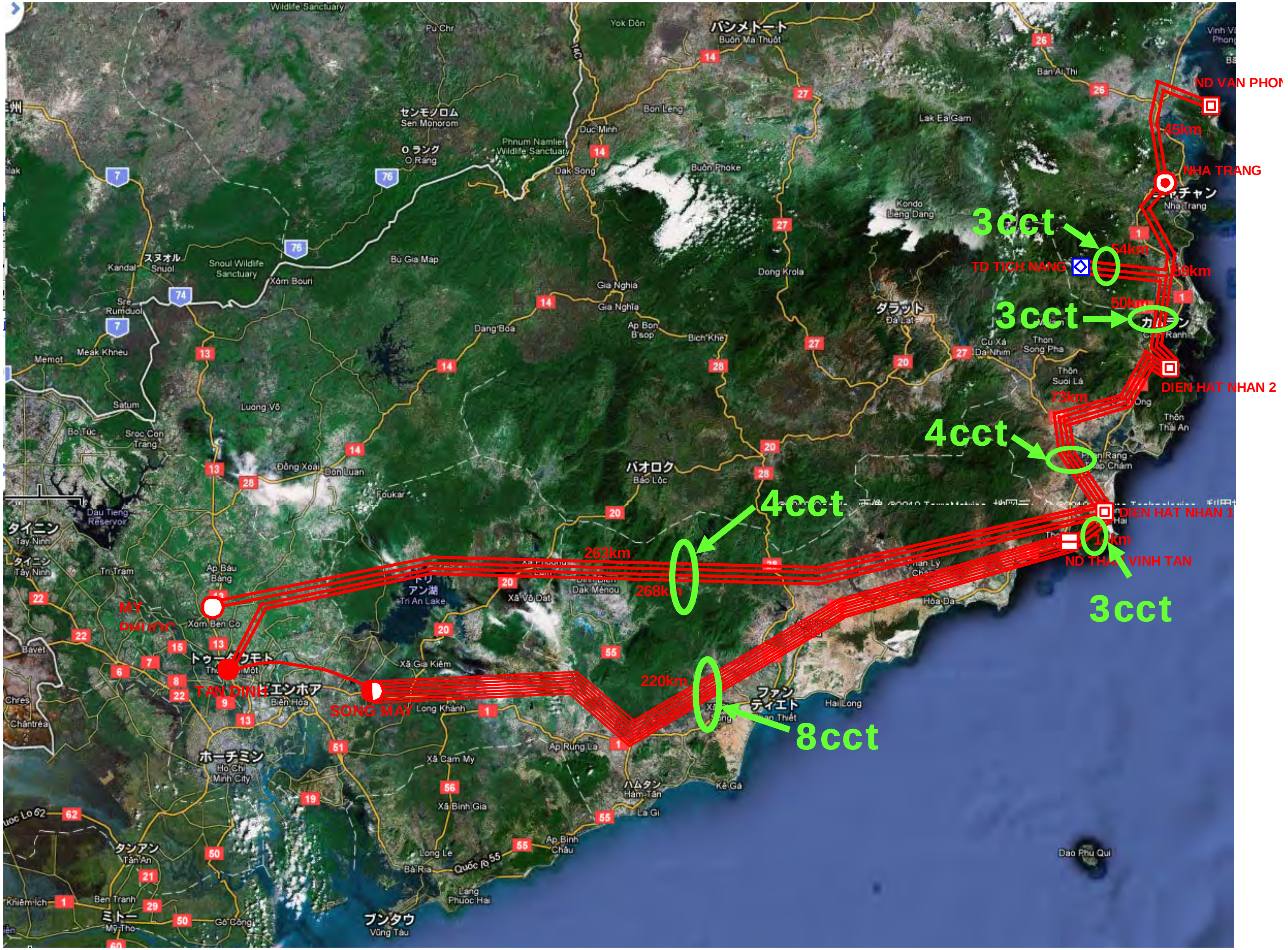


Stability Analysis
- System Configuration #2

- Analysis Result
  - **Stable**



Modified System Plan consisted only of 500kV Lines



Number of Circuits Required

- Results

Transmission Line		Number of Circuits		
From	To	Original Plan	Modified Plan	Difference
ND Van Phong	Nha Trang	2	2	0
Nha Trang	TD Tich Nang	1	1	0
Nha Trang	Dien Hat Nhan 2	1	1	0
TD Tich Nang	Dien Hat Nhan 2	1	2	**+1**
Dien Hat Nhan 1	Dien Hat Nhan 2	2	4	**+2**
Dien Hat Nhan 1	ND Than Vinh Tan	2	3	**+1**
Dien Hat Nhan 1	Ho Chi Minh (My Phuoc)	2	2	0
Dien Hat Nhan 1	Ho Chi Minh (Tan Dinh)	2	2	0
ND Than Vinh Tan	Ho Chi Minh (Song May)	4	8	**+4**

Application of UHV System

- Large-scale power development in remote location and grid expansion
  - System stability problem
  - Short-circuit fault current problem
    - 500kV System
      - Need a number of routes to secure required transmission capacity and to improve stability
      - Huge investment
      - Route selection
      - Land acquisition and compensation
    - 1000kV (UHV) System
      - Smaller number of routes
      - Improvement in stability

Power Flow Analysis

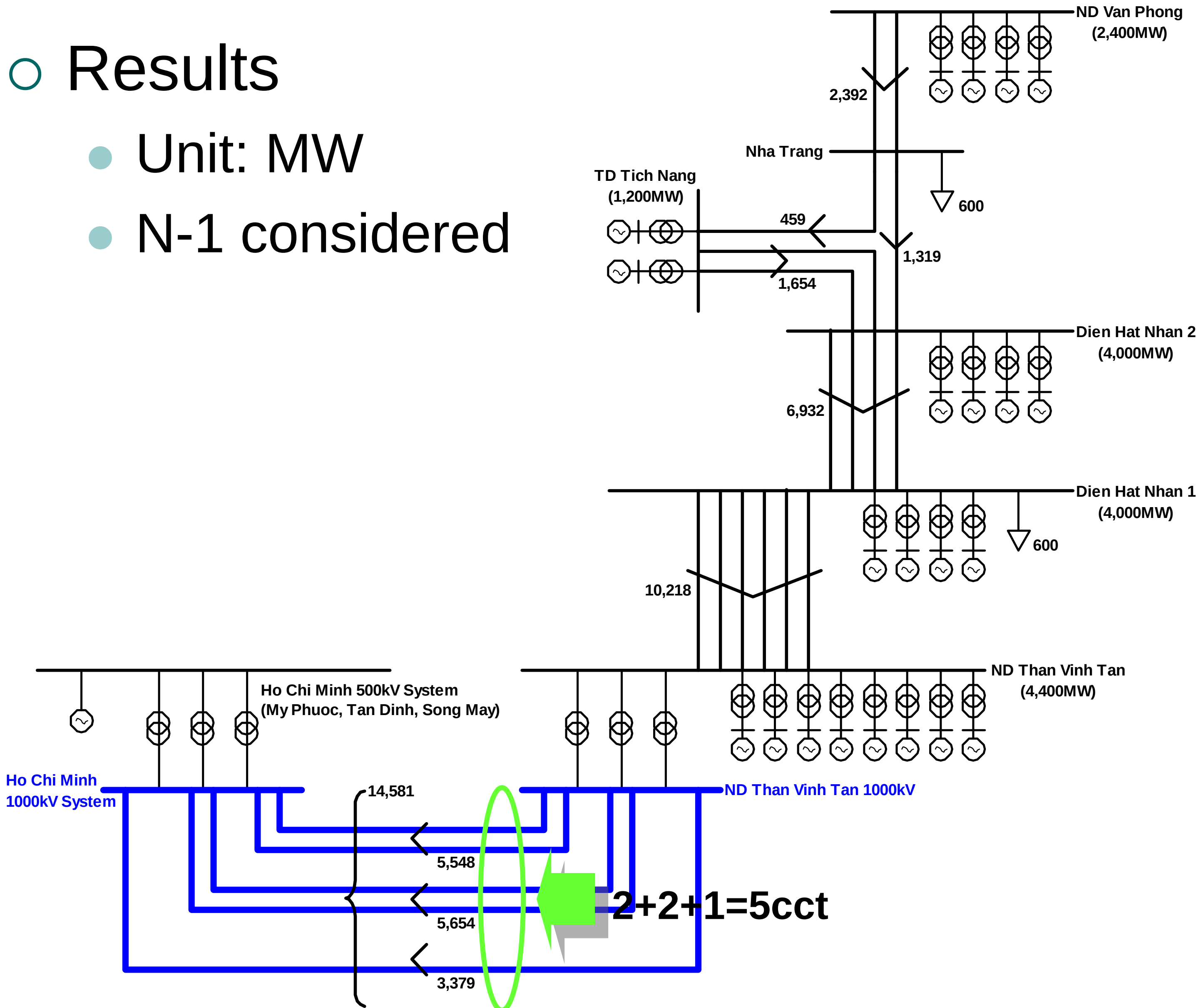
- 1000kV Transmission Line
  - Line Constants (ACSR810x8,100MVA Base)
    - R: 0.00000082pu/km
    - X: 0.00002599pu/km
    - B: 0.02988817pu/km
  - Thermal Rating
    - 17,800MVA/cct
- Transformer
  - Impedance b/w Primary and Secondary Sides
    - 12% (Machine Base)
  - Rated Capacity
    - 6,000MVA/unit

Stability Analysis

- Assumptions
  - Same as those of 500kV System Case
- Analysis Case
  - Fault Section (1cct)
    - ND Than Vinh Tan P/S – Ho Chi Minh 1000kV Bus
  - Fault Sequence
    - 0msec: Single Circuit Three-phase Short Circuit Fault
    - 80msec: Fault Clearance (1cct open)
    - 10sec: End of Calculation
  - Phase Angle Difference
    - Ho Chi Minh – ND Than Vinh Tan: **Green**
    - Ho Chi Minh – Dien Hat Nhan 1 : **Blue**
    - Ho Chi Minh – Dien Hat Nhan 2 : **Light Blue**
    - Ho Chi Minh – ND Van Phong : **Pink**
    - Ho Chi Minh – TD Tich Nang : **Yellow**

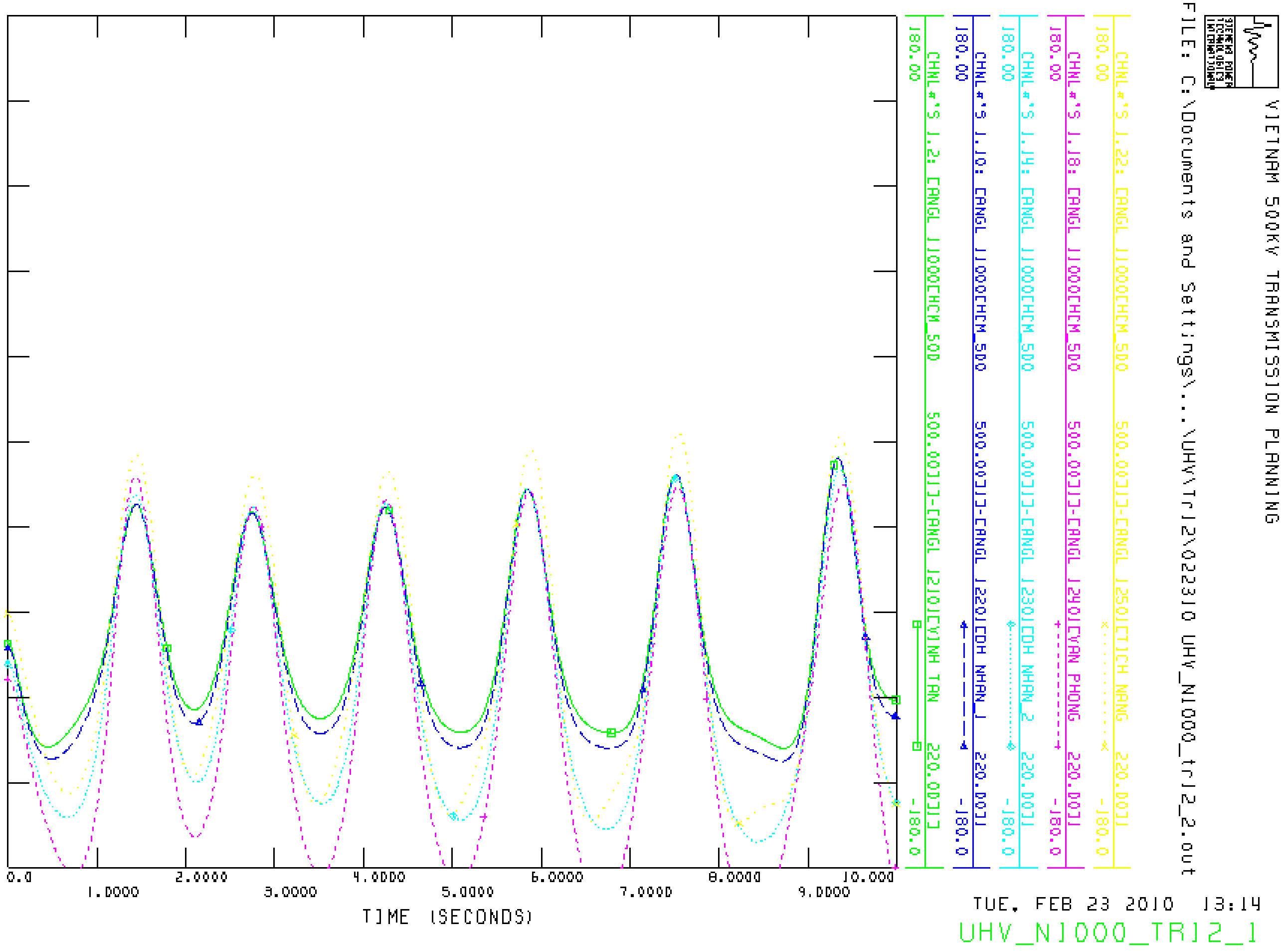
Stability Analysis
- System Configuration #1

- Results
  - Unit: MW
  - N-1 considered



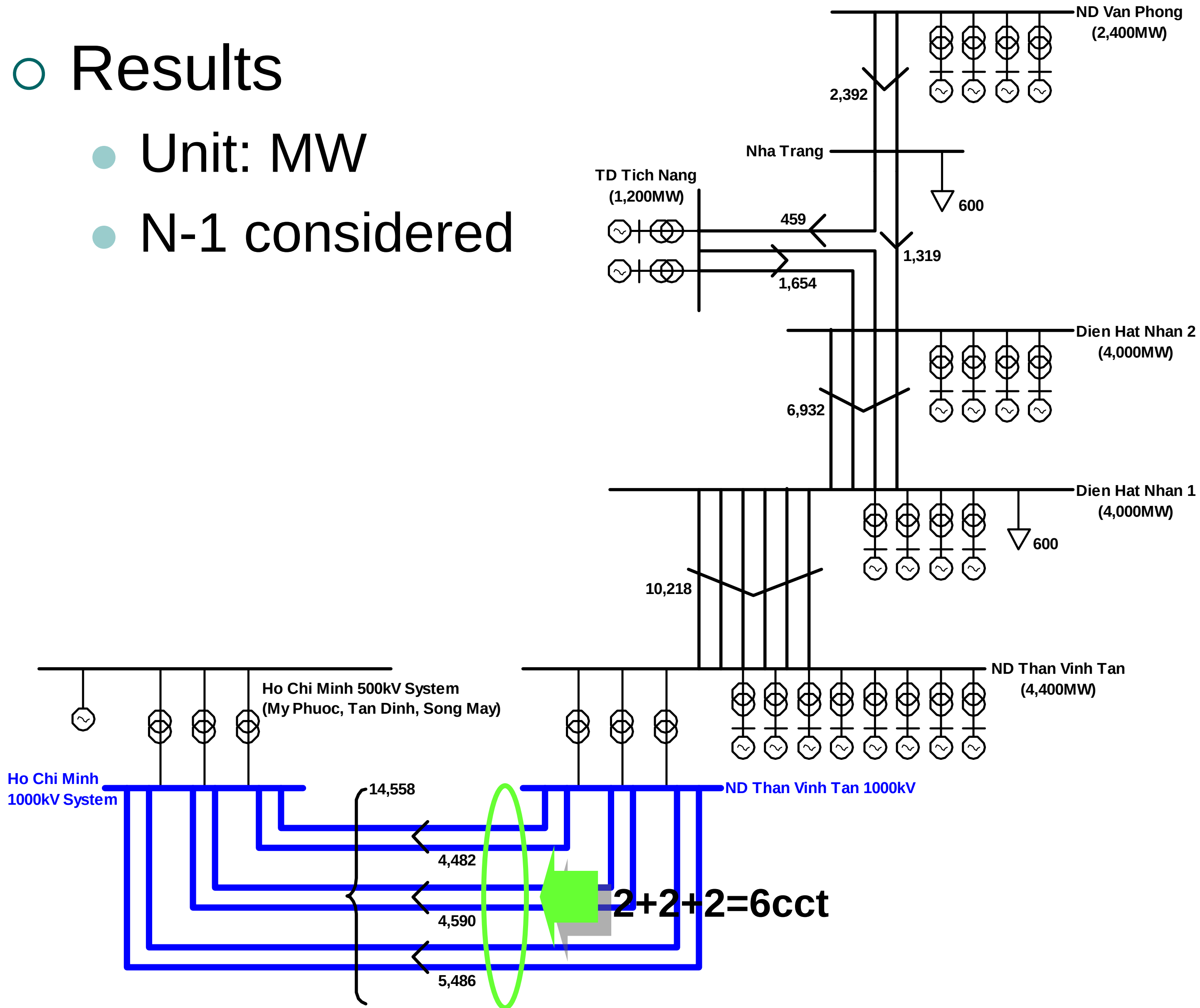
Stability Analysis
- System Configuration #1

- Analysis Result
  - **Unstable**



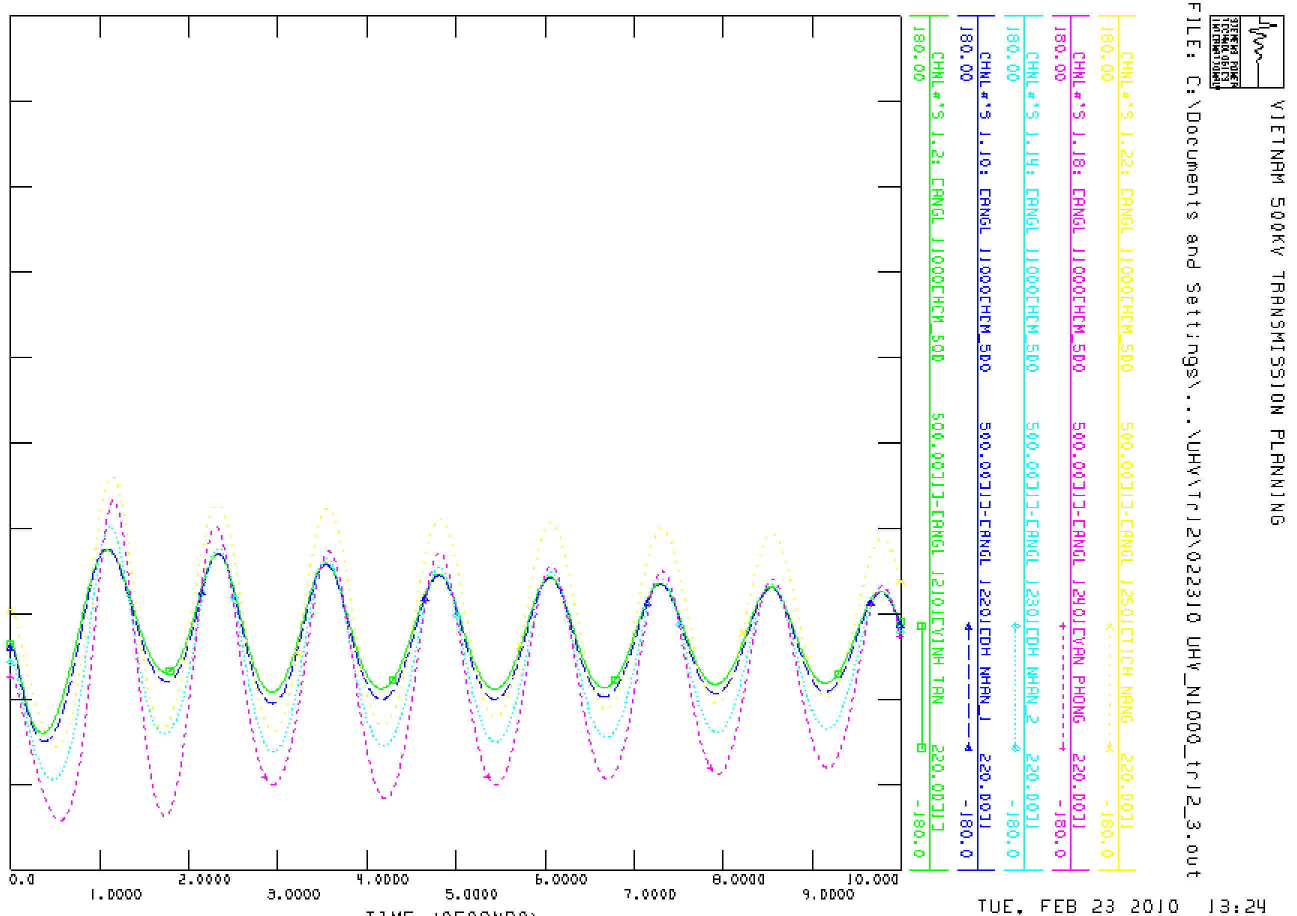
Stability Analysis
- System Configuration #2

- Results
  - Unit: MW
  - N-1 considered

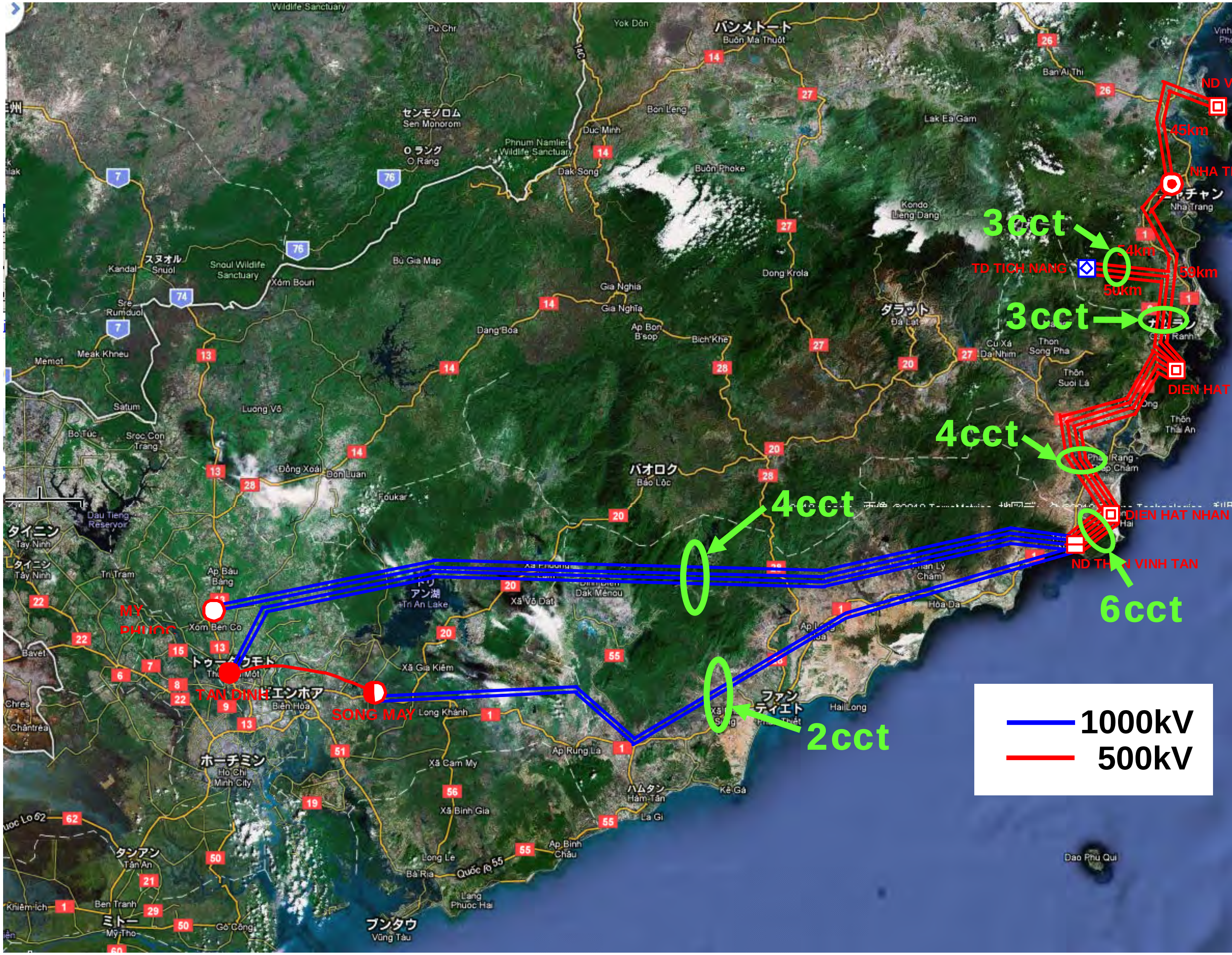


Stability Analysis
- System Configuration #2

- Analysis Result
  - **Stable**



Modified System Plan consisted 1000kV and 500kV Lines



Number of Circuits Required

- Results

Transmission Line		Number of Circuits		
From	To	Original Plan	Modified Plan	Difference
ND Van Phong	Nha Trang	2	2	0
Nha Trang	TD Tich Nang	1	1	0
Nha Trang	Dien Hat Nhan 2	1	1	0
TD Tich Nang	Dien Hat Nhan 2	1	2	**+1**
Dien Hat Nhan 1	Dien Hat Nhan 2	2	4	**+2**
Dien Hat Nhan 1	ND Than Vinh Tan	2	6	**+4**
Dien Hat Nhan 1	Ho Chi Minh (My Phuoc)	2	**2 (UHV)**	0
Dien Hat Nhan 1	Ho Chi Minh (Tan Dinh)	2	**2 (UHV)**	0
ND Than Vinh Tan	Ho Chi Minh (Song May)	4	**2 (UHV)**	**-2**

Transmission Line Loss

Voltage	500kV		UHV		
Num. of cct	11	**12**	3	5	**6**
P loss (MW)	684.57	**641.11**	376.52	308.85	**290.5**
Q loss (MVAR)	8,685.78	**8,193.19**	11,345.81	9,098.09	**8,500.52**
Stability	△	**OK**	NG	NG	**OK**

- Calculation Condition
  - P loss difference: 350.61MW (=641.11-290.50)
  - Annual load factor: 0.75
  - Loss factor: 0.61875
  - Long-term marginal cost: 0.0407US$/kWh
  - Project life time: 30years
  - Discount rate: 7%
- Annual Energy Loss
  - 1,900,394 MWh/year
  - US$77.3million/year
- Transmission Line Loss over the Project Life Time (Difference)
  - US$1,027million

Other Issues to be considered (1)

- Application of large size conductors
  - ACSR330x4 →ACSR610x4, ACSR810x4
- Increase in the number of conductors per bundle
  - 6-bundle, 8-bundle, …
- Application of series capacitor
  - Sub-synchronous resonance (SSR) problem
- Application of HVDC
- Application of PSS for stability improvement

Other Issues to be considered (2)

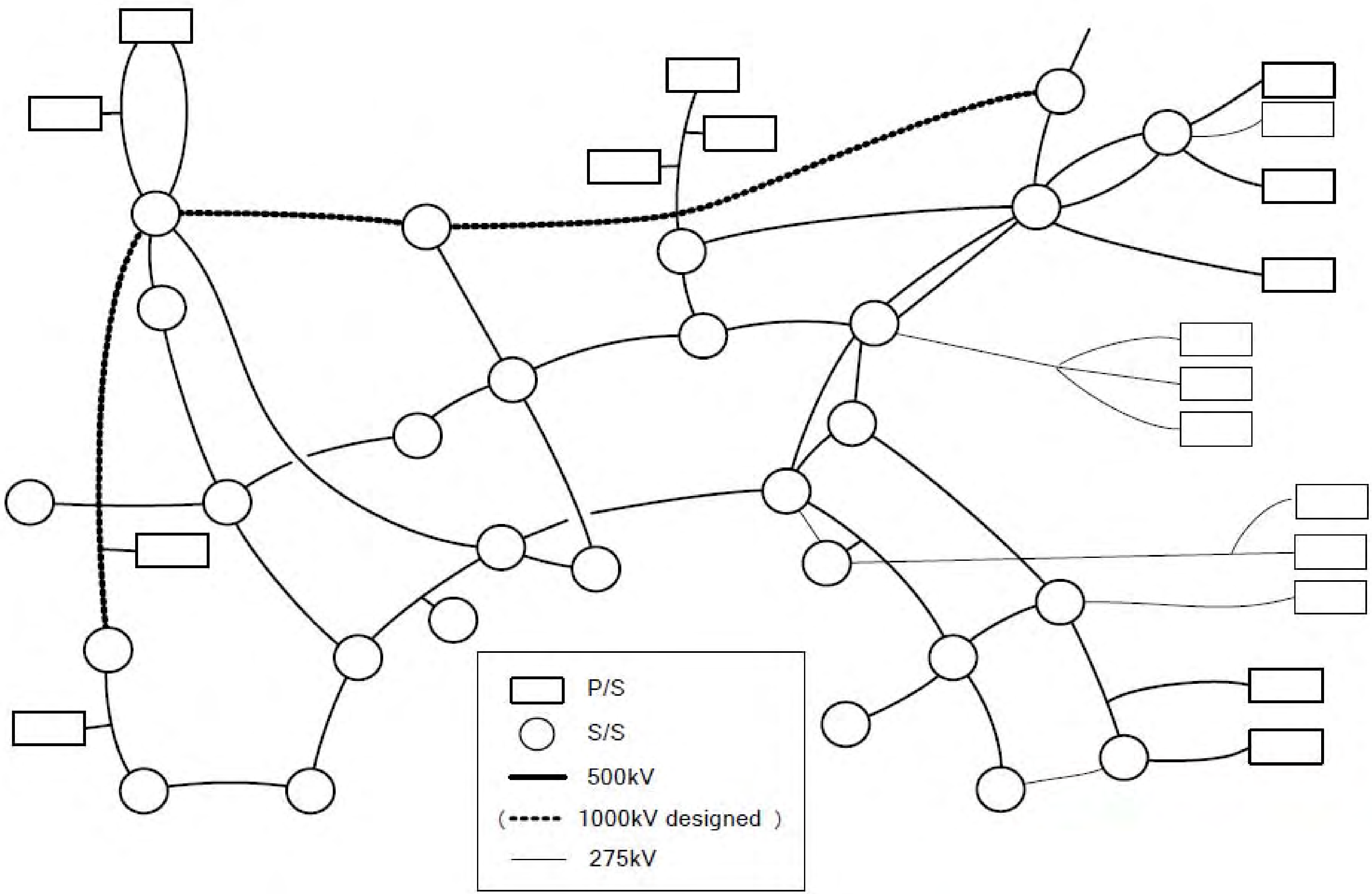
- Cost estimation
  - Construction cost
    - Transmission line
    - Substation
      - Transformer
      - GIS
  - Land acquisition cost
  - Compensation for land beneath the T/L
  - …

Fault Currents at Generation Sites

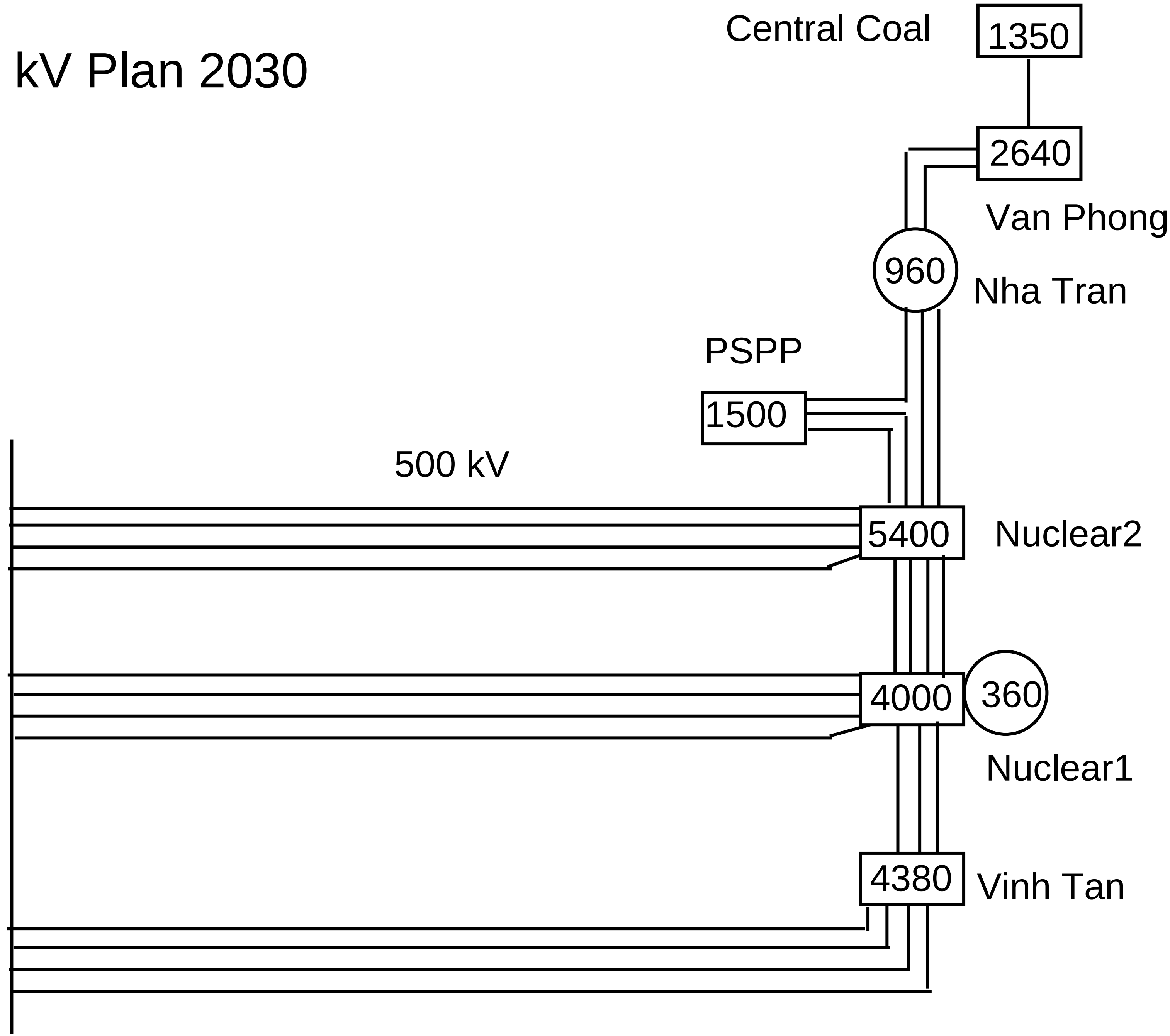
3rd June 2010

Hanoi

Bulk Power Transmission System

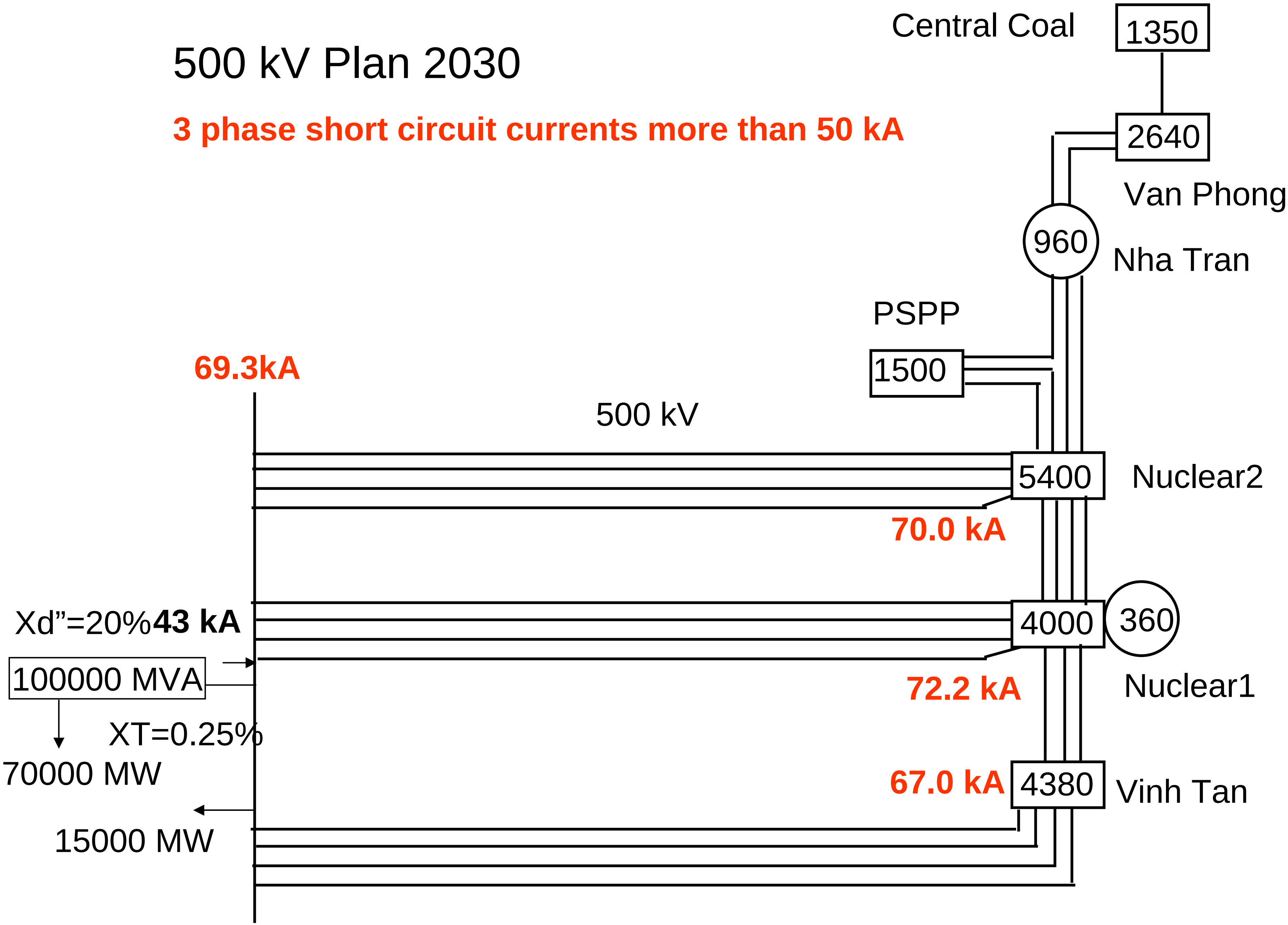


500 kV Plan 2030

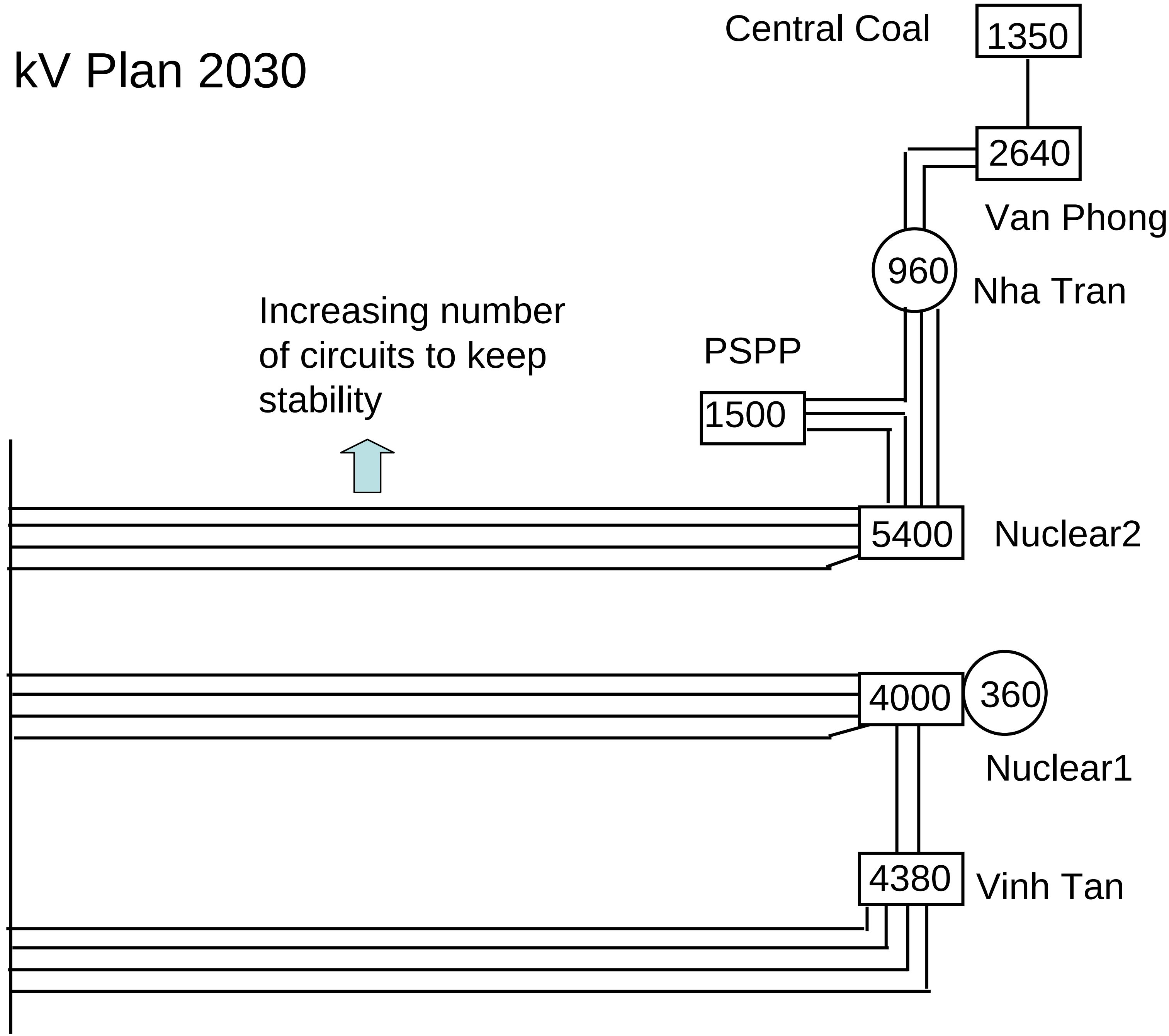


500 kV Plan 2030

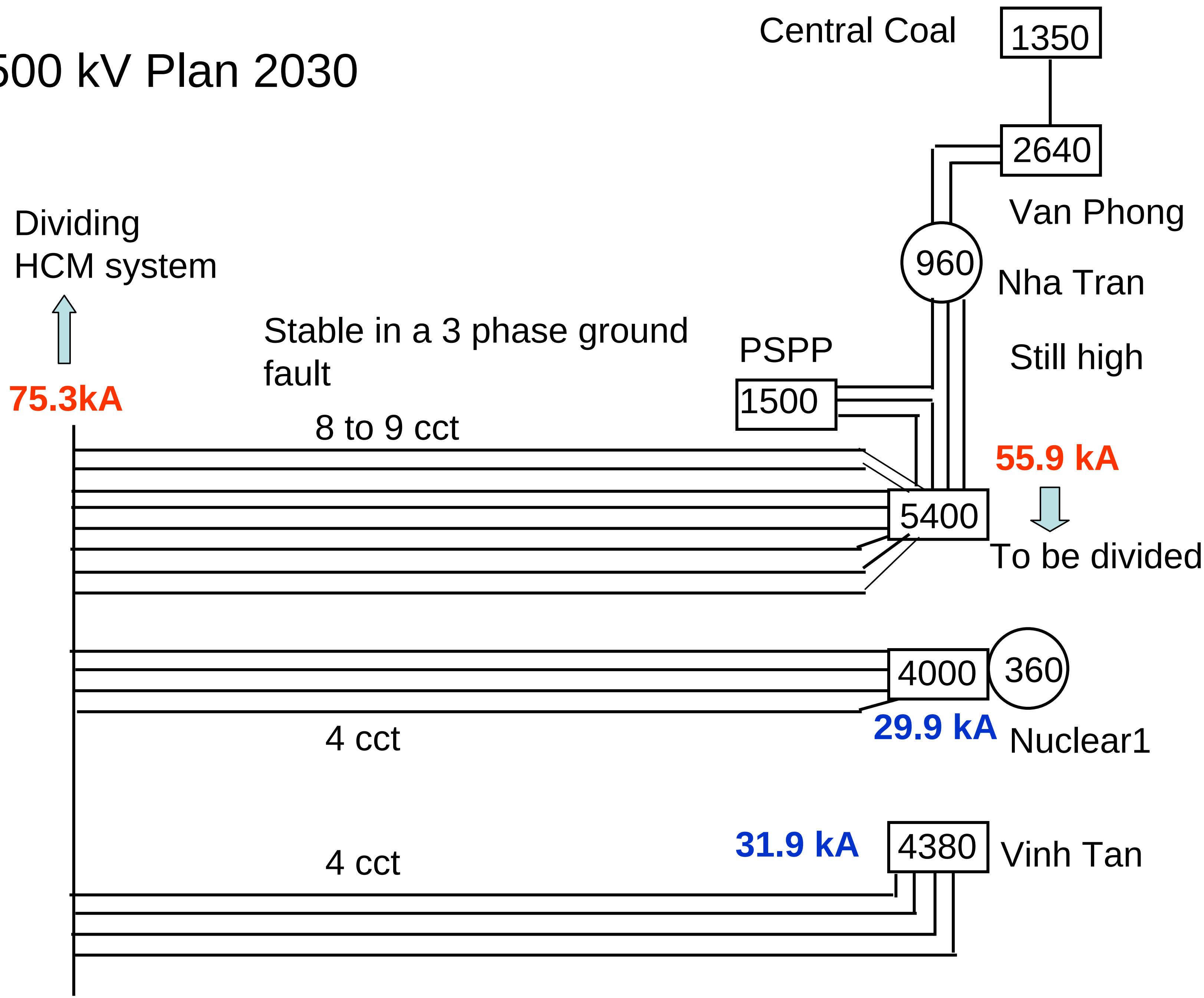
3 phase short circuit currents more than 50 kA



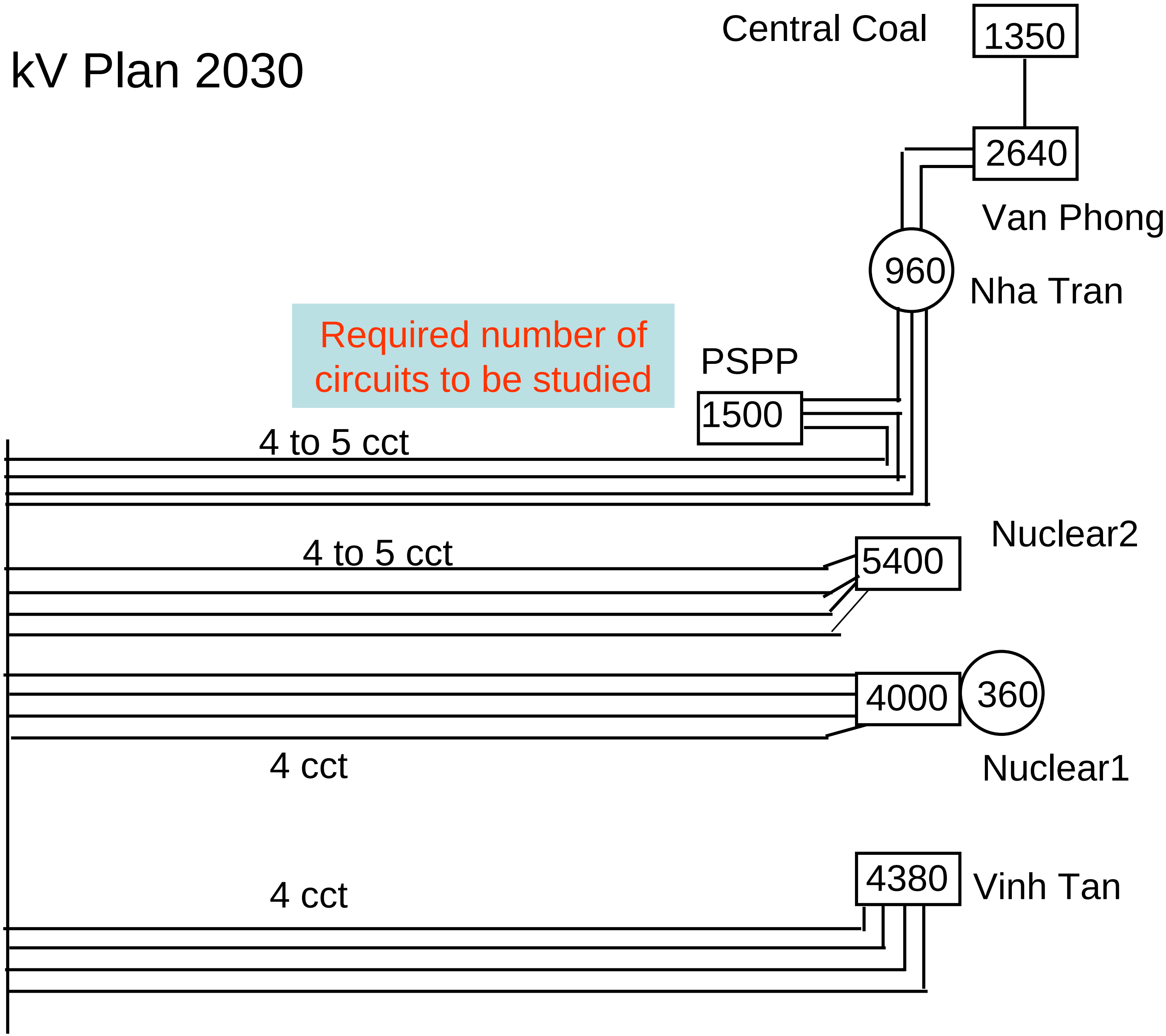
500 kV Plan 2030



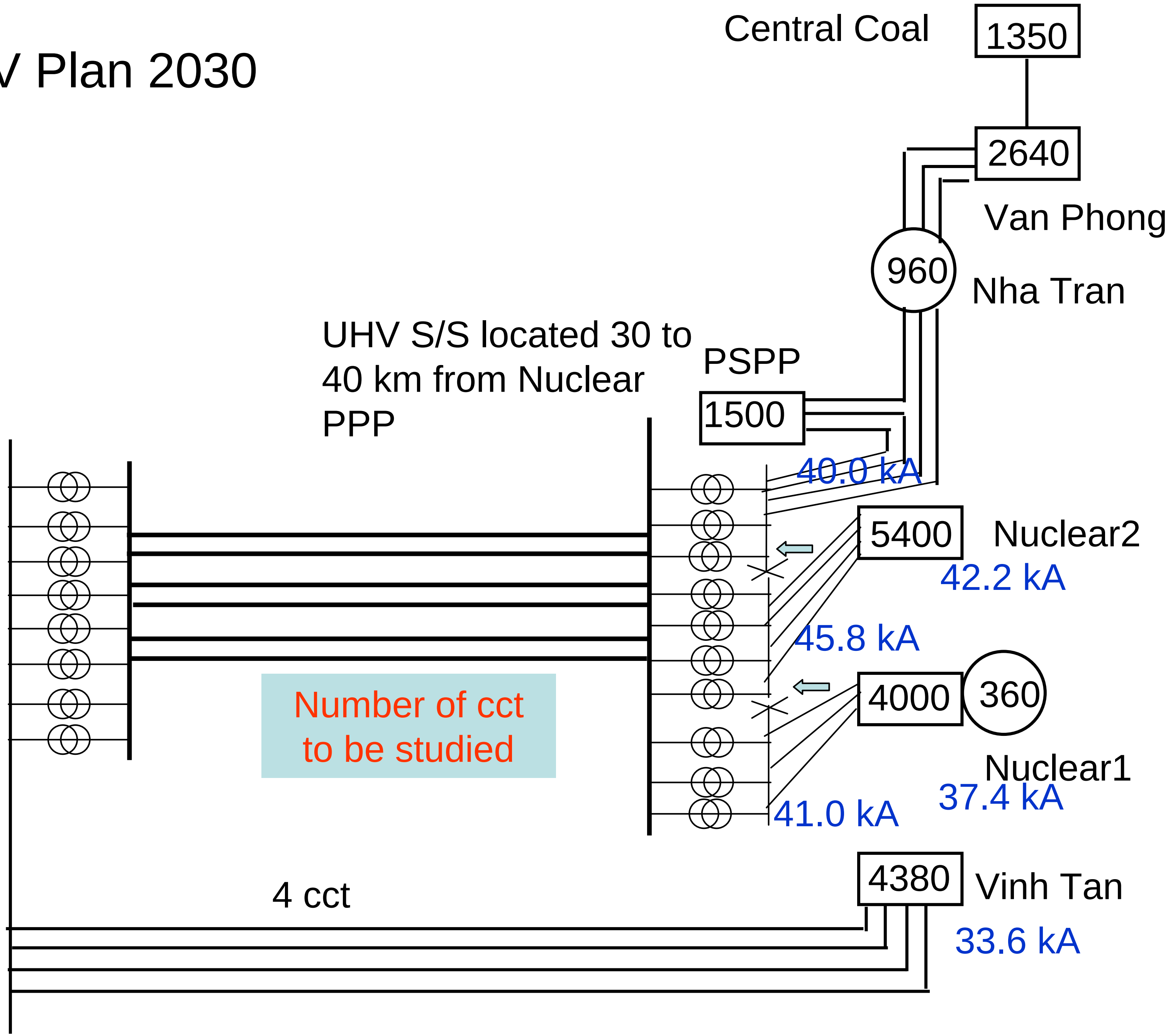
500 kV Plan 2030



500 kV Plan 2030



UHV Plan 2030



- Nuclear2, Nuclrea1 and Vinh Than should be in separate operation due to large fault currents.
- The number of required circuits will be studied.
  - 500kV
  - UHV
  - To keep stability and fault current levels
  - Cost Comparison including losses

•Next week

Comparison of 500 kV and UHV system from South East Area in Vietnam

- in consideration with power stations delayed, UHV cost or loss value increasing

June 14 2010

TEPCO/JICA TA Team

Power Generation to be Transmitted to Ho Chi Min City

Unit: MW

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Van Phong #1	660	660	660	660	660	660	660	660	660	660	660	660	660	660
Van Phong #2		660	660	660	660	660	660	660	660	660	660	660	660	660
Van Phong #3		660	660	660	660	660	660	660	660	660	660	660	660	660
Van Phong #4			660	660	660	660	660	660	660	660	660	660	660	660
Pump Storage PP		300	900	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
From Central Area*							75	75	75	225	300	540	705	870
Nha Trang Load	-320	-360	-400	-480	-480	-520	-560	-600	-680	-720	-760	-840	-920	-960
Nuclear PP #1				1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Nuclear PP #2					1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Nuclear PP #3								1,000	1,000	1,000	1,000	1,000	1,000	1,000
Nuclear PP #4									1,000	1,000	1,000	1,000	1,000	1,000
Nuclear PP #5											1,350	1,350	1,350	1,350
Nuclear PP #6												1,350	1,350	1,350
Nuclear PP #7													1,350	1,350
Nuclear PP #8														1,350
Total	340	1,920	3,140	4,660	5,660	5,620	5,655	6,615	7,535	7,645	9,030	10,540	11,975	13,450

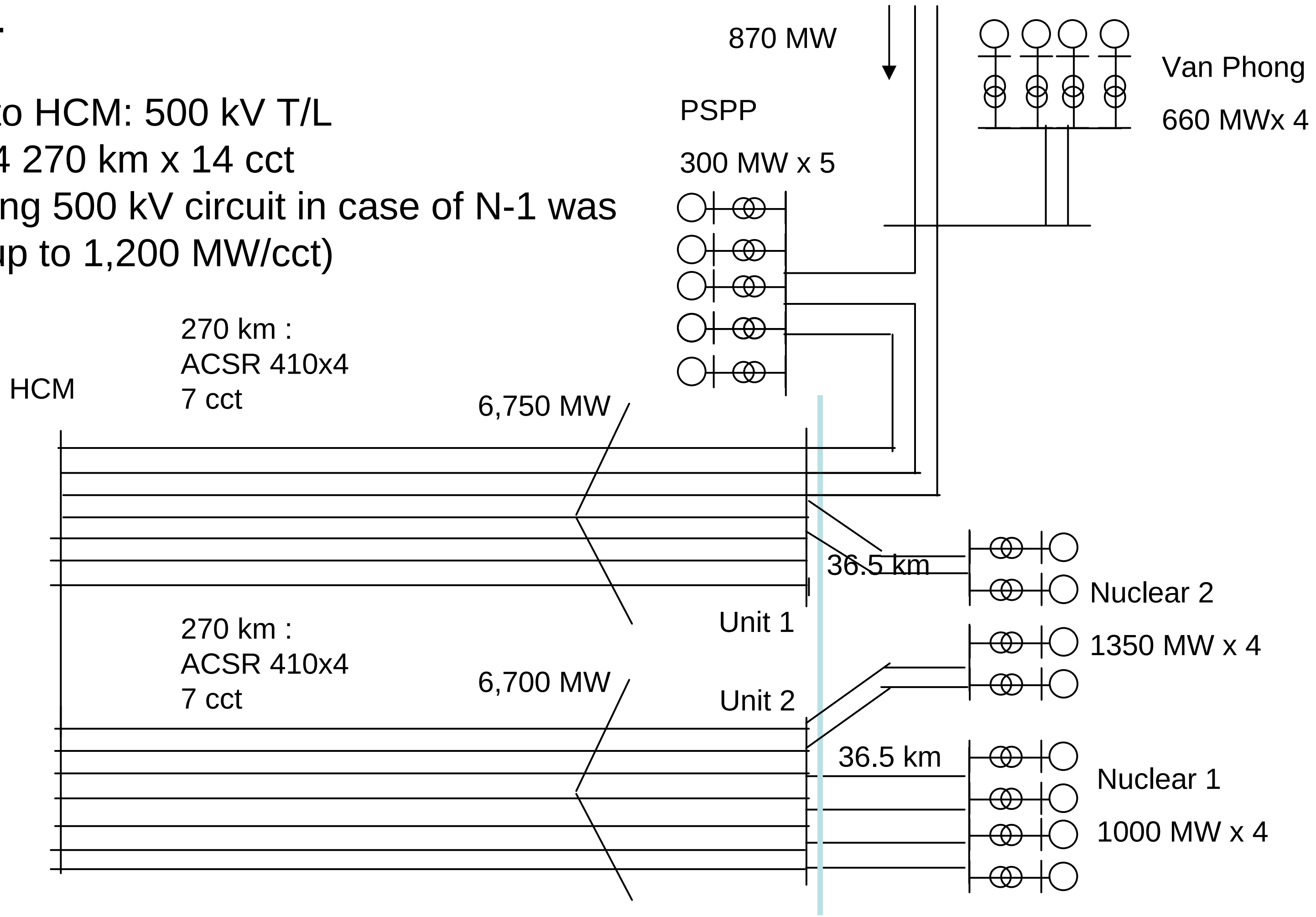
- Vinh Tan Coal Thermal Power Station is excluded because the transmission line already decided.
- All the gen. with full outputs except for ¼ of Coal Central Generation from Central Area
- Ninh Thuan Load assumed 0. Nha Trang Load assumed 80% peak

500 kV Option in 2030

- Generation Side have to be divided into 2 or 3 Units in consideration of both 3 phase short circuit current and 1 phase ground fault.

- Generation Side to HCM: 500 kV T/L
    - ACSR 410x4 270 km x 14 cct

(Load on a remaining 500 kV circuit in case of N-1 was assumed allowed up to 1,200 MW/cct)

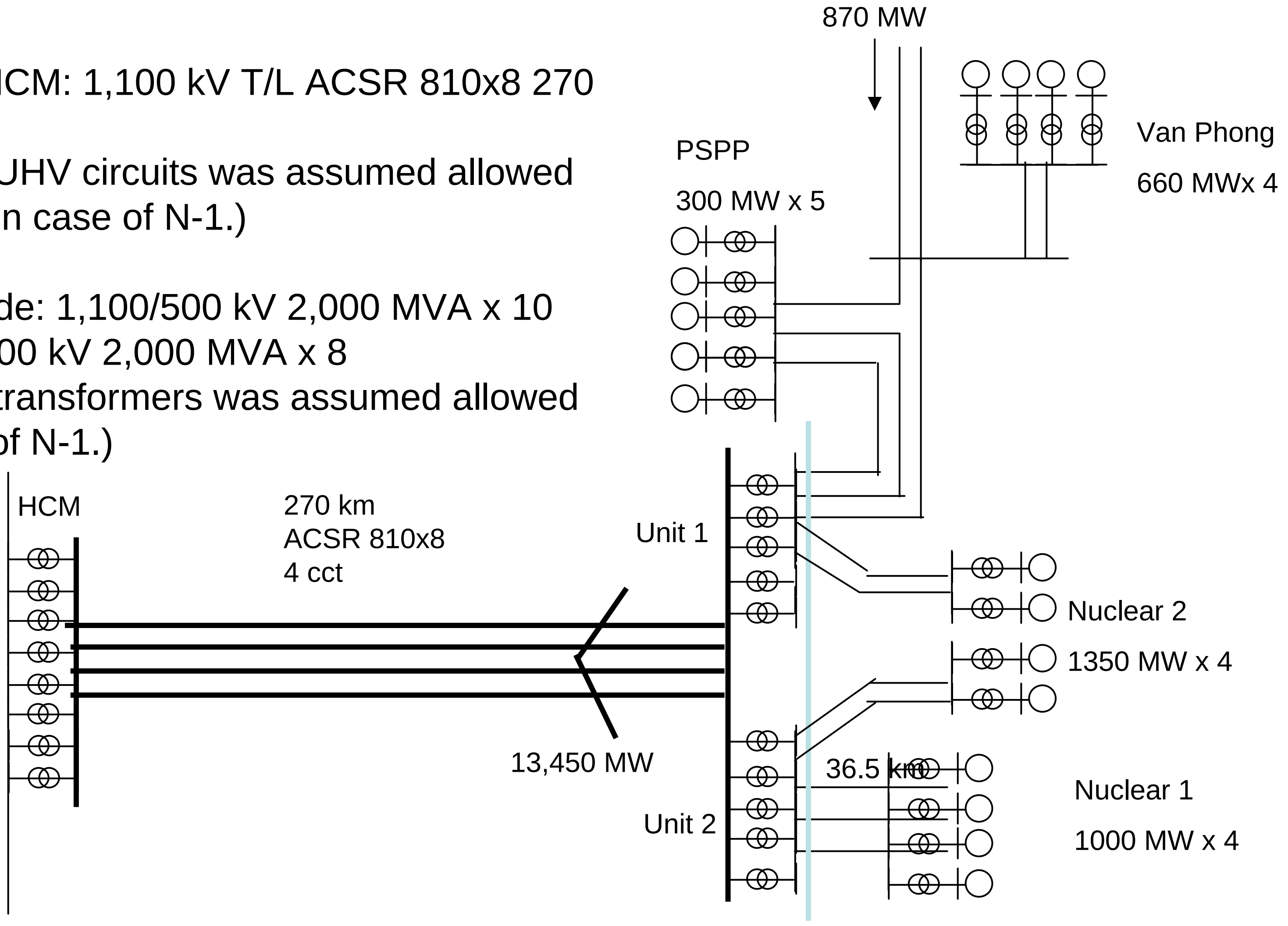


UHV Option in 2030

• Generation Side have to be divided into 2 or 3 Units in consideration of both 3 phase short circuit current and 1 phase ground fault.

•Generation Side - HCM: 1,100 kV T/L ACSR 810x8 270 km x 4 cct
(Load on remaining UHV circuits was assumed allowed up to 4,500 MW/cct in case of N-1.)

• S/S Generation Side: 1,100/500 kV 2,000 MVA x 10
• S/S HCM: 1,100/500 kV 2,000 MVA x 8
(Load on remaining transformers was assumed allowed up to 120% in case of N-1.)



Cost of Facilities

500 kV T/L in Vietnam	**0.5**	**million USD/km/cct**
UHV T/L in Vietnam	**1.25**	**million USD/km/cct**
UHV S/S in Vietnam	**0.0406**	**million USD/MVA**

Loss Values

Loss Factor	**0.8**	
Unit Cost of Loss	**0.08**	**USD/kWh**

Others

O&M	**2%**	
RoW for 500 kV in Vietnam	**0.105**	**million USD/cct/km**
RoW for UHV in Vietnam	**0.189**	**million USD/cct/km**
Discount Rate	**9%**	

Transmission Capacity per circuit

500 kV	**1,200**	**MW**
1,100 kV	**4,500**	**MW**

Systems in 2017 to 2051 were evaluated on the condition that from 2031 the same values kept as in 2030 up to 2051.

Result of Base Case

	500 kV	UHV
Loss	1,305	390
RoW	264	226
Investment + OM	1,531	2,415
Total Cost	3,100	3,031
Ratio of Total Cost	100%	98%
NPV Investment + OM for 5 years (mUSD)	962	1,596

Nuclear I 2023 & NII 2027

	500 kV	UHV
Loss	1,212	357
RoW	243	211
Investment + OM	1,406	2,263
Total Cost	2,861	2,832
Ratio of Total Cost	100%	99%
NPV Investment + OM for 5 years (mUSD)	654	1,195

Nuclear I 2025 & NII 2027

	500 kV	UHV
Loss	1,162	339
RoW	232	202
Investment + OM	1,340	2,181
Total Cost	2,733	2,722
Ratio of Total Cost	100%	100%
NPV Investment + OM for 5 years (mUSD)	654	1,195

Nuclear I 2023 & NII 2030

	500 kV	UHV
Loss	1,099	322
RoW	233	207
Investment + OM	1,350	2,181
Total Cost	2,682	2,710
Ratio of Total Cost	100%	101%
NPV Investment + OM for 5 years (mUSD)	654	1,195

Nuclear I 2025 & NII 2032

	500 kV	UHV
Loss	988	285
RoW	217	197
Investment + OM	1,253	2,055
Total Cost	2,458	2,538
Ratio of Total Cost	100%	103%
NPV Investment + OM for 5 years (mUSD)	654	1,195

Raising up Investment of UHV to 10%

	500 kV	UHV
Loss	1,305	390
RoW	264	226
Investment + OM	1,531	2,657
Total Cost	3,100	3,273
Ratio of Total Cost	100%	106%
NPV Investment + OM for 5 years (mUSD)	962	1,755

Loss value increased 2 % a year up to 2030

	500 kV	UHV
Loss	1,612	483
RoW	264	226
Investment + OM	1,531	2,415
Total Cost	3,407	3,125
Ratio of Total Cost	100%	92%
NPV Investment + OM for 5 years (mUSD)	962	1,596

Summary of Sensitivity to Nuclear P/S Delay, UHV Cost or Loss Value Increasing

Commissioning year of Nuclear I	Commissioning year of Nuclear II	Annual Growth Ratio of Unit Cost of Loss	Increase in cost of UHV	500 kV	UHV
2020	2027	2%	0%	100%	92%
2020	2027	0%	0%	100%	98%
2023	2027	0%	0%	100%	99%
2025	2027	0%	0%	100%	100%
2023	2030	0%	0%	100%	101%
2025	2032	0%	0%	100%	103%
2020	2027	0%	10%	100%	106%

- If loss value becomes higher, UHV take much advantages.
- When NI and NII delayed 3 years, the difference of cost between 500 kV and UHV would not be so large.
- If the cost of UHV is increased by 10%, the difference of the cost between 500 kV and UHV would be increase by 6%.

Summary of Compariosn of 500 kV and UHV

The values shown in the table were evaluated in the base case.

	500 kV	UHV
Number of circuit (Number in 2030)	Large 14	Small 4
Total Cost	Almost same as UHV	Almost same as 500 kV
Investment (Initial 5 years)	Small 1,531 million USD (962 million USD)	Large 2,415 million USD (1,596 million USD)
System Loss	Large 1,305 million USD	Small 390 million USD

Ref. EXCEL DATA

Data

T/L UHV/500 in Japan	2.5		
500 kV substation in Vietnam (2x600MVA+1x250MVA (220/110 kV			
	32.2	million USD	
500 kV S/S in Vietnam	0.024	million USD/MVA	
500kV S/S in Japan	Share	Ratio in kVA Unit Price 500kV/UHV	
Civil	0.13	1.16	
Equipment	0.87	1.97	
Total	1	1.86	
500 kV S/S in Vietnam	Share	Ratio in kVA Unit Price 500kV/UHV	
Civil	0.342	0.395	
Equipment	0.474	0.932	
Others	0.093	0.173	
Reserve	0.091	0.169	
Total	1	1.669	
SS UHV/500 in Japan	1.669		
RoW D cct tower	3,000	million VND/km	
RoW S cct tower	2,000	million VND/km	
Exchange Rate	19,050	VND/USD	
500kV RoW in Japan	21.7	m	
UHV RoW in Japan	39	m	
RoW UHV/500kV per circuit n Japan			1.797

Line resistance

degree Celsius	20	90							
	ohm/km		No.	ohm/km/cct	MVA	pu/km/cct	**kV**	**km**	**pu/cct**
ACSR 810	0.0356	0.045767	8	0.0057209	100	2.2884E-06	**500**	**270**	**0.000617859**
ACSR 810	0.0356	0.045767	8	0.0057209	100	4.728E-07	**1,100**	**270**	**0.000127657**
ACSR 410 (Drake)	0.07167	0.092139	4	0.0230347	100	9.2139E-06	**500**	**270**	**0.002487752**

1,100/500 kV Transformer winding loss ratio

0.20%

Base Case (Nuclear I 2020 & NII 2027)

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	6	7	7	7
No. cct Gen. Side-HCM Uniit2		0	0	0	2	3	3	3	4	5	5	5	5	6	7
Loss (MW)		2	38	76	98	123	121	123	149	175	180	228	286	339	397
Loss (mUSD/Y)		1	21	42	55	69	68	69	84	98	101	128	160	190	222
NPV Loss (mUSD)	1,305	1	19	36	42	49	44	41	46	49	46	54	62	68	73
ROW (mUSD/Y)		57	28	28	85	28	0	0	28	28	0	28	28	28	28
NPV ROW (mUSD)	264	57	26	24	66	20	0	0	16	14	0	12	11	10	9
Investment Gen. Side-HCM Uniit1 (mUSD		270	135	135	135	0	0	0	0	0	0	135	135	0	0
Investment Gen. Side-HCM Uniit2 (mUSD		0	0	0	270	135	0	0	135	135	0	0	0	135	135
OM (mUSD)		5	8	11	14	19	22	22	22	24	27	30	32	32	35
NPV Investment + OM (mUSD	1,531	275	131	123	323	109	14	13	86	80	12	70	65	60	55
NPV Total (mUSD)	3,100	333	177	182	431	178	58	54	147	143	59	135	138	137	137
	100%														
UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	16,000	16,000	16,000	16,000	20,000	20,000	20,000	26,000	28,000	32,000	36,000
No. cct U-design Gen. Side -HCM		2	2	2	3	3	3	3	3	3	3	4	4	4	4
Loss (MW)		0	7	16	25	37	36	37	45	58	60	63	84	101	122
Loss (mUSD/Y)		0	4	9	14	21	20	20	25	32	33	35	47	57	68
NPV Loss (mUSD)	390	0	4	7	11	15	13	12	14	16	15	15	18	20	22
ROW (mUSD/Y)		142	0	0	71	0	0	0	0	0	0	71	0	0	0
NPV ROW (mUSD)	226	142	0	0	55	0	0	0	0	0	0	30	0	0	0
Investment UHV S/S (mUSD)		0	324	162	162	0	0	0	162	0	0	243	81	162	162
Invesetment UHV TL Gen. Side-HCM (mU		675	0	0	338	0	0	0	0	0	0	338	0	0	0
OM (mUSD)		14	20	23	33	33	33	33	36	36	36	48	50	53	56
NPV Investment + OM (mUSD	2,415	689	316	156	412	24	22	20	109	18	17	266	51	77	71
NPV Total (mUSD)	3,031	830	320	164	477	38	35	32	122	35	32	311	69	97	93
	98%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	962
UHV	1,596

NI 2023 & NII 2027

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	6	7	7	7
No. cct Gen. Side-HCM Uniit2		0	0	0	0	0	0	2	3	3	3	4	5	6	7
Loss (MW)		2	38	76	82	82	80	97	121	118	123	199	286	339	397
Loss (mUSD/Y)		1	21	42	46	46	45	55	68	66	69	111	160	190	222
NPV Loss (mUSD)	1,212	1	19	36	36	33	29	33	37	33	32	47	62	68	73
ROW (mUSD/Y)		57	28	28	28	0	0	57	28	0	0	57	57	28	28
NPV ROW (mUSD)	243	57	26	24	22	0	0	34	16	0	0	24	22	10	9
Investment Gen. Side-HCM Uniit1 (mUSI		270	135	135	135	0	0	0	0	0	0	135	135	0	0
Investment Gen. Side-HCM Uniit2 (mUSI		0	0	0	0	0	0	270	135	0	0	135	135	135	135
OM (mUSD)		5	8	11	14	14	14	14	19	22	22	24	30	32	35
NPV Investment + OM (mUSI	1,406	275	131	123	115	10	9	169	84	11	10	124	116	60	55
NPV Total (mUSD)	2,861	333	177	182	172	42	38	235	137	44	42	195	200	137	137
	100%														
UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	12,000	12,000	12,000	16,000	16,000	16,000	16,000	24,000	28,000	32,000	36,000
No. cct U-design Gen. Side -HCM		2	2	2	2	2	2	3	3	3	3	3	4	4	4
Loss (MW)		0	7	16	22	22	21	25	36	35	36	61	84	101	122
Loss (mUSD/Y)		0	4	9	12	12	12	14	20	20	20	34	47	57	68
NPV Loss (mUSD)	357	0	4	7	9	9	8	8	11	10	9	15	18	20	22
ROW (mUSD/Y)		142	0	0	0	0	0	71	0	0	0	0	71	0	0
NPV ROW (mUSD)	211	142	0	0	0	0	0	42	0	0	0	0	27	0	0
Investment UHV S/S (mUSD)		0	324	162	0	0	0	162	0	0	0	324	162	162	162
Invesetment UHV TL Gen. Side-HCM (mU		675	0	0	0	0	0	338	0	0	0	0	338	0	0
OM (mUSD)		14	20	23	23	23	23	33	33	33	33	40	50	53	56
NPV Investment + OM (mUSI	2,263	689	316	156	18	16	15	318	18	17	15	154	213	77	71
NPV Total (mUSD)	2,832	830	320	164	27	25	23	368	29	27	25	168	259	97	93
	99%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	654
UHV	1,195

NI 2023 & NII 2030

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	5	5	5	6
No. cct Gen. Side-HCM Uniit2		0	0	0	0	0	0	2	3	3	3	4	5	5	5
Loss (MW)		2	38	76	82	82	80	97	121	118	123	152	189	193	248
Loss (mUSD/Y)		1	21	42	46	46	45	55	68	66	69	85	106	108	139
NPV Loss (mUSD)	1,099	1	19	36	36	33	29	33	37	33	32	36	41	38	45
ROW (mUSD/Y)		57	28	28	28	0	0	57	28	0	0	28	28	0	28
NPV ROW (mUSD)	233	57	26	24	22	0	0	34	16	0	0	12	11	0	9
Investment Gen. Side-HCM Uniit1 (mUSI		270	135	135	135	0	0	0	0	0	0	0	0	0	135
Investment Gen. Side-HCM Uniit2 (mUSI		0	0	0	0	0	0	270	135	0	0	135	135	0	0
OM (mUSD)		5	8	11	14	14	14	14	19	22	22	22	24	27	30
NPV Investment + OM (mUSI	1,350	275	131	123	115	10	9	169	84	11	10	66	62	10	54
NPV Total (mUSD)	2,682	333	177	182	172	42	38	235	137	44	42	114	114	48	108
	100%														
UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	12,000	12,000	12,000	16,000	16,000	16,000	16,000	22,000	22,000	22,000	26,000
No. cct U-design Gen. Side -HCM		2	2	2	2	2	2	3	3	3	3	3	3	3	4
Loss (MW)		0	7	16	22	22	21	25	36	35	36	44	60	61	69
Loss (mUSD/Y)		0	4	9	12	12	12	14	20	20	20	25	34	34	38
NPV Loss (mUSD)	322	0	4	7	9	9	8	8	11	10	9	10	13	12	13
ROW (mUSD/Y)		142	0	0	0	0	0	71	0	0	0	0	0	0	71
NPV ROW (mUSD)	207	142	0	0	0	0	0	42	0	0	0	0	0	0	23
Investment UHV S/S (mUSD)		0	324	162	0	0	0	162	0	0	0	243	0	0	162
Invesetment UHV TL Gen. Side-HCM (ml		675	0	0	0	0	0	338	0	0	0	0	0	0	338
OM (mUSD)		14	20	23	23	23	23	33	33	33	33	38	38	38	48
NPV Investment + OM (mUSI	2,181	689	316	156	18	16	15	318	18	17	15	119	15	14	179
NPV Total (mUSD)	2,710	830	320	164	27	25	23	368	29	27	25	129	28	26	214
	101%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	654
UHV	1,195

NI 2025 & NII 2027

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	6	7	7	7
No. cct Gen. Side-HCM Uniit2		0	0	0	0	0	0	0	0	2	3	3	3	5	7
Loss (MW)		2	38	76	82	82	80	82	80	92	123	170	229	309	397
Loss (mUSD/Y)		1	21	42	46	46	45	46	45	52	69	96	128	173	222
NPV Loss (mUSD)	1,162	1	19	36	36	33	29	27	25	26	32	40	50	62	73
ROW (mUSD/Y)		57	28	28	28	0	0	0	0	57	28	28	28	57	57
NPV ROW (mUSD)	232	57	26	24	22	0	0	0	0	28	13	12	11	20	18
Investment Gen. Side-HCM Uniit1 (mUSI		270	135	135	135	0	0	0	0	0	0	135	135	0	0
Investment Gen. Side-HCM Uniit2 (mUSI		0	0	0	0	0	0	0	0	270	135	0	0	270	270
OM (mUSD)		5	8	11	14	14	14	14	14	14	19	24	27	27	32
NPV Investment + OM (mUSI	1,340	275	131	123	115	10	9	8	7	142	71	67	63	106	99
NPV Total (mUSD)	2,733	333	177	182	172	42	38	35	32	197	116	120	123	187	190
	100%														

UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	12,000	12,000	12,000	12,000	12,000	16,000	16,000	22,000	24,000	32,000	36,000
No. cct U-design Gen. Side -HCM		2	2	2	2	2	2	2	2	3	3	3	3	4	4
Loss (MW)		0	7	16	22	22	21	22	21	23	36	48	69	85	122
Loss (mUSD/Y)		0	4	9	12	12	12	12	12	13	20	27	39	48	68
NPV Loss (mUSD)	339	0	4	7	9	9	8	7	6	7	9	11	15	17	22
ROW (mUSD/Y)		142	0	0	0	0	0	0	0	71	0	0	0	71	0
NPV ROW (mUSD)	202	142	0	0	0	0	0	0	0	36	0	0	0	25	0
Investment UHV S/S (mUSD)		0	324	162	0	0	0	0	0	162	0	243	81	324	162
Invesetment UHV TL Gen. Side-HCM (mU		675	0	0	0	0	0	0	0	338	0	0	0	338	0
OM (mUSD)		14	20	23	23	23	23	23	23	33	33	38	40	53	56
NPV Investment + OM (mUSI	2,181	689	316	156	18	16	15	14	13	267	15	119	47	254	71
NPV Total (mUSD)	2,722	830	320	164	27	25	23	21	19	310	25	130	62	296	93
	100%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	654
UHV	1,195

NI 2025 & NII 2032

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	5	5	5	5
No. cct Gen. Side-HCM Uniit2		0	0	0	0	0	0	0	0	2	3	3	3	4	5
Loss (MW)		2	38	76	82	82	80	82	80	92	123	124	132	164	199
Loss (mUSD/Y)		1	21	42	46	46	45	46	45	52	69	70	74	92	112
NPV Loss (mUSD)	988	1	19	36	36	33	29	27	25	26	32	29	29	33	36
ROW (mUSD/Y)		57	28	28	28	0	0	0	0	57	28	0	0	28	28
NPV ROW (mUSD)	217	57	26	24	22	0	0	0	0	28	13	0	0	10	9
Investment Gen. Side-HCM Uniit1 (mUSI		270	135	135	135	0	0	0	0	0	0	0	0	0	0
Investment Gen. Side-HCM Uniit2 (mUSI		0	0	0	0	0	0	0	0	270	135	0	0	135	135
OM (mUSD)		5	8	11	14	14	14	14	14	14	19	22	22	22	24
NPV Investment + OM (mUSD	1,253	275	131	123	115	10	9	8	7	142	71	9	8	56	52
NPV Total (mUSD)	2,458	333	177	182	172	42	38	35	32	197	116	39	37	98	98
	100%														

UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	12,000	12,000	12,000	12,000	12,000	16,000	16,000	18,000	18,000	22,000	22,000
No. cct U-design Gen. Side -HCM		2	2	2	2	2	2	2	2	3	3	3	3	3	3
Loss (MW)		0	7	16	22	22	21	22	21	23	36	35	37	47	63
Loss (mUSD/Y)		0	4	9	12	12	12	12	12	13	20	20	21	26	36
NPV Loss (mUSD)	285	0	4	7	9	9	8	7	6	7	9	8	8	9	12
ROW (mUSD/Y)		142	0	0	0	0	0	0	0	71	0	0	0	0	0
NPV ROW (mUSD)	197	142	0	0	0	0	0	0	0	36	0	0	0	0	0
Investment UHV S/S (mUSD)		0	324	162	0	0	0	0	0	162	0	81	0	162	0
Invesetment UHV TL Gen. Side-HCM (mU		675	0	0	0	0	0	0	0	338	0	0	0	0	0
OM (mUSD)		14	20	23	23	23	23	23	23	33	33	35	35	38	38
NPV Investment + OM (mUSD	2,055	689	316	156	18	16	15	14	13	267	15	49	14	71	12
NPV Total (mUSD)	2,538	830	320	164	27	25	23	21	19	310	25	57	22	81	24
	103%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	654
UHV	1,195

UHV Cost +10%

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	6	7	7	7
No. cct Gen. Side-HCM Uniit2		0	0	0	2	3	3	3	4	5	5	5	5	6	7
Loss (MW)		2	38	76	98	123	121	123	149	175	180	228	286	339	397
Loss (mUSD/Y)		1	21	42	55	69	68	69	84	98	101	128	160	190	222
NPV Loss (mUSD)	1,305	1	19	36	42	49	44	41	46	49	46	54	62	68	73
ROW (mUSD/Y)		57	28	28	85	28	0	0	28	28	0	28	28	28	28
NPV ROW (mUSD)	264	57	26	24	66	20	0	0	16	14	0	12	11	10	9
Investment Gen. Side-HCM Uniit1 (mUSD		270	135	135	135	0	0	0	0	0	0	135	135	0	0
Investment Gen. Side-HCM Uniit2 (mUSD		0	0	0	270	135	0	0	135	135	0	0	0	135	135
OM (mUSD)		5	8	11	14	19	22	22	22	24	27	30	32	32	35
NPV Investment + OM (mUSD	1,531	275	131	123	323	109	14	13	86	80	12	70	65	60	55
NPV Total (mUSD)	3,100	333	177	182	431	178	58	54	147	143	59	135	138	137	137
	100%														

UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	16,000	16,000	16,000	16,000	20,000	20,000	20,000	26,000	28,000	32,000	36,000
No. cct U-design Gen. Side -HCM		2	2	2	3	3	3	3	3	3	3	4	4	4	4
Loss (MW)		0	7	16	25	37	36	37	45	58	60	63	84	101	122
Loss (mUSD/Y)		0	4	9	14	21	20	20	25	32	33	35	47	57	68
NPV Loss (mUSD)	390	0	4	7	11	15	13	12	14	16	15	15	18	20	22
ROW (mUSD/Y)		142	0	0	71	0	0	0	0	0	0	71	0	0	0
NPV ROW (mUSD)	226	142	0	0	55	0	0	0	0	0	0	30	0	0	0
Investment UHV S/S (mUSD)	10%	0	357	178	178	0	0	0	178	0	0	268	89	178	178
Invesetment UHV TL Gen. Si	10%	743	0	0	371	0	0	0	0	0	0	371	0	0	0
OM (mUSD)		15	22	26	37	37	37	37	40	40	40	53	55	58	62
NPV Investment + OM (mUSD	2,657	757	348	172	453	26	24	22	120	20	18	292	56	84	78
NPV Total (mUSD)	3,273	899	351	179	518	40	37	34	133	36	34	337	74	104	101
	106%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	962
UHV	1,755

Loss Cost +2% per year (up to 2003)

500 kV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
No. cct Gen. Side-HCM Uniit1		2	3	4	5	5	5	5	5	5	5	6	7	7	7
No. cct Gen. Side-HCM Uniit2		0	0	0	2	3	3	3	4	5	5	5	5	6	7
Loss (MW)		2	38	76	98	123	121	123	149	175	180	228	286	339	397
Loss (mUSD/Y)		1	22	44	58	75	75	78	96	115	121	156	199	241	288
NPV Loss (mUSD)	1,612	1	20	37	45	53	49	46	53	58	55	66	77	86	94
ROW (mUSD/Y)		57	28	28	85	28	0	0	28	28	0	28	28	28	28
NPV ROW (mUSD)	264	57	26	24	66	20	0	0	16	14	0	12	11	10	9
Investment Gen. Side-HCM Uniit1 (mUSI		270	135	135	135	0	0	0	0	0	0	135	135	0	0
Investment Gen. Side-HCM Uniit2 (mUSI		0	0	0	270	135	0	0	135	135	0	0	0	135	135
OM (mUSD)		5	8	11	14	19	22	22	22	24	27	30	32	32	35
NPV Investment + OM (mUSI	1,531	275	131	123	323	109	14	13	86	80	12	70	65	60	55
NPV Total (mUSD)	3,407	333	177	184	434	182	63	59	154	152	68	147	153	155	159
	100%														

UHV		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
UHV S/S (MVA)			8,000	12,000	16,000	16,000	16,000	16,000	20,000	20,000	20,000	26,000	28,000	32,000	36,000
No. cct U-design Gen. Side -HCM		2	2	2	3	3	3	3	3	3	3	4	4	4	4
Loss (MW)		0	7	16	25	37	36	37	45	58	60	63	84	101	122
Loss (mUSD/Y)		0	4	9	15	22	22	23	29	38	40	43	58	72	88
NPV Loss (mUSD)	483	0	4	8	11	16	15	14	16	19	18	18	23	26	29
ROW (mUSD/Y)		142	0	0	71	0	0	0	0	0	0	71	0	0	0
NPV ROW (mUSD)	226	142	0	0	55	0	0	0	0	0	0	30	0	0	0
Investment UHV S/S (mUSD)		0	324	162	162	0	0	0	162	0	0	243	81	162	162
Invesetment UHV TL Gen. Side-HCM (mU		675	0	0	338	0	0	0	0	0	0	338	0	0	0
OM (mUSD)		14	20	23	33	33	33	33	36	36	36	48	50	53	56
NPV Investment + OM (mUSI	2,415	689	316	156	412	24	22	20	109	18	17	266	51	77	71
NPV Total (mUSD)	3,125	830	320	164	478	39	36	34	124	37	35	314	73	102	100
	92%														

NPV Investment + OM for initial 5Y (mUSD)

500 kV	962
UHV	1,596

Thank you.

Appendix 1.B

Explanatory Materials
for Technical Assistance
on System Planning
(Ho Chi Minh City
Power Supply System)

JICA Technical Assistance for Power Development Plan 7 in Vietnam

System Planning in Ho Chi Minh City taking into account Fault Current Reduction

(Preliminary Study Results)

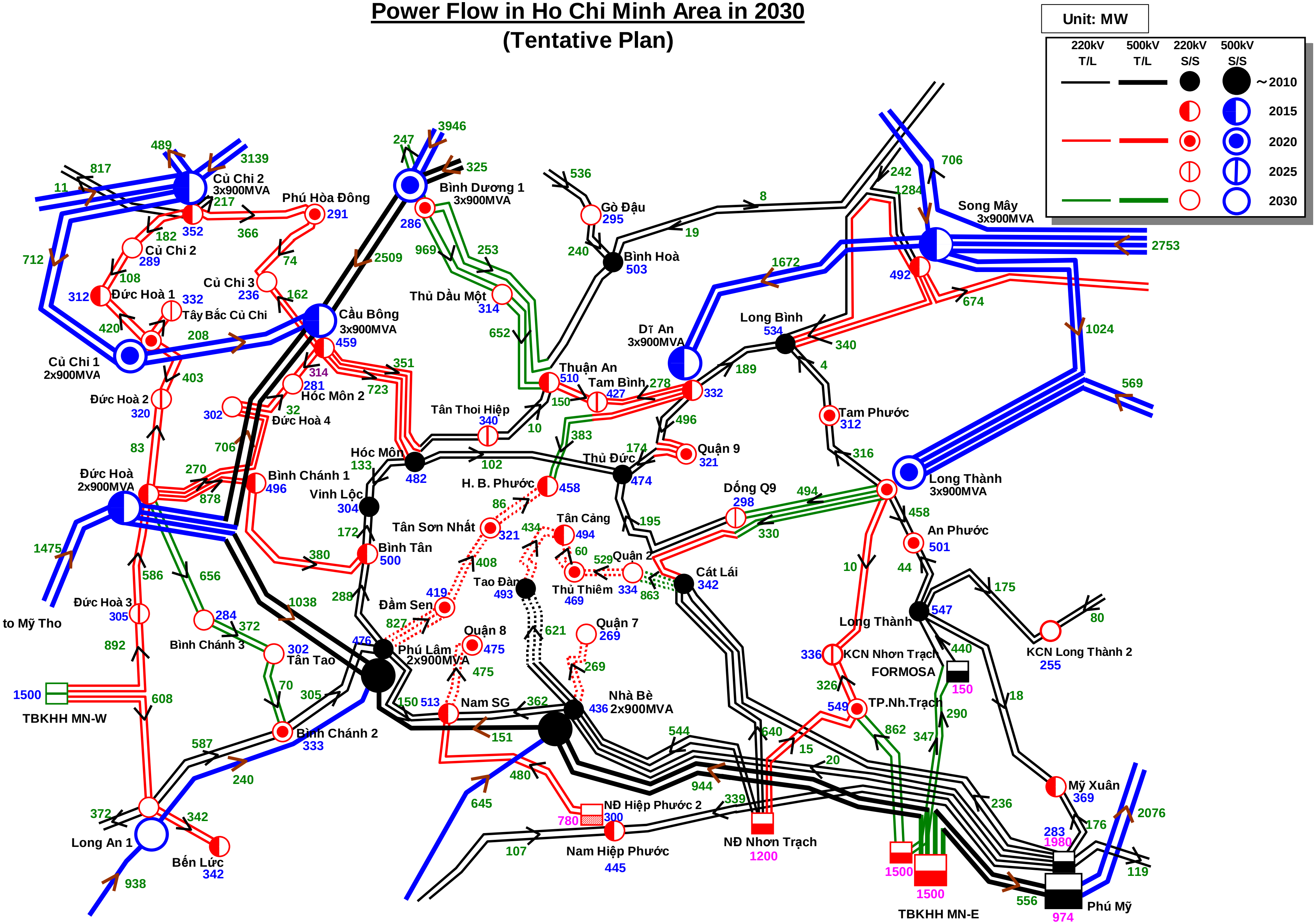
June 11th, 2010

JICA Technical Assistance Team

Power Flow Analysis

Power Flow in Ho Chi Minh Area in 2030

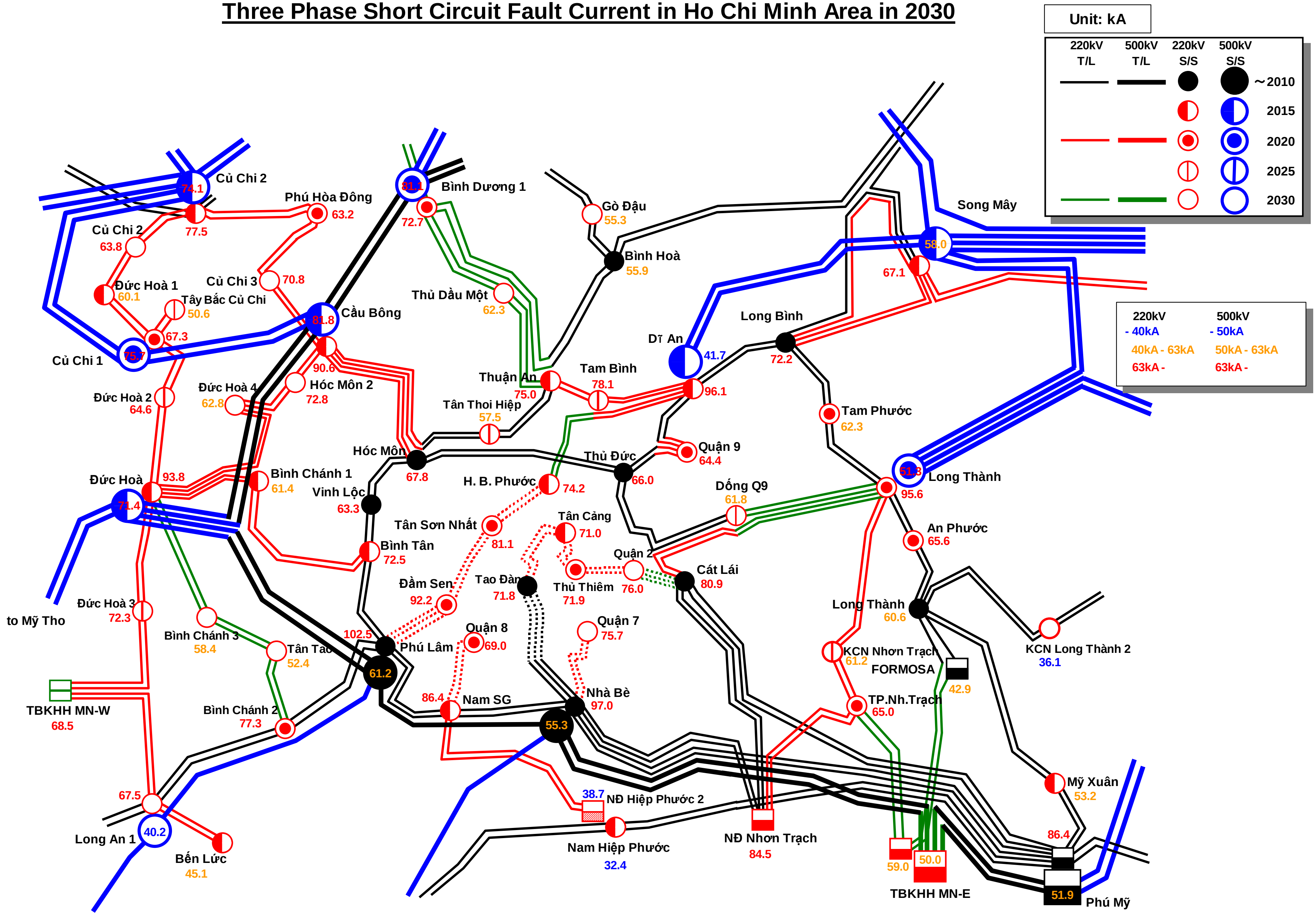
(Tentative Plan)



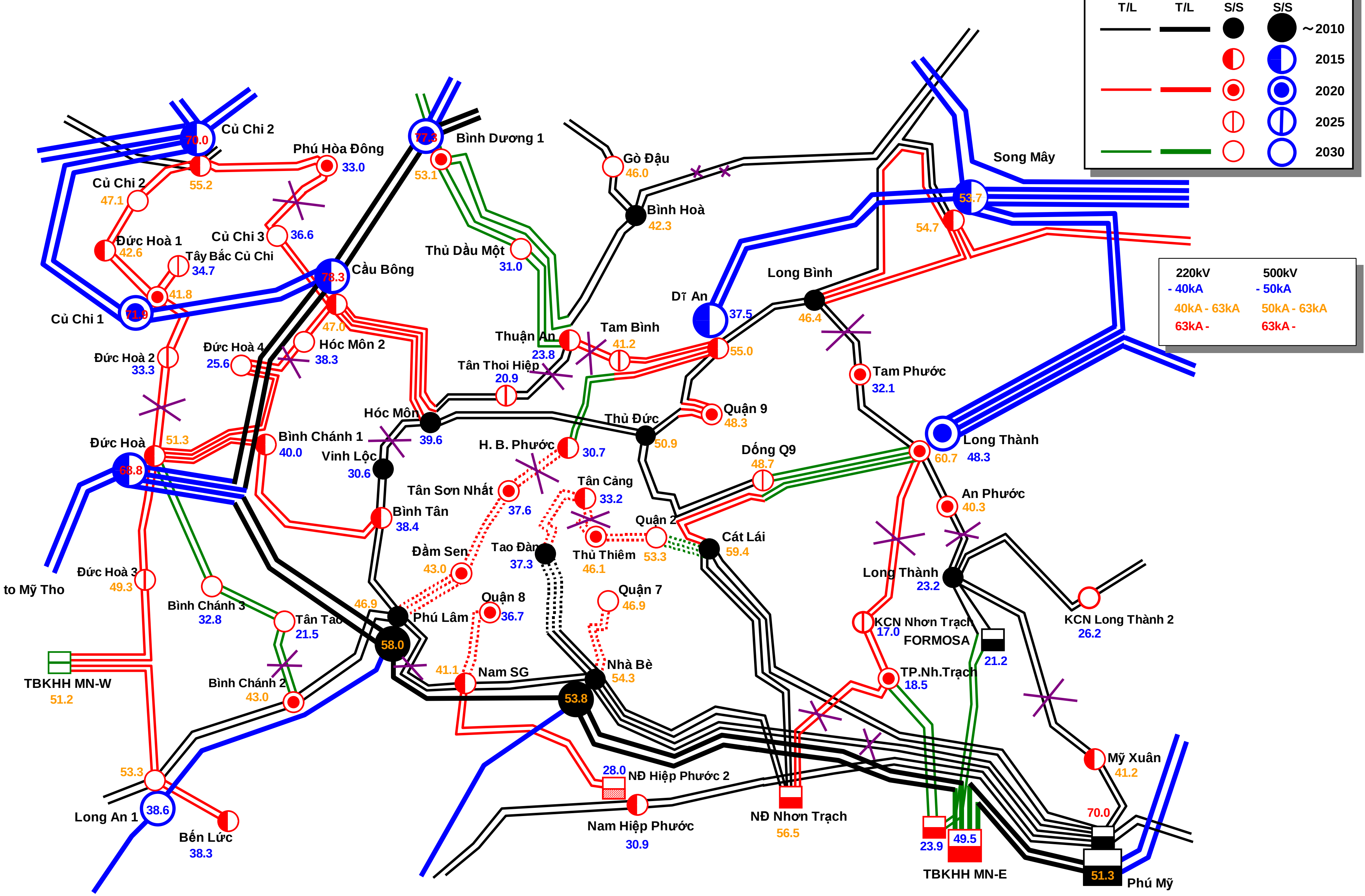
Fault Current (3LS) Analysis

- Allowable fault current level
  - 50kA (500kV)
  - 40kA (220kV)

Three Phase Short Circuit Fault Current in Ho Chi Minh Area in 2030



Three Phase Short Circuit Fault Current in Ho Chi Minh Area in 2030
(System separation for fault current reduction #1)



Reduction in Fault Current

- Separate sections to form sub-system groups
- Reference
  - TEPCO's 275kV system
- Other countermeasures
  - Split bus at the secondary side
  - Separate 500kV system in certain section
  - Application of fault current limiting equipment

End of Presentation

Cảm ơn!

Appendix 1.C

Explanatory Materials
for Technical Assistance
on System Planning
(Underground Transmission
System)

Examples of Study Items of Tokyo Underground Cables

April 2010

Tokyo Electric Power Company

Typical Study Items for Underground Cables

1. Series resonance overvoltage
2. Parallel resonance overvoltage
3. Oscillatory overvoltage by islanding
4. Voltage Variation
5. Reactive Power Compensation
6. Switching overvoltage
7. Lightning overvoltage
8. Auto-reclose system

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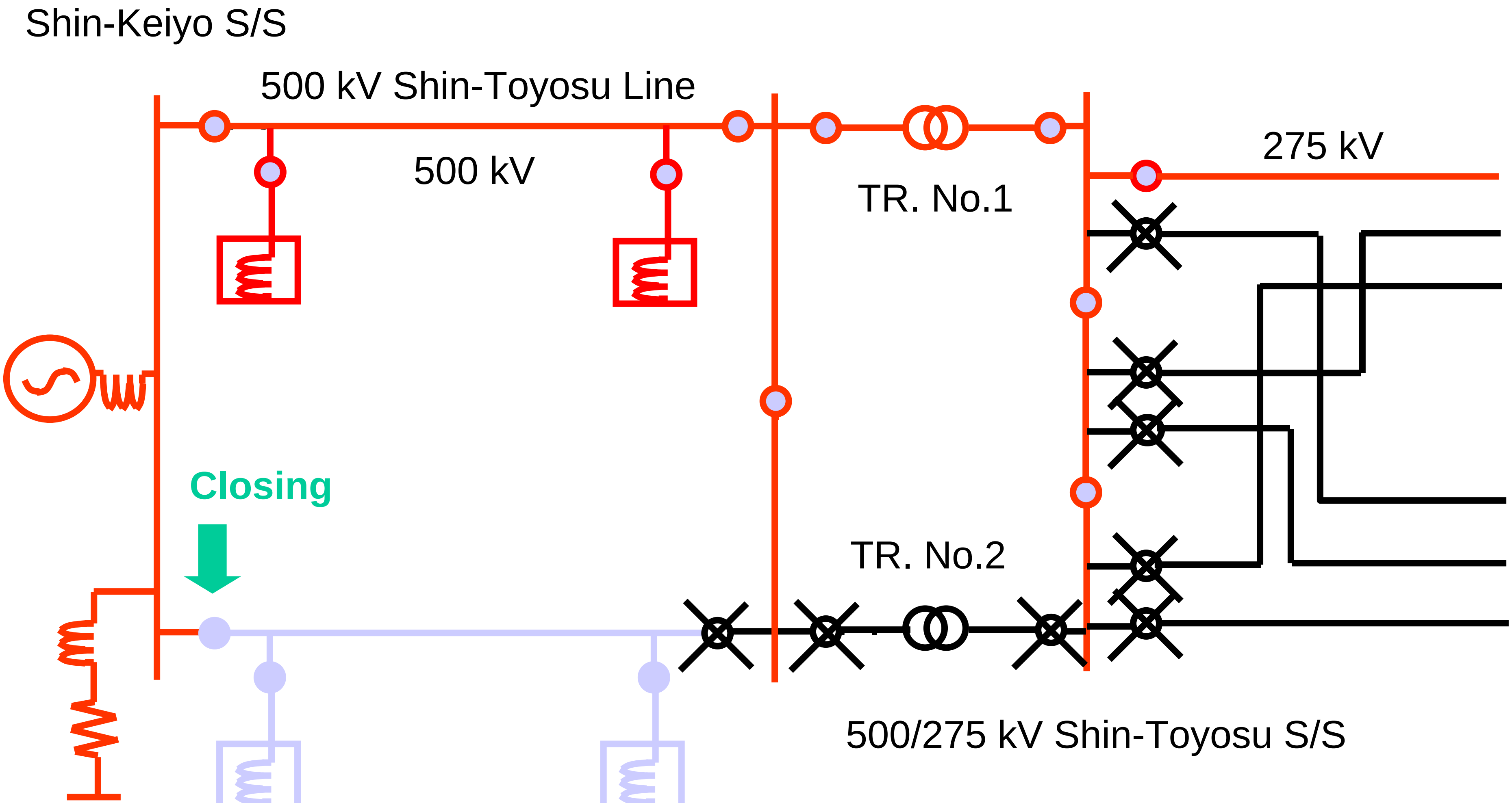
1. Series Resonance Overvoltage



TOKYO ELECTRIC POWER COMPANY

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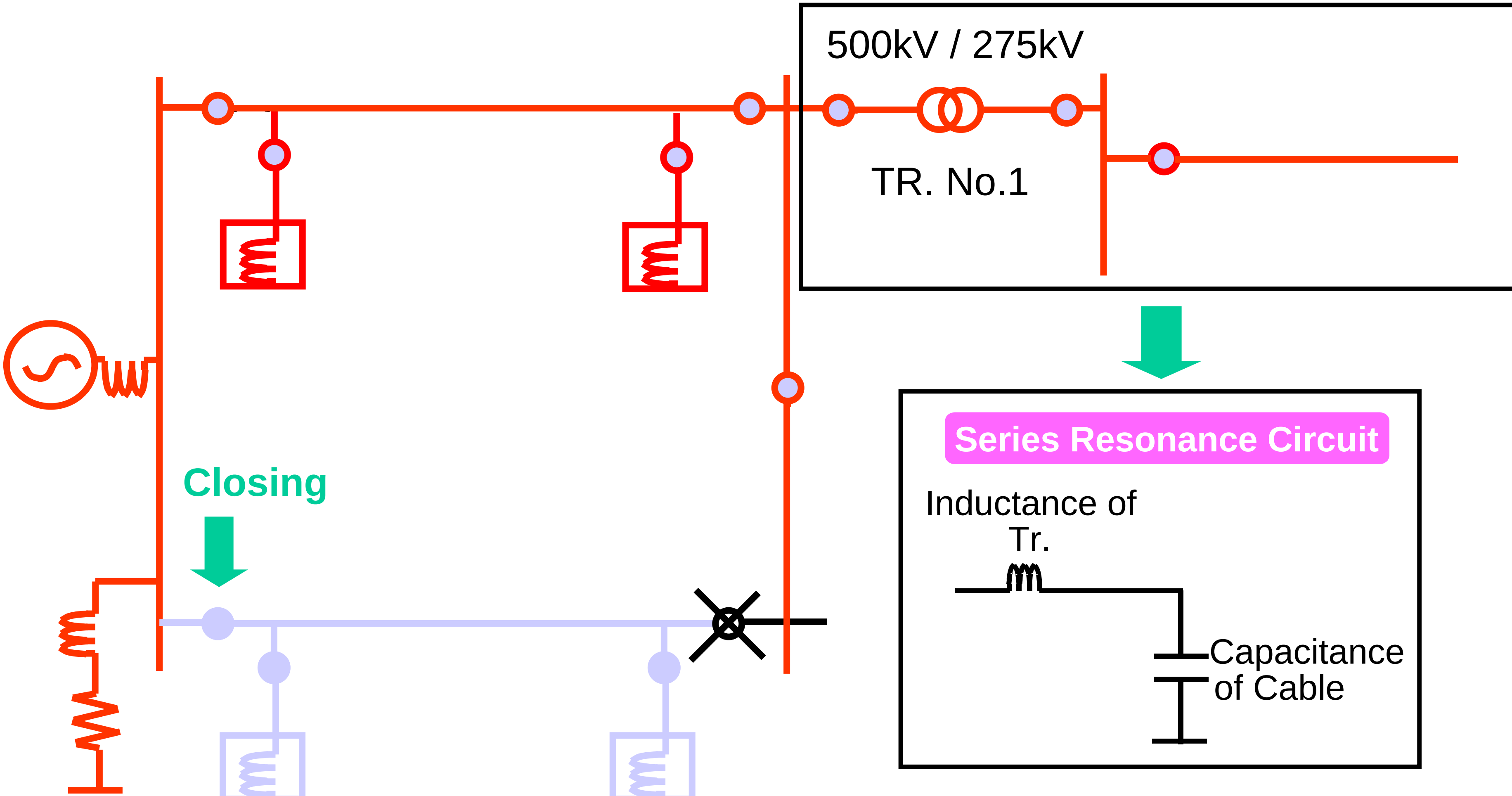
1. Series Resonance Overvoltage



Series resonance frequency: $f = \dfrac{1}{2\pi\sqrt{LC}}$

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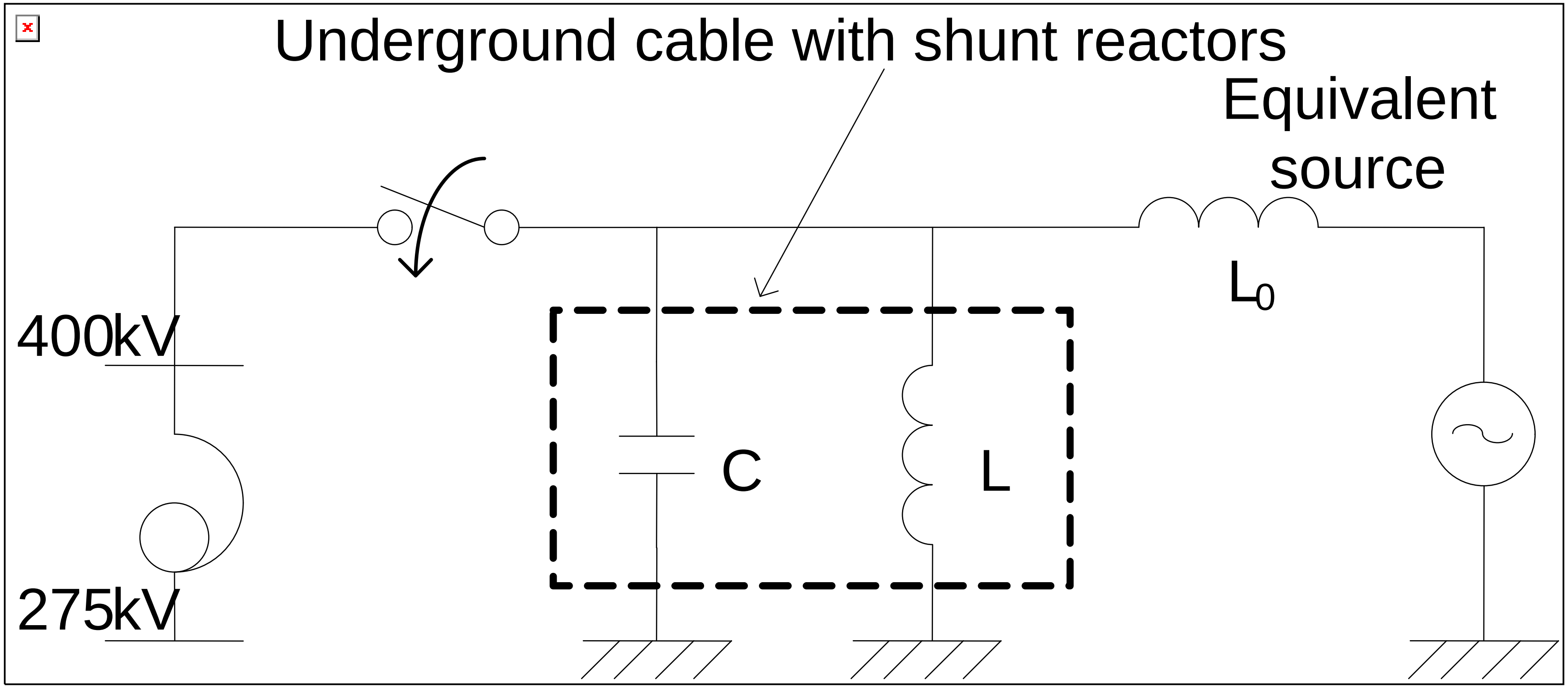
2. Parallel Resonance Overvoltage



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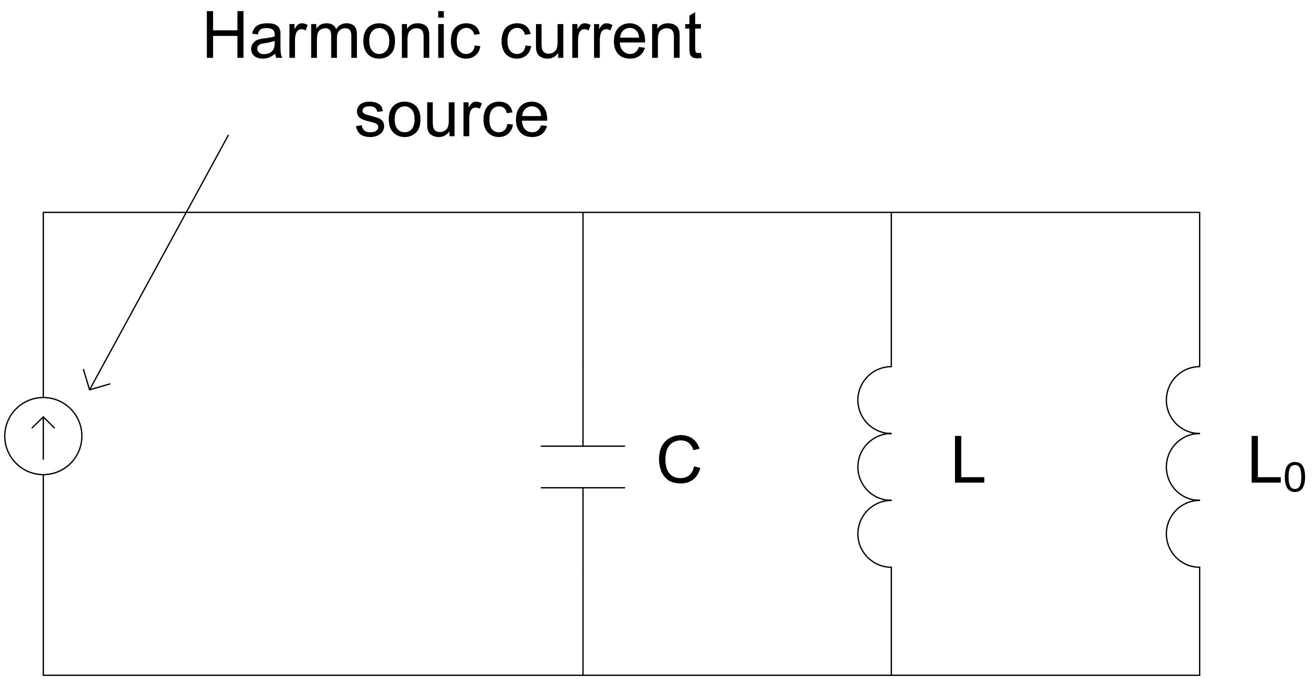
2. Parallel Resonance Overvoltage



At parallel resonance frequency, $n\omega C = \dfrac{1}{n\omega L} + \dfrac{1}{n\omega L_0}$

(n = 2 for transformer inrush)

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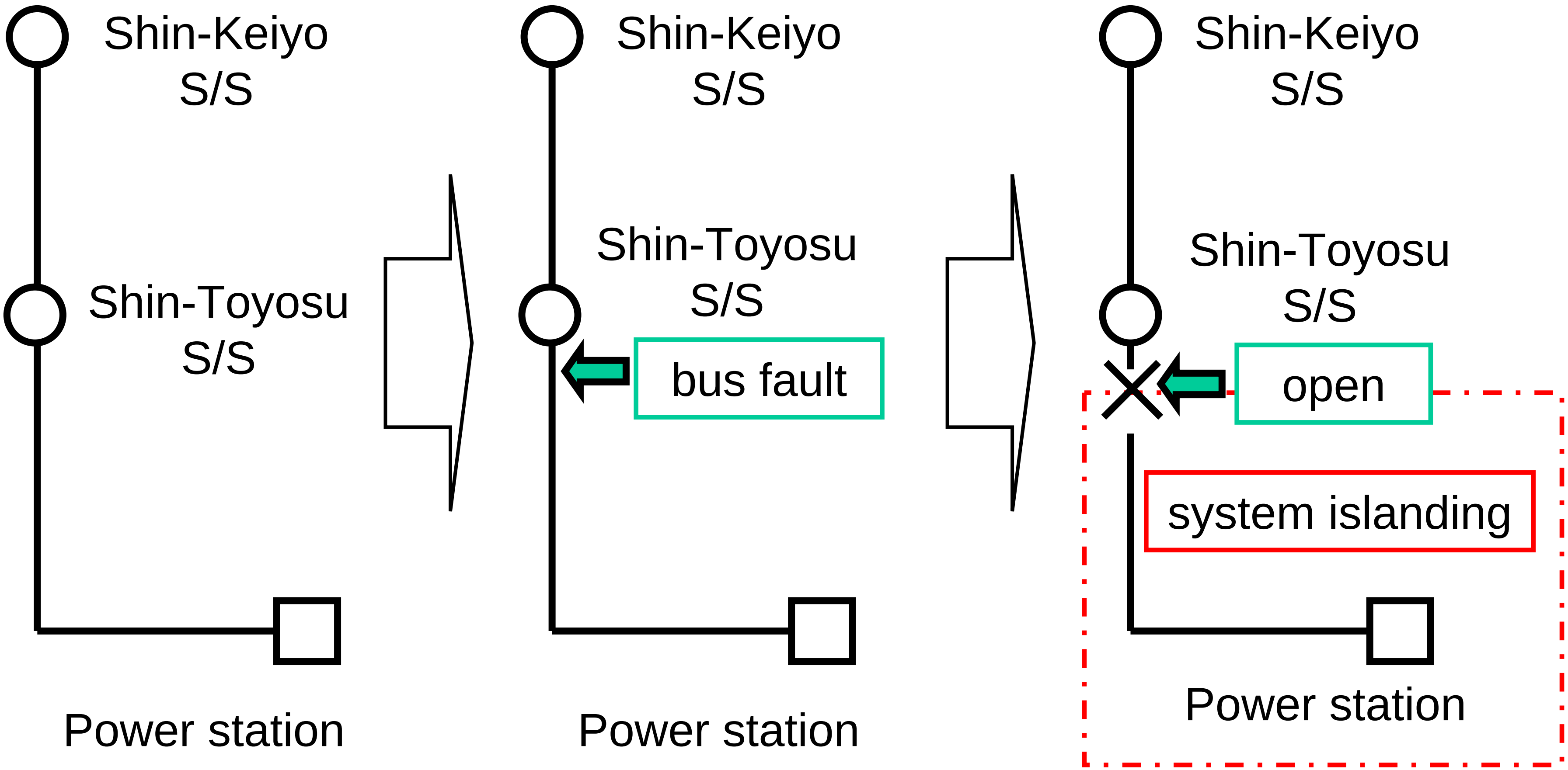
3. Oscillatory Overvoltage by Islanding



Example of the system islanding

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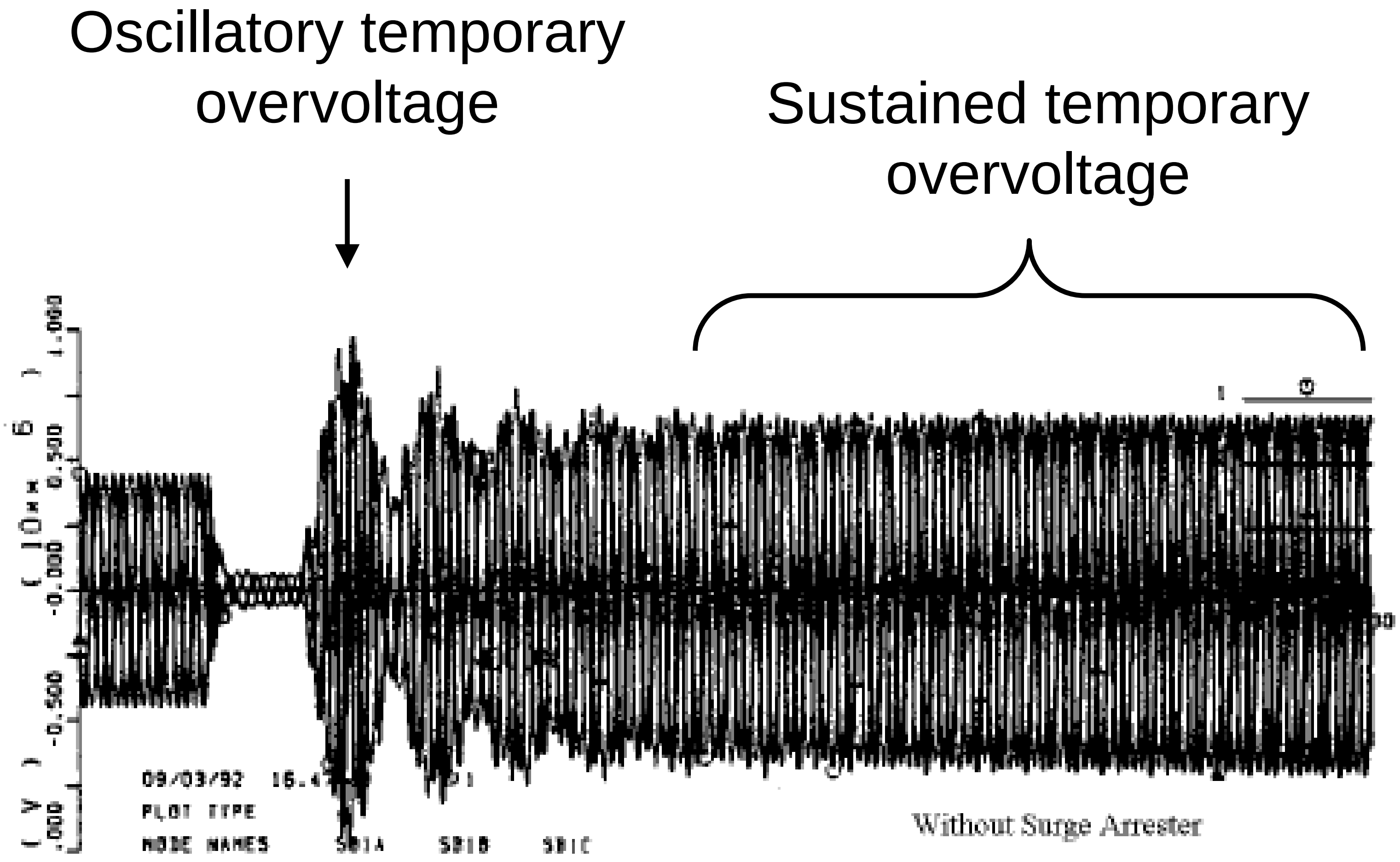
3. Oscillatory Overvoltage by Islanding



Example of the overvoltage caused by the system islanding

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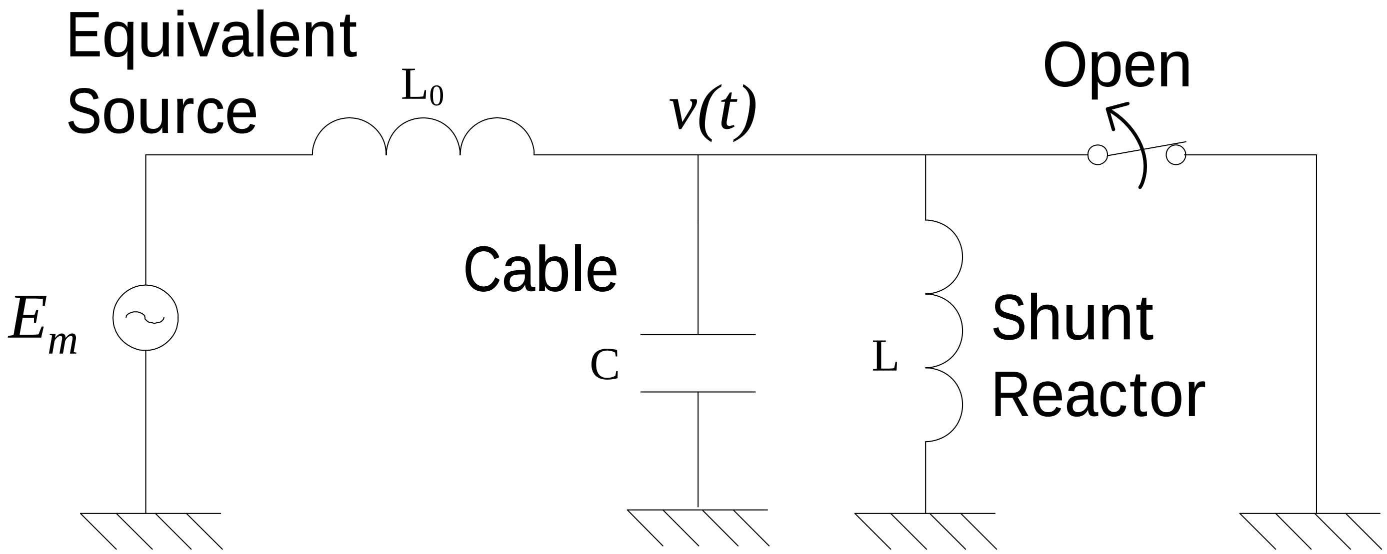
3. Oscillatory Overvoltage by Islanding



$$v(t) = V_m \sin \omega t - \frac{\omega}{\omega_0} V_m \sin \omega_0 t$$

Here,

$$V_m = \frac{E_m L}{L_0 (1 - \omega^2 CL) + L}, \quad \omega_0 = \sqrt{\frac{1}{CL_0} + \frac{1}{CL}}$$

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4. Voltage Variation

Compensation rate of a cable is low as a design or due to an outage of a shunt reactor.

↓

The cable is a reactive power source.

↓

Sudden loss of the cable can cause voltage variation.

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5. Reactive Power Compensation

- Appropriate amount of shunt reactors will be found from the voltage profile in off-peak demand
- Necessity of shunt reactor stations (or switching stations) along the length of the cables will be found from the following aspects:
  - ✓ Voltage around the center of the cable
  - ✓ Active power loss in the cables
  - ✓ Impact on the transmission capacity

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5. Reactive Power Compensation
Installed Location of Shunt Reactors

	Advantage	Disadvantage
Directly connected to the cable	- Can limit the overvoltage when one side of the cable is opened	- Cannot be used for voltage control when the cable is not-in-service (Some exceptions exist.) - May cause DC offset current when the cable is energized
Connected to substation buses	- Can be shared by multiple cable routes - Cheaper (tertiary side)	- May cause reactive power imbalance during switching operations

For long cables, shunt reactors are often directly connected to the cables due to the concern for the overvoltage and voltage variation.

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5. Reactive Power Compensation
Effects of Compensation Rate

	Close to 100%	Away from 100%
Reactive power compensation	Preferable	Generally not preferable (depends on typical operating conditions)
DC offset current	Not preferable (but can be avoided by a special relay)	Preferable
Oscillatory overvoltage	Preferable	Not preferable

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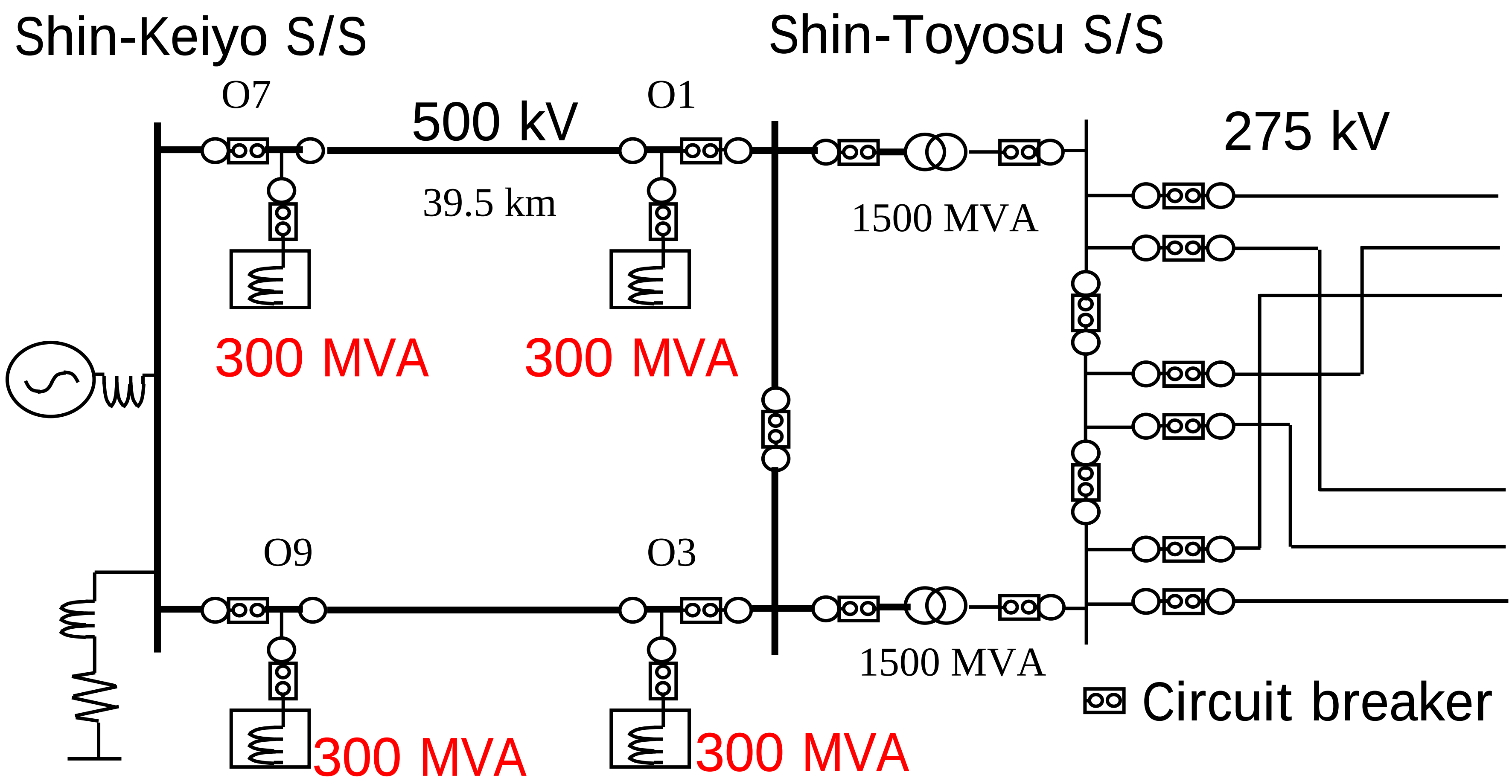
5. Reactive Power Compensation
500kV Shin-Toyosu Cable Line



Compensation Rate: $\dfrac{1200\text{MVar}}{1286\text{MVar}} \times 100 = 93.3\%$

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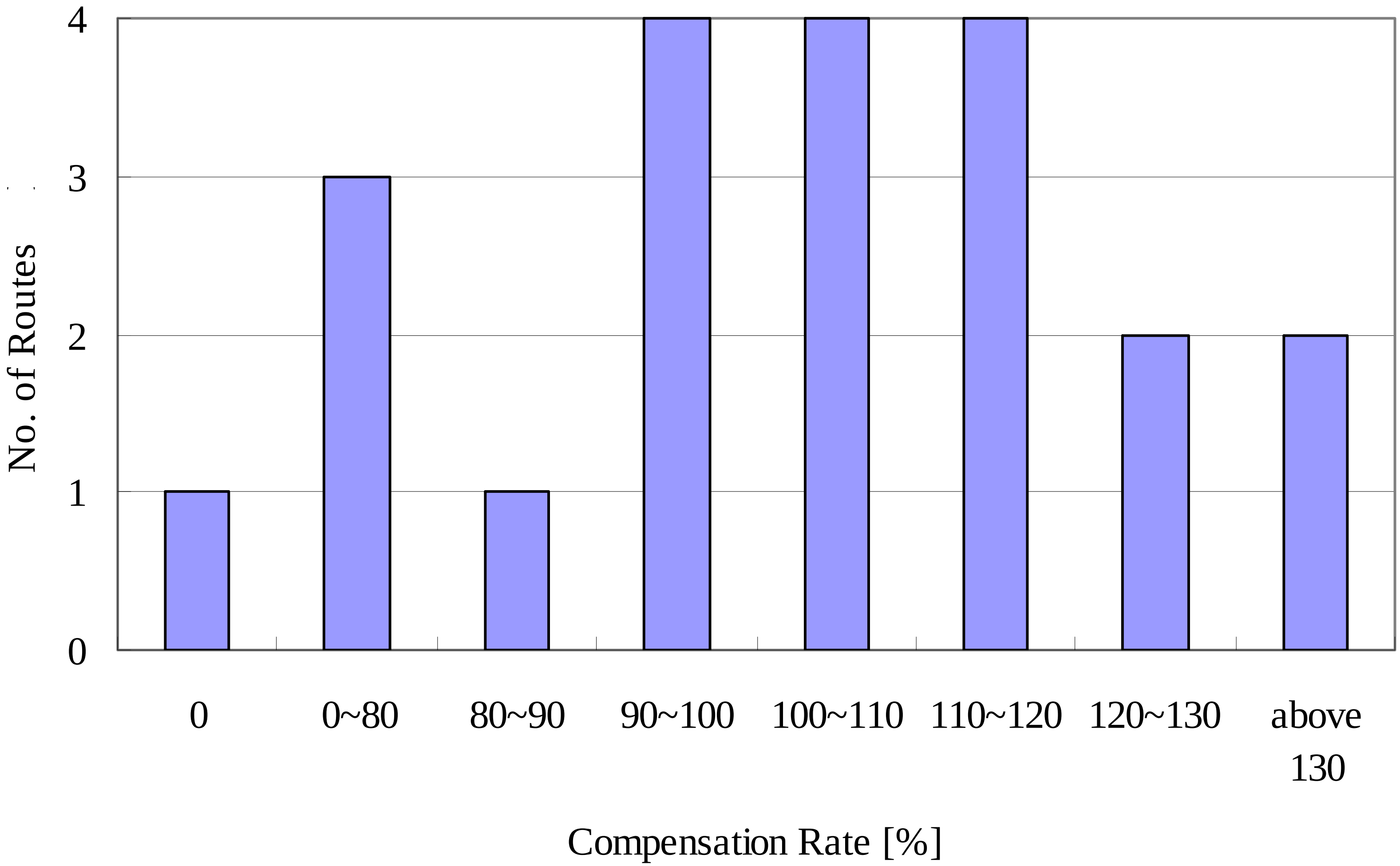
5. Reactive Power Compensation: Compensation Rates of EHV Cables in TEPCO



Most shunt reactors are automatically switched at scheduled times to control system voltages.

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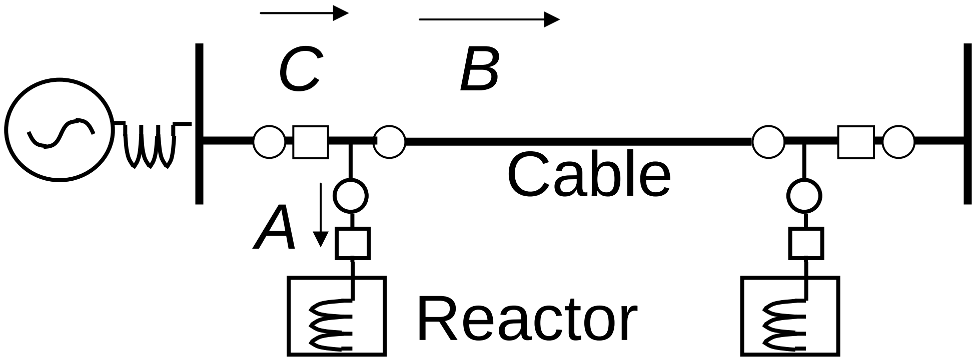
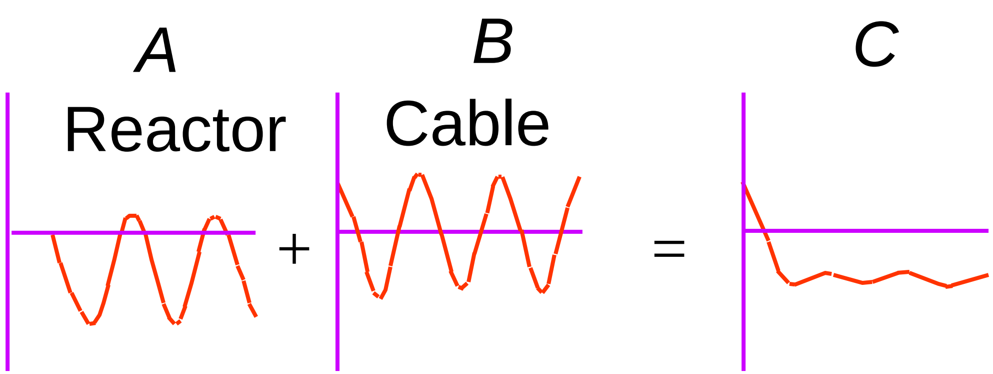
5. Reactive Power Compensation
DC Offset Current



Close *C* under a no load condition with a shunt reactor

Current on *C* has dc-component for several seconds.



If a fault occurs during this periods, circuit breaker cannot interrupt fault current.

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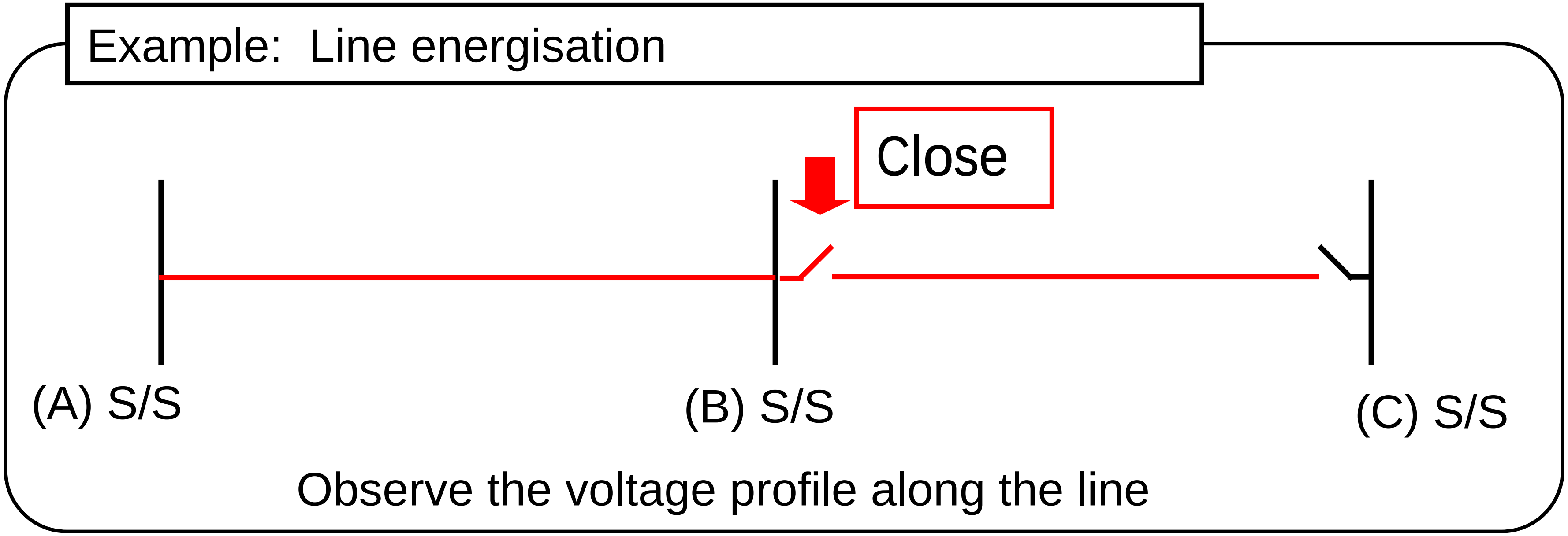
6. Switching overvoltage
Line energisation overvoltage



Example of Simulated randomness in line energisation

(1) Timing when CBs (three phases) receive the instruction to close themselves

→ uniform distribution over one cycle

(2) Close timing difference between phases

→ normal distribution with standard deviation 1ms

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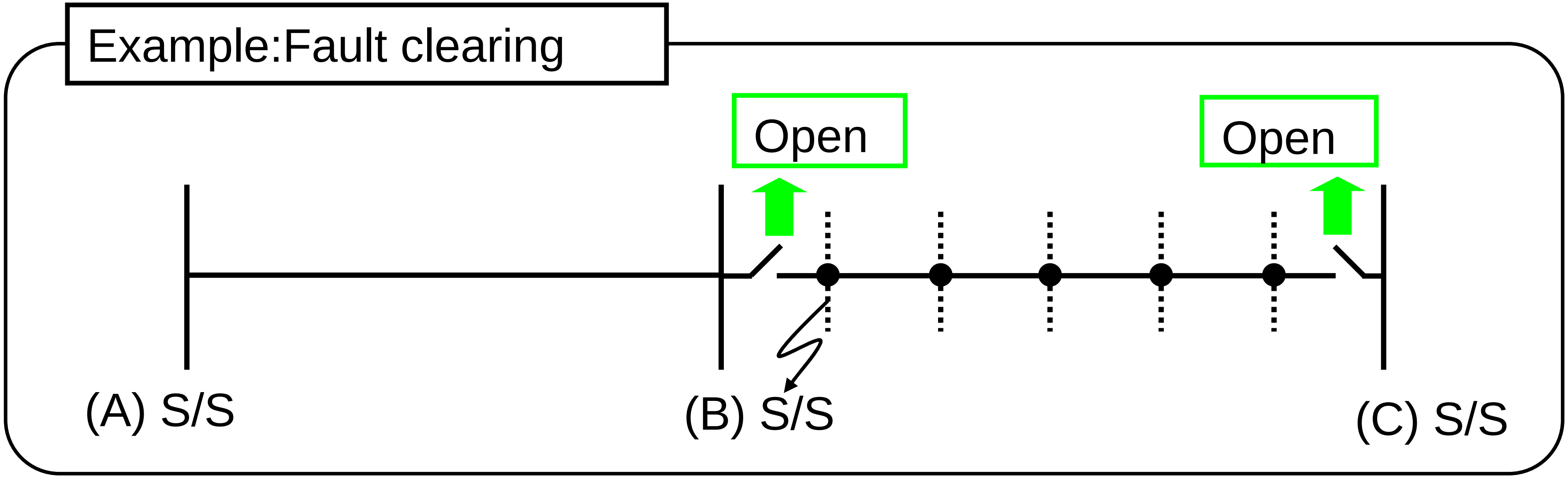
6. Switching overvoltage
Ground fault and Fault-clearing overvoltage



Example of different fault timings

(1) Fault point → Five points in each cable route

(2) Fault type → Single line to ground fault(core to sheath) in Phase A

(3) Fault timing → 0º-180º(10º step)

The slow-front overvoltage (2% value) will be evaluated against SIWV of equipment

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TEPCO

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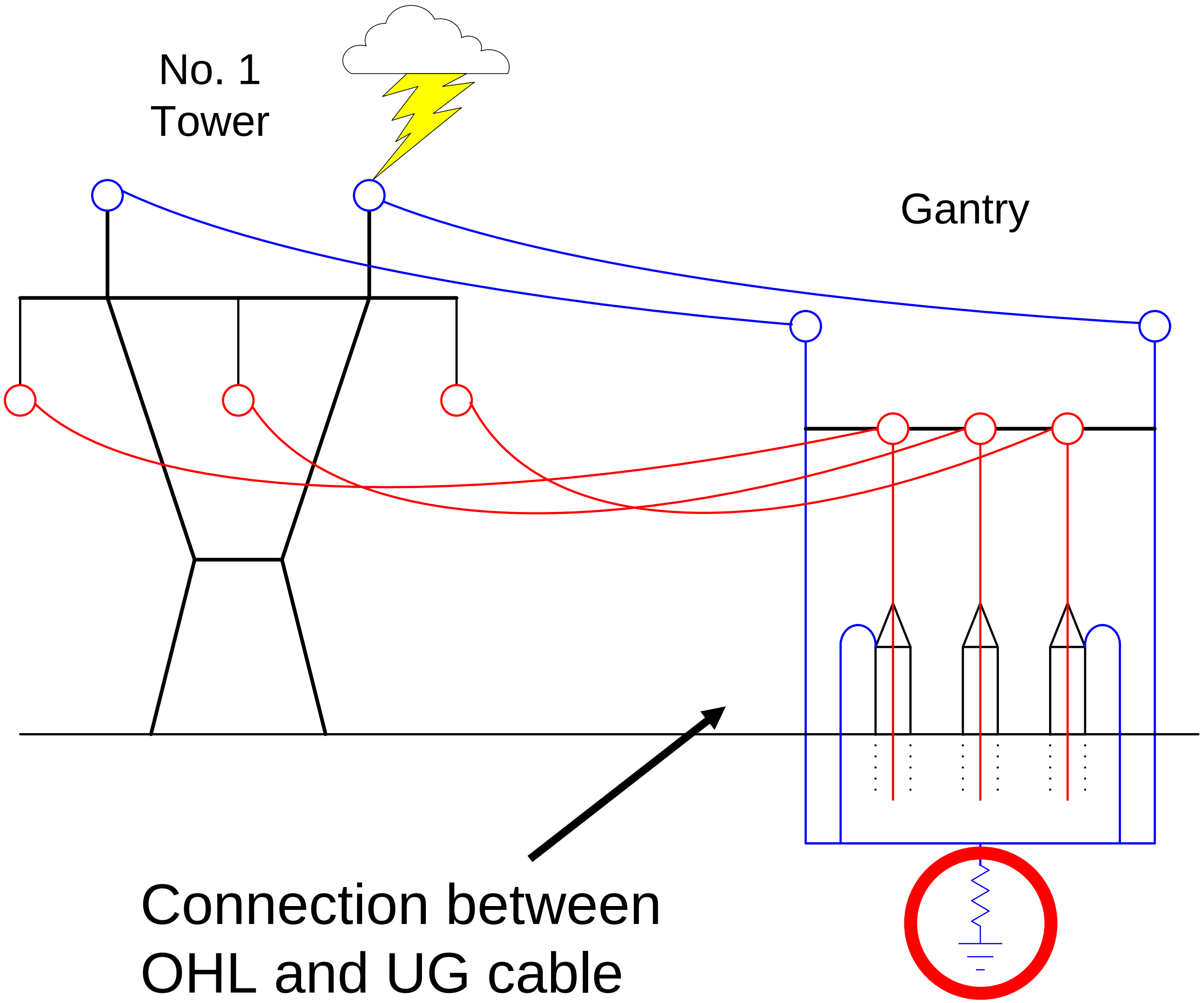
7. Lightning Overvoltage



Sheath overvoltage can be severe due to high grounding resistance of the gantry.

Evaluation of sheath overvoltage with SVL (sheath voltage limiter) is necessary.

Connection between OHL and UG cable

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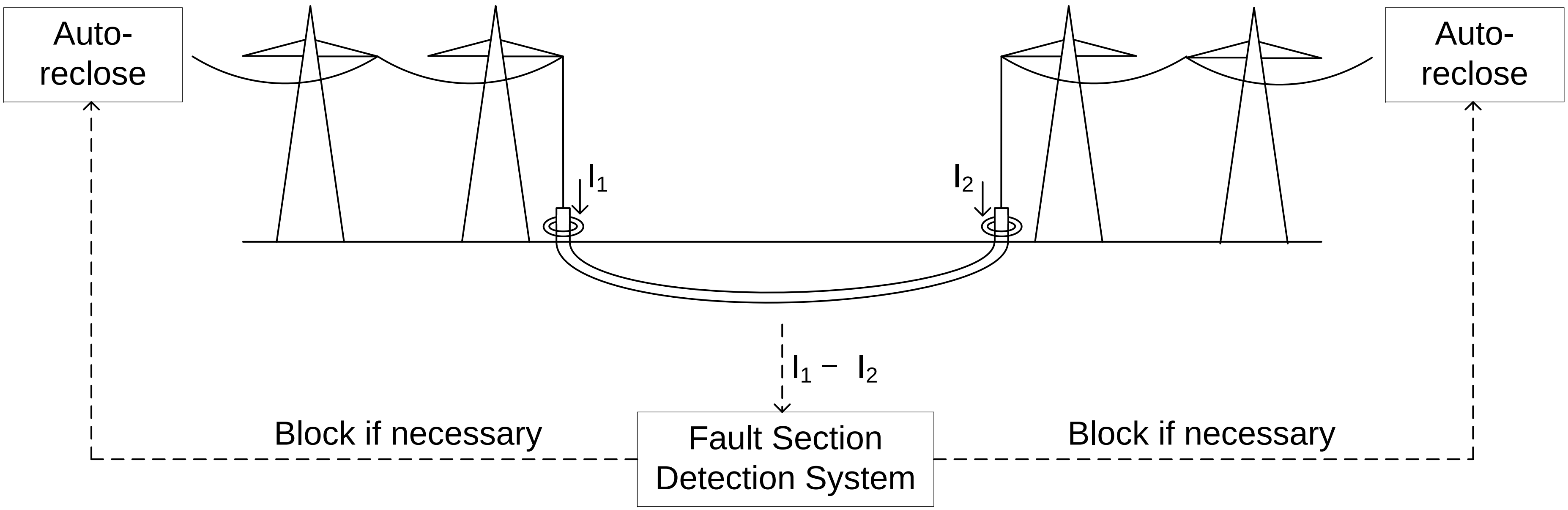
8. Auto-reclose system

Fault section detection for a mixed OHL / cable line



Unless the block signal is received, auto-reclose will be executed.

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Utilization of Underground System - Example of Tokyo

April 2010

TEPCO

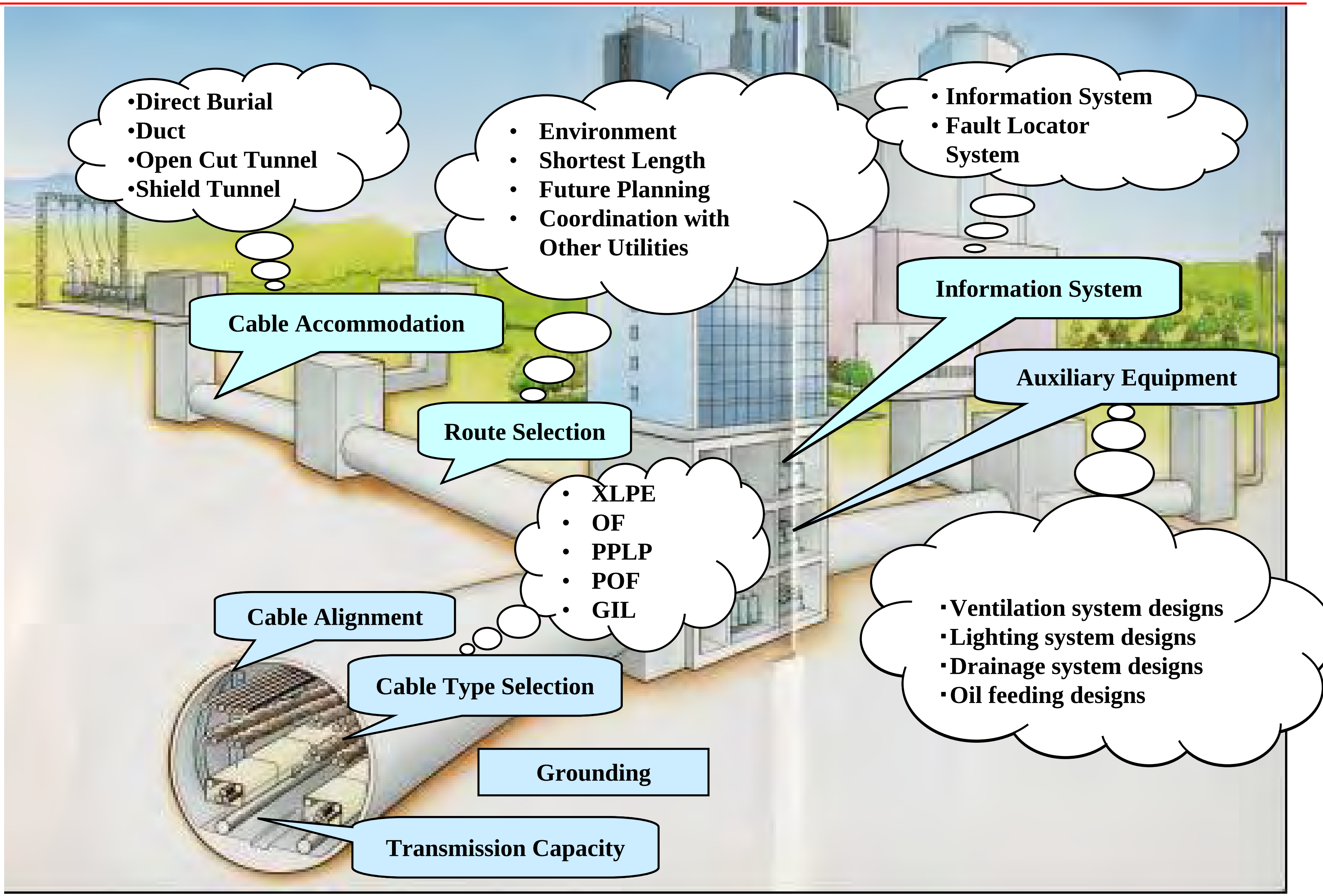
TOKYO ELECTRIC POWER COMPANY

Contents

- Underground Cables
- Underground Substations

1. Underground Cables

Outline of Underground Cables



Route Selection and Coordination with Other Load Utilizations

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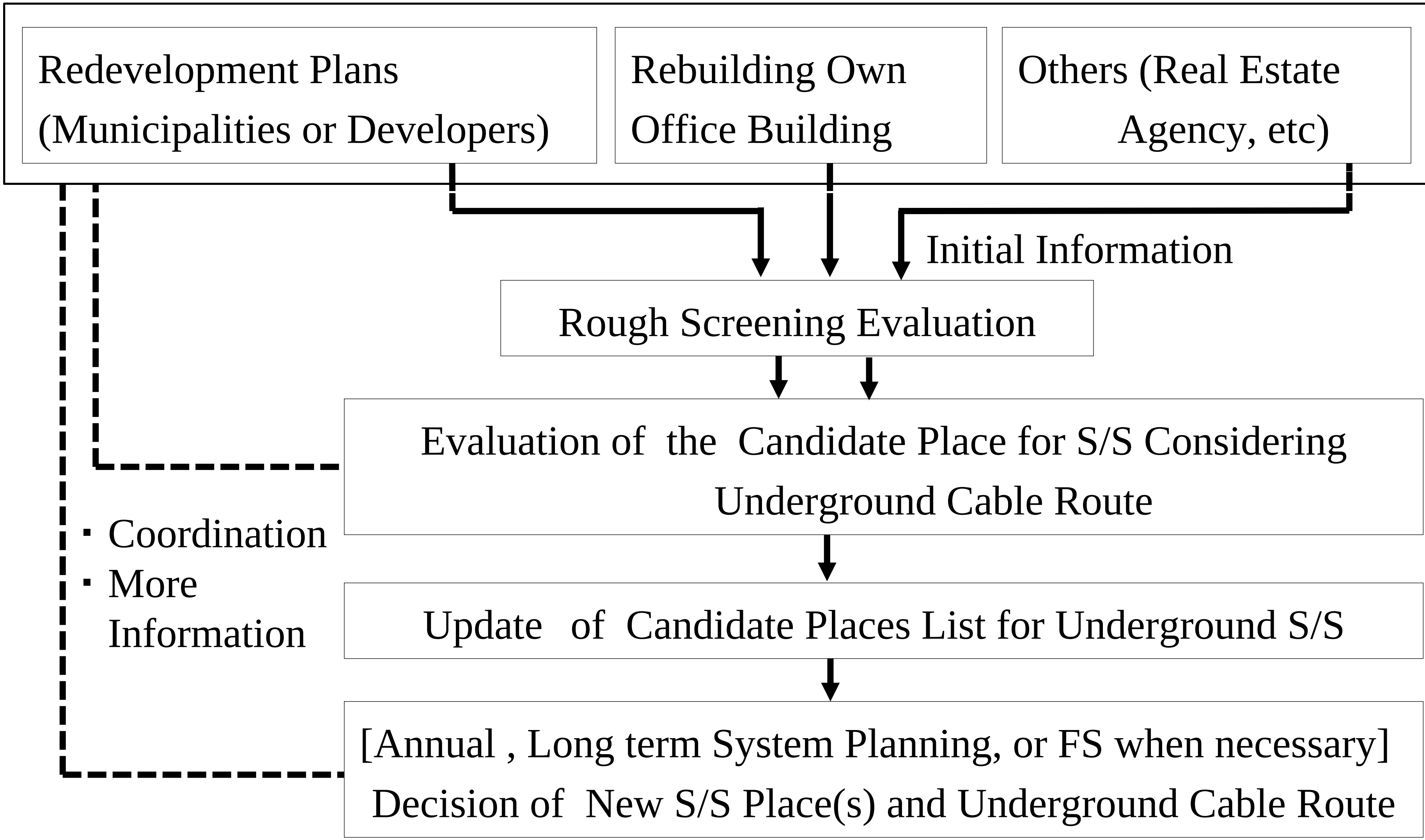
Route Selection

- Environment
- Shortest Length
- Future Planning
- Coordination with Other Utilities

Decision of New Underground S/S Place



Coordination with Road Administrators to Construct Underground Cable

	Road administrator	Utility
• Information acquisition	○	○
• Planning of the construction		○
• Coordination of the construction plan		
• Ex-ante coordination	○	○
• Coordination of the construction plan	○	○
• Planning and cordination about the road	○	
• Coordination for an implementation of the construction plan	○	○
• Order from the administrator	○	
• Report from utilities	○	○
• Request from utilities and discussion	○	○
• Management of road usage		○
• Applications for an occupancy of the underground of the road		
• Report of start and completion of the work		
• Record of the progress of the work		
• Response to an accident or a disaster	○	○

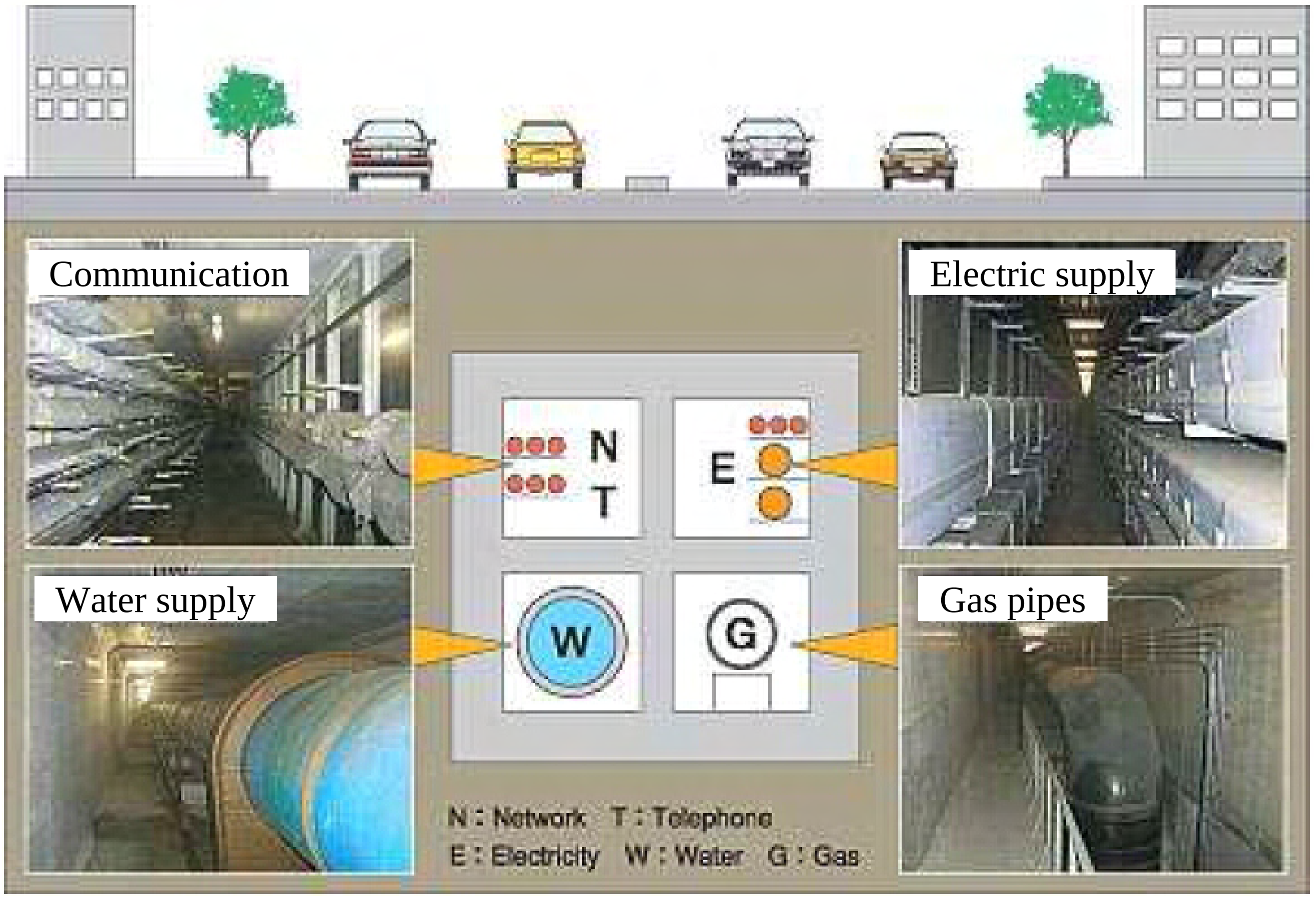
Common-use tunnel

Why common-use tunnels are recommended in Tokyo metropolitan area?

- To prevent users of underground of roads from digging them repetitively
- To utilize underground of roads effectively

Common-use tunnel

Example of a common-use tunnel



http://www.mlit.go.jp/road/road_e/contents01/1-4-4.html

Coordination with Road Administrators for Usage of Common-use Tunnels

Road administrator

Designation of a road to prepare for constructing a common-use tunnel:
The road administrator designates a certain road section which can be used as a common-use tunnel in the future. After the designation, occupancy of the underground of the road will be limited.

Public notice that a common-use tunnel should be constructed:
When utilities propose the road administrator to construct a common-use tunnel under a certain road, and if the propose is accepted as feasible enough, the administrator shall officially announce that the common-use tunnel should be constructed.

Making a plan to construct the common-use tunnel:
After considering requirement from prospective occupants of the tunnel, a plan to construct the common-use tunnel is made.

Construct of the common-use tunnel:
The road administrator collects contributions for the construction and for occupancy of the road. A common-use tunnel itself is constructed by the input.

Installation into the common-use tunnel:
After the completion of the construction, prospective occupants install their objects into the tunnel.

Finalization of installation:
The road administrator collects contributions for the maintenances
・to maintain, repair or rebuild the common-use tunnel when necessary,
・and to deal with a post-disaster restoration, etc..

Utilities

Request for a construction of a common duct

Comments and requests about the common duct

Contributions for the construction

Installation of objects

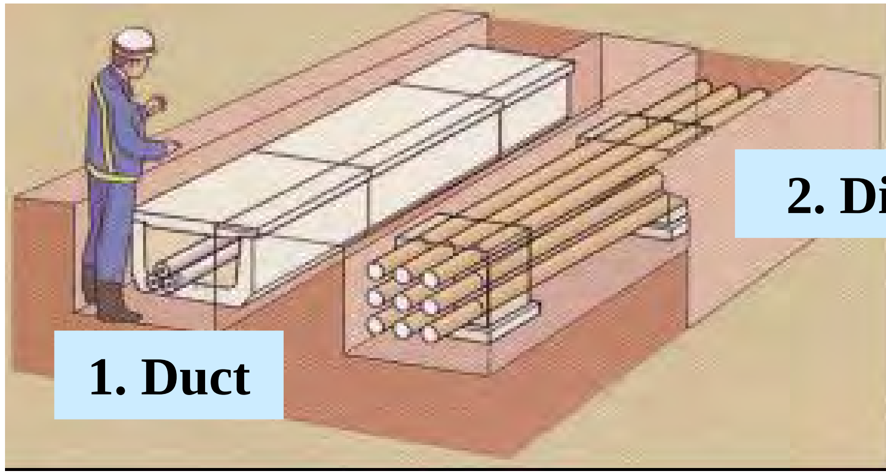
Contributions for maintenances

Construction Methods

TOKYO ELECTRIC POWER COMPANY

TEPCO

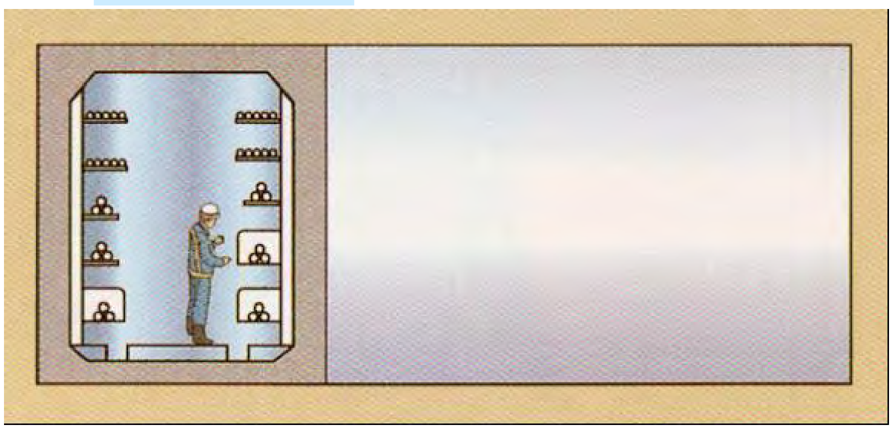
Types of Cable Accommodation (1)



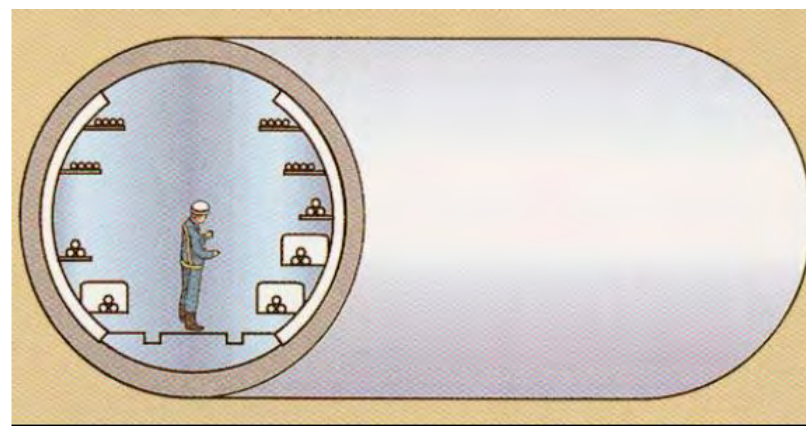
1. Duct

2. Direct Burial

3. Tunnel



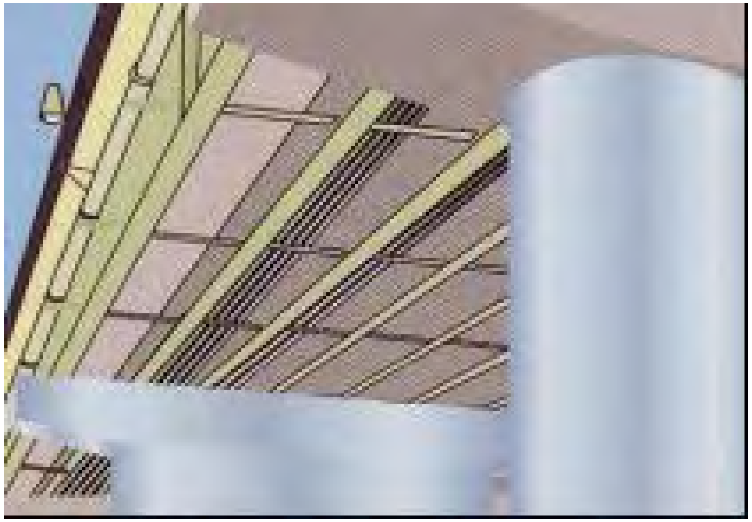
Open Cut Tunnel

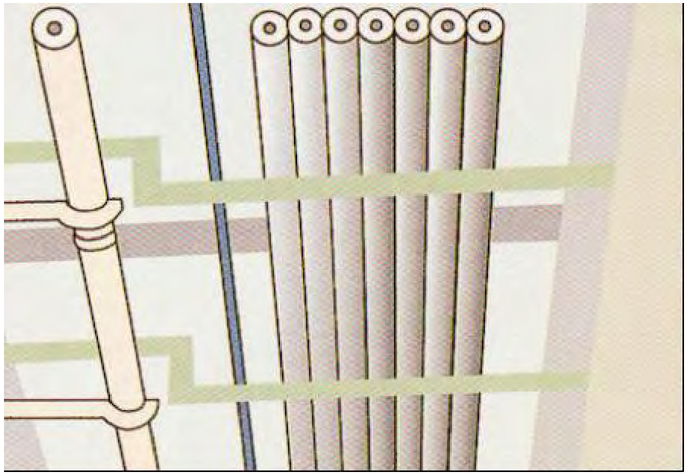


Pipe Jacking, Shield Tunnel

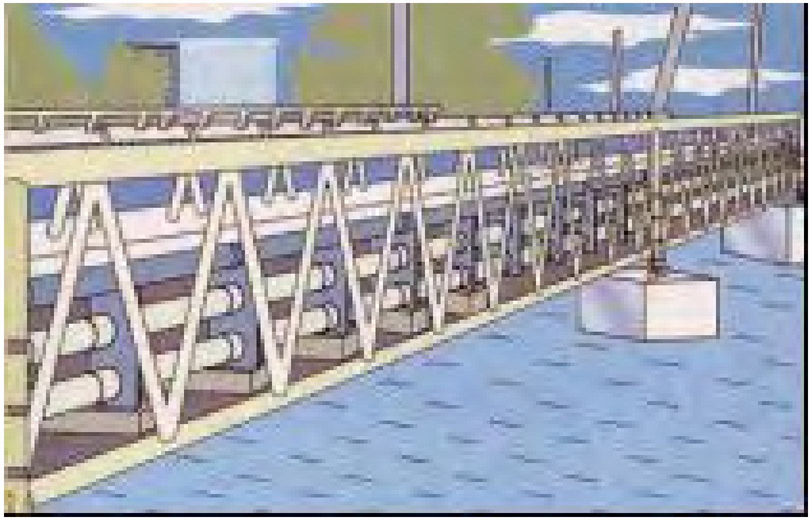
Types of Cable Accommodation (2)

4. Under Road Bridge





5. Bridge for cables only



Open-Cut Construction Method

Suburb or Tokyo 30 years ago

- Light Traffic
- Few Underground Objects

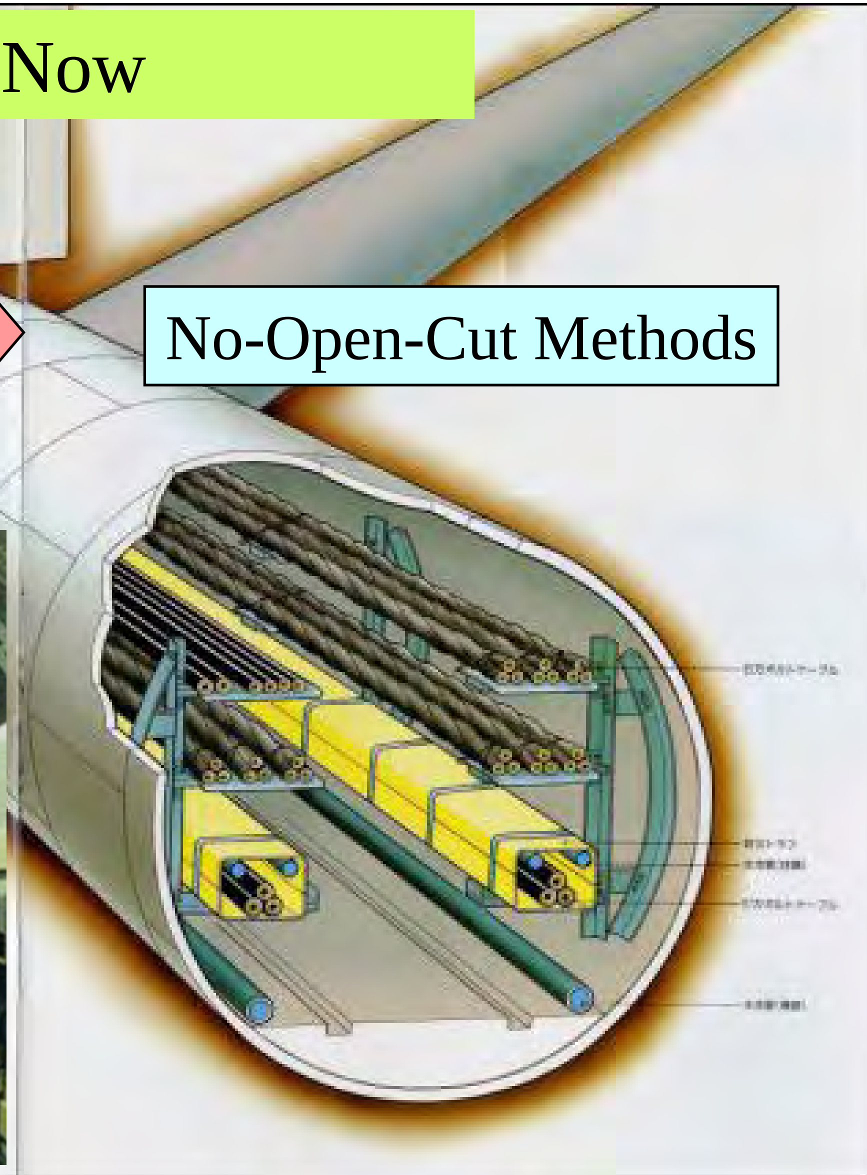
→ Open-Cut Ducts, Tunnels

No-Open-Cut Construction Method

Central Tokyo Now

- Heavy Traffic
- Many Underground Objects

No-Open-Cut Methods



Cable Alignment Design

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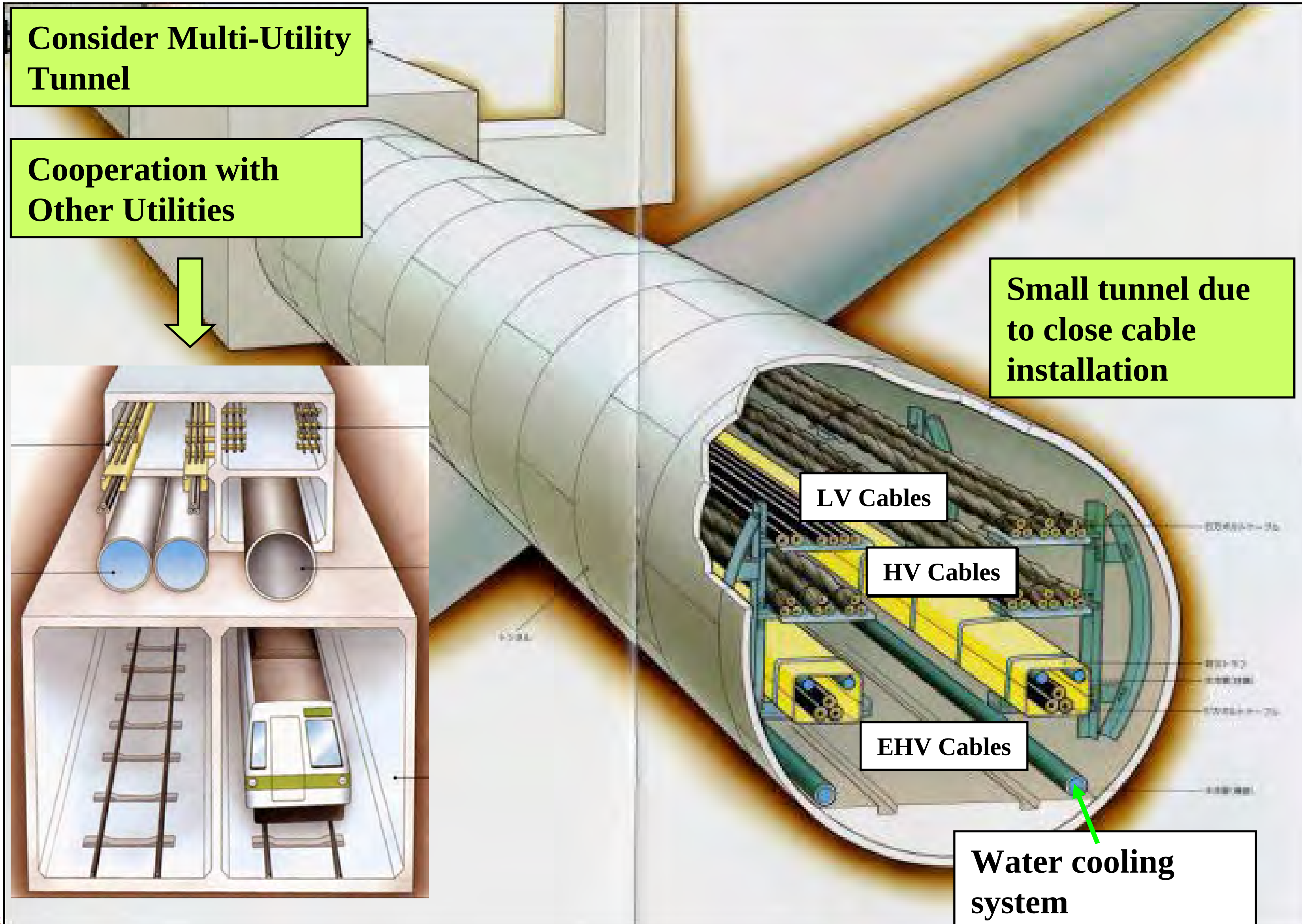
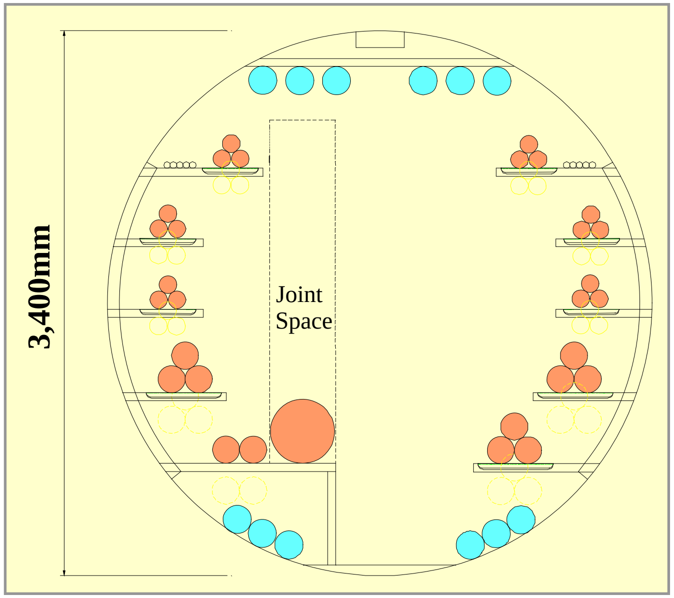
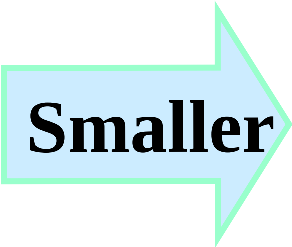
TEPCO

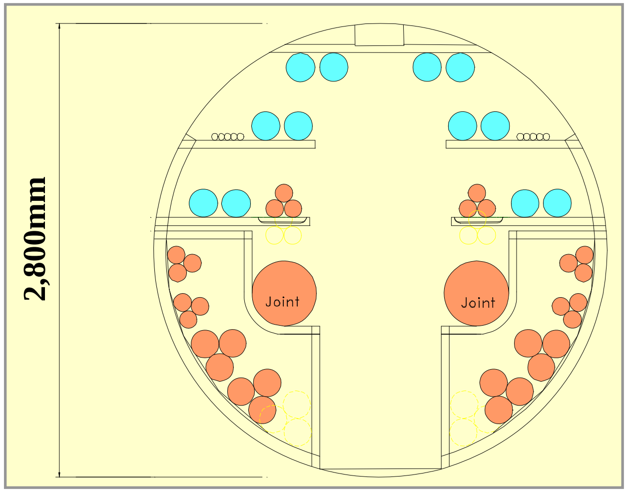
Cable Alignment Design



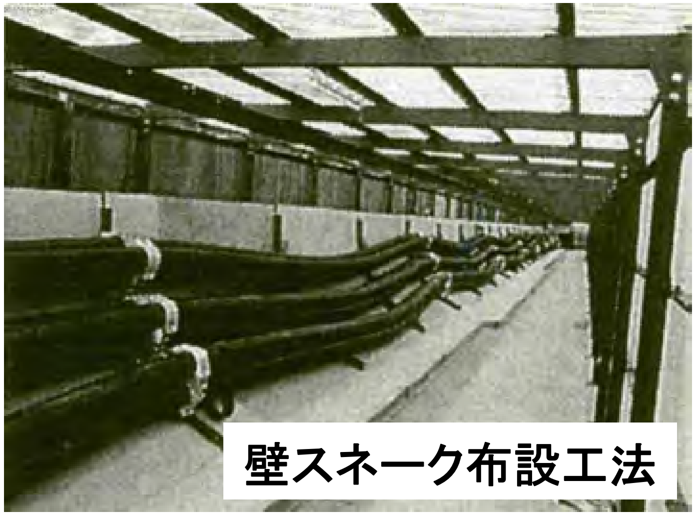
Cable Alignment Design



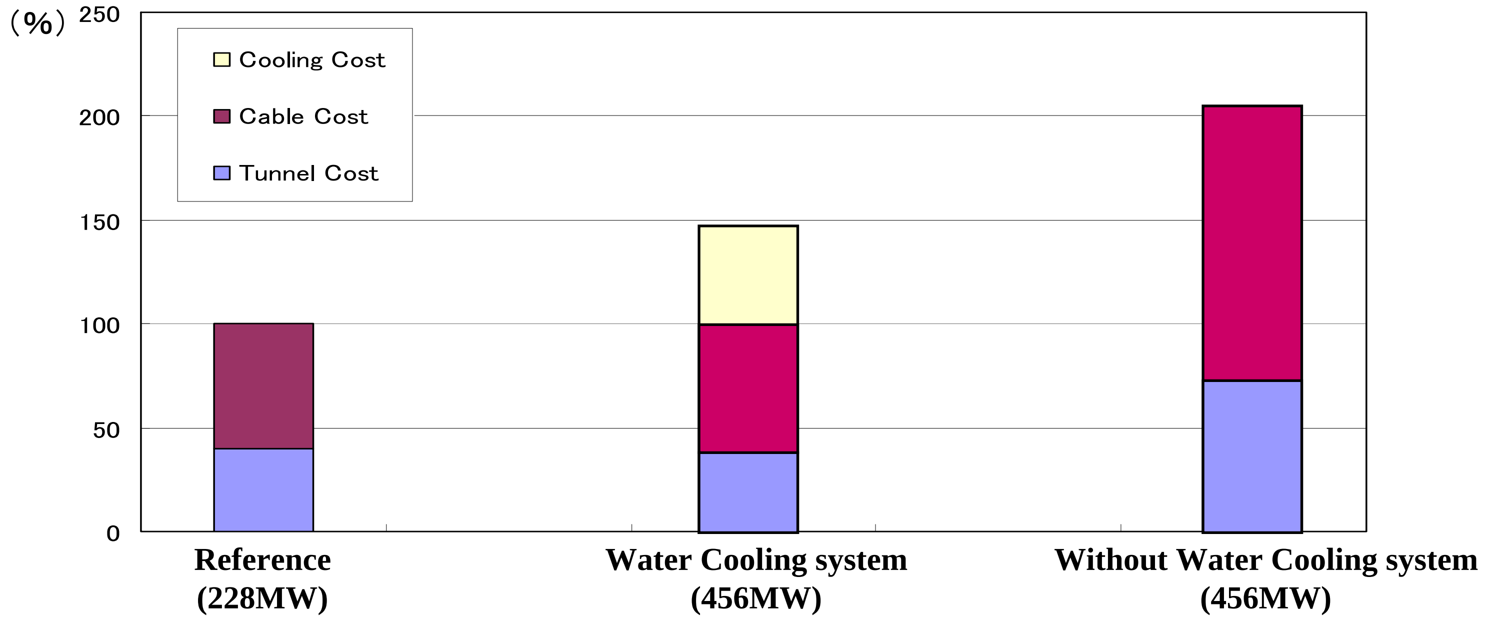


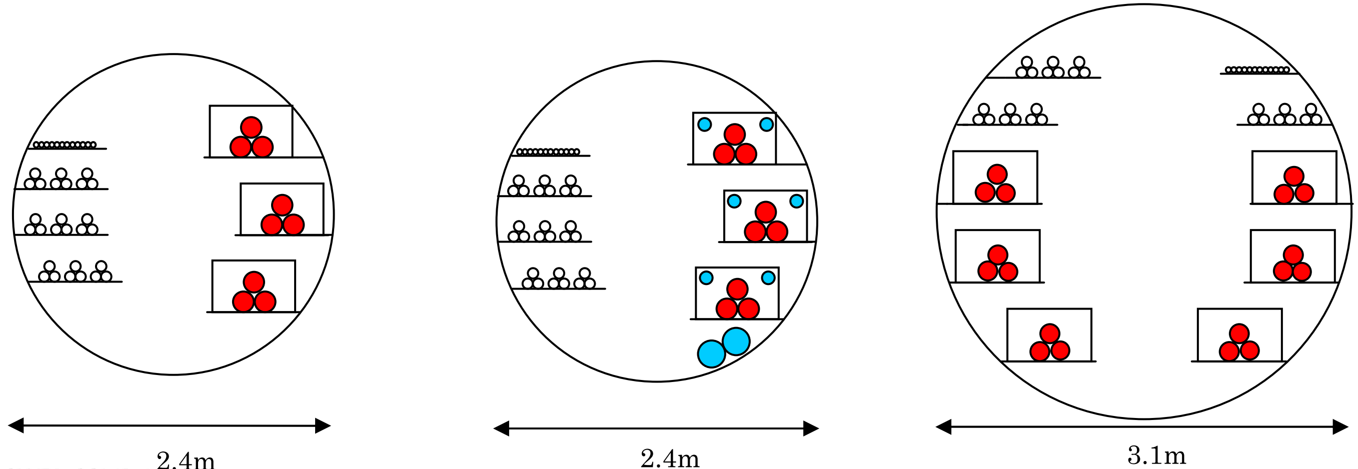


* pulling tension & thermal expansion, together with civil design

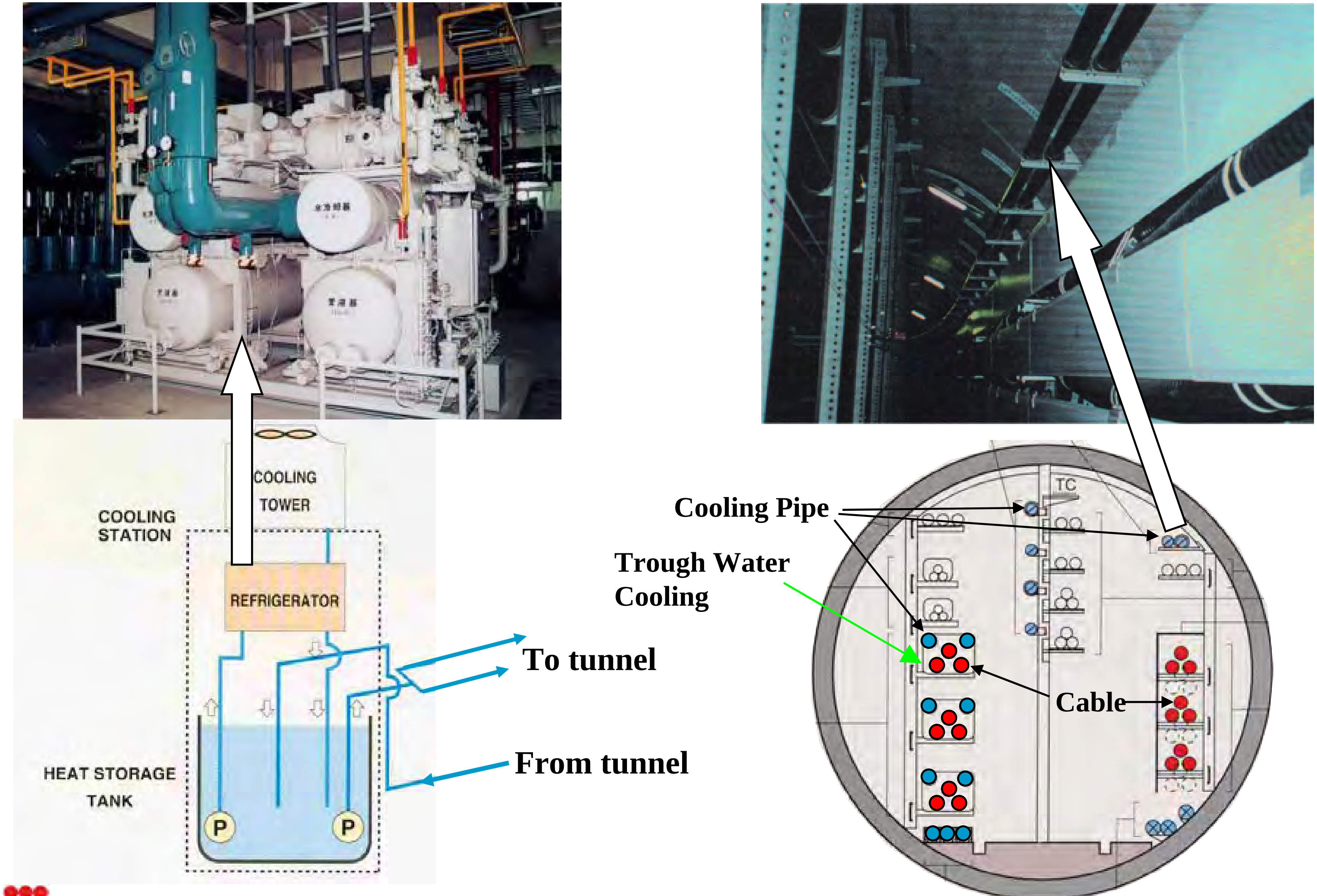


Water Cooling Design



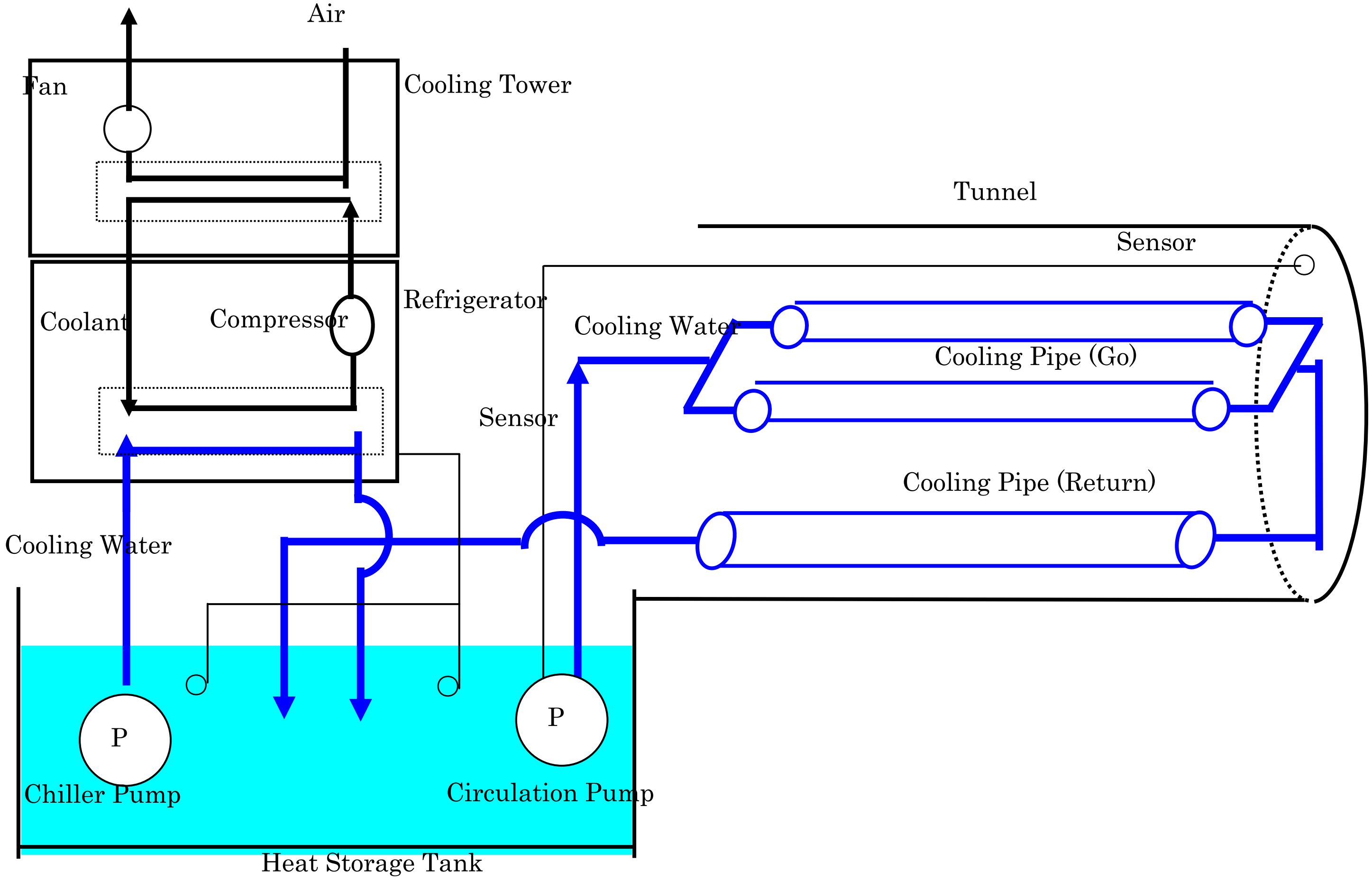


Tunnel Cooling

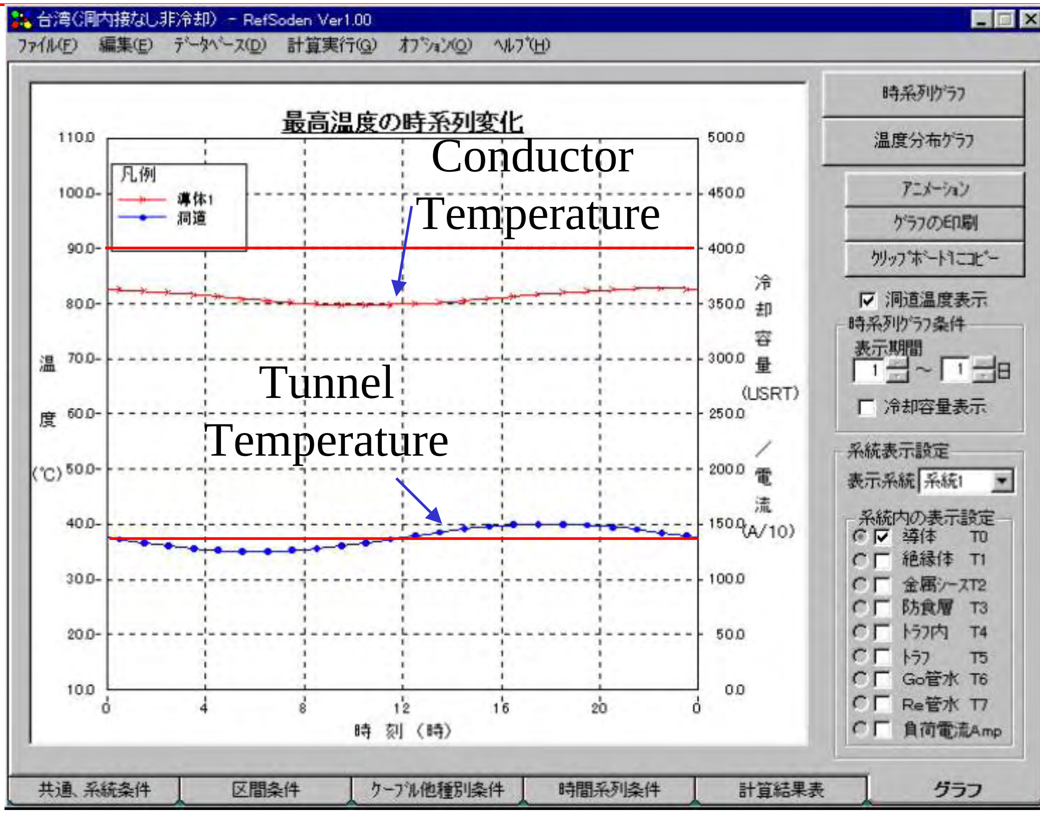


Water Cooling System

- Consists of Tunnel part and Cooling station

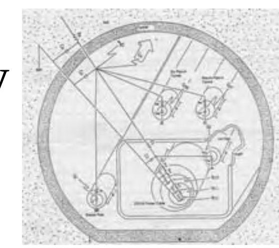


Transmission Capacity Design



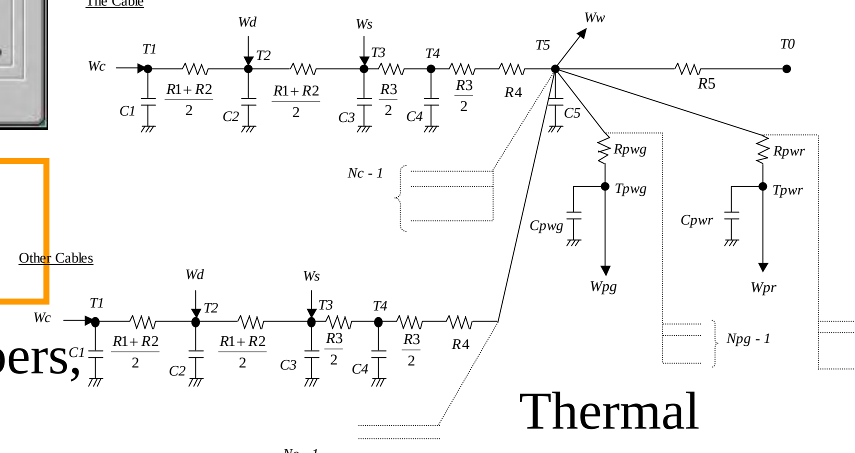
Input Data

- current
- cable parameters
- water speed
- number & size of pipes, etc.
- water pipe pressure
- refrigerator capacity (USRT, kW, cal/h)



Conductor Temperature < max. (i.e. 90C)
Tunnel Temperature < max. (i.e. 37C)

If not, re-consider conductor sizes, cable numbers, tunnel sizes or water cooling system



Thermal Circuit

Summary of Design Items of Underground Cables

Power system study
(Operational conditions, LIWV, short circuit level, etc.)

Route Selection

↓

Construction Method Selection

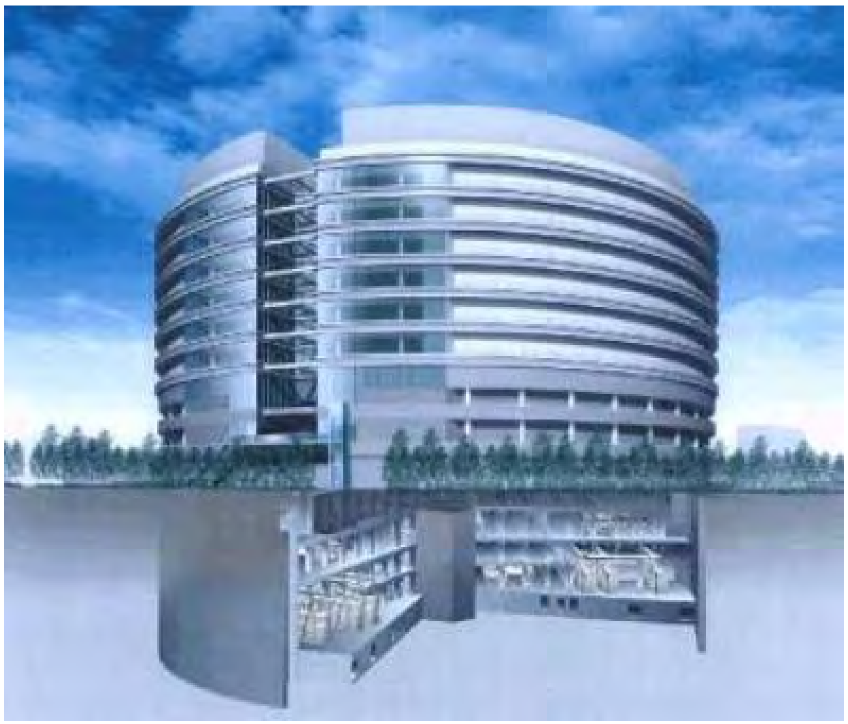
Cable Alignment Design

- Offset in manholes
- Snaking
- with/without water cooling etc.
- Joint and termination
- Sheath, earthing
- Overhead-connection
- Auxiliary equipment design (ventilation, drainage, lighting, cooling station, information system, fire prevention design, etc.)

2. Underground Substation

Underground Substations in Tokyo Metropolitan Area

- Land space limitation
- Construction restriction



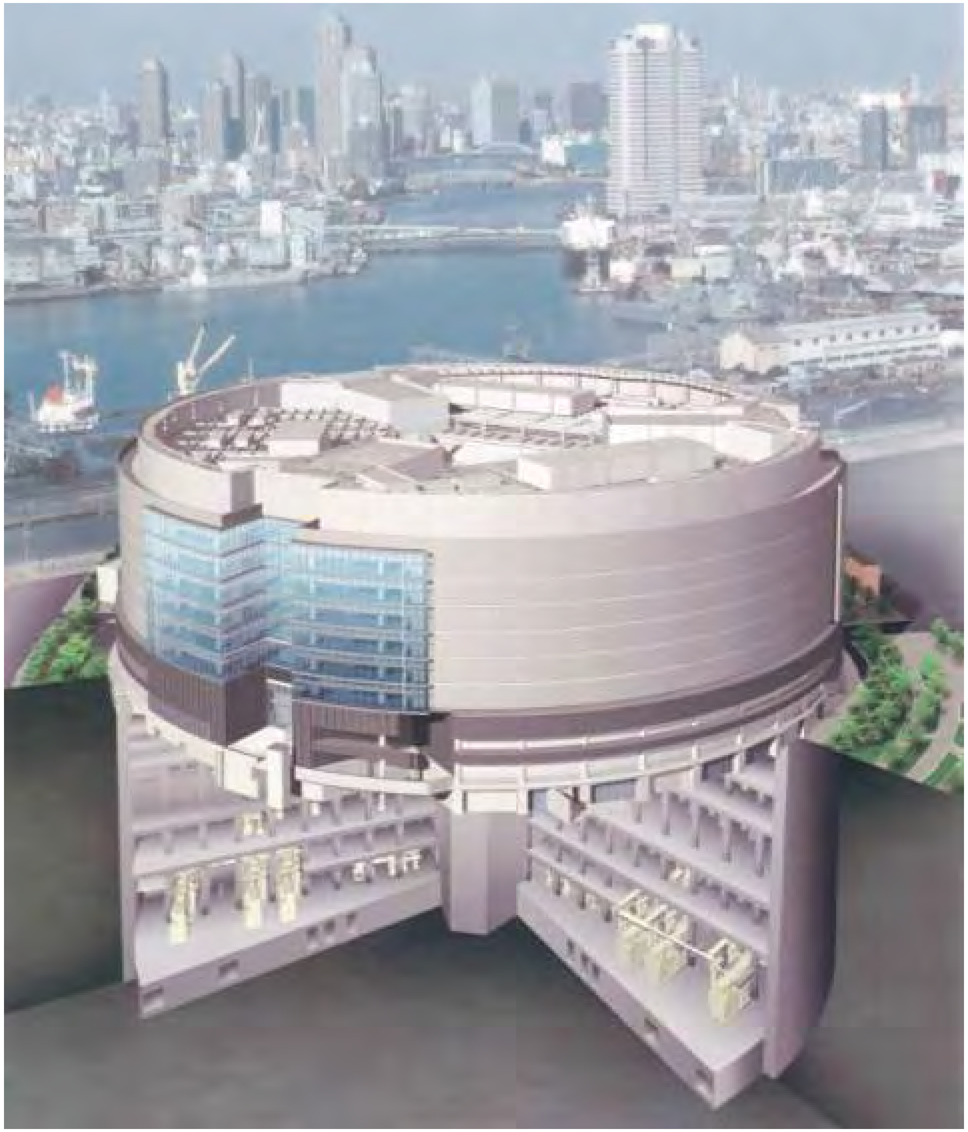
Design;

- ･Reliability
- ･Economic efficiency;
  space and volume cost
- ･Safety
- ･Environmental harmony /
  Public acceptance

500kV U.ground S/S： 1 site
（Output：1,500MVA）

275kV U.ground S/S： 23 site
（Output：12,320MVA）

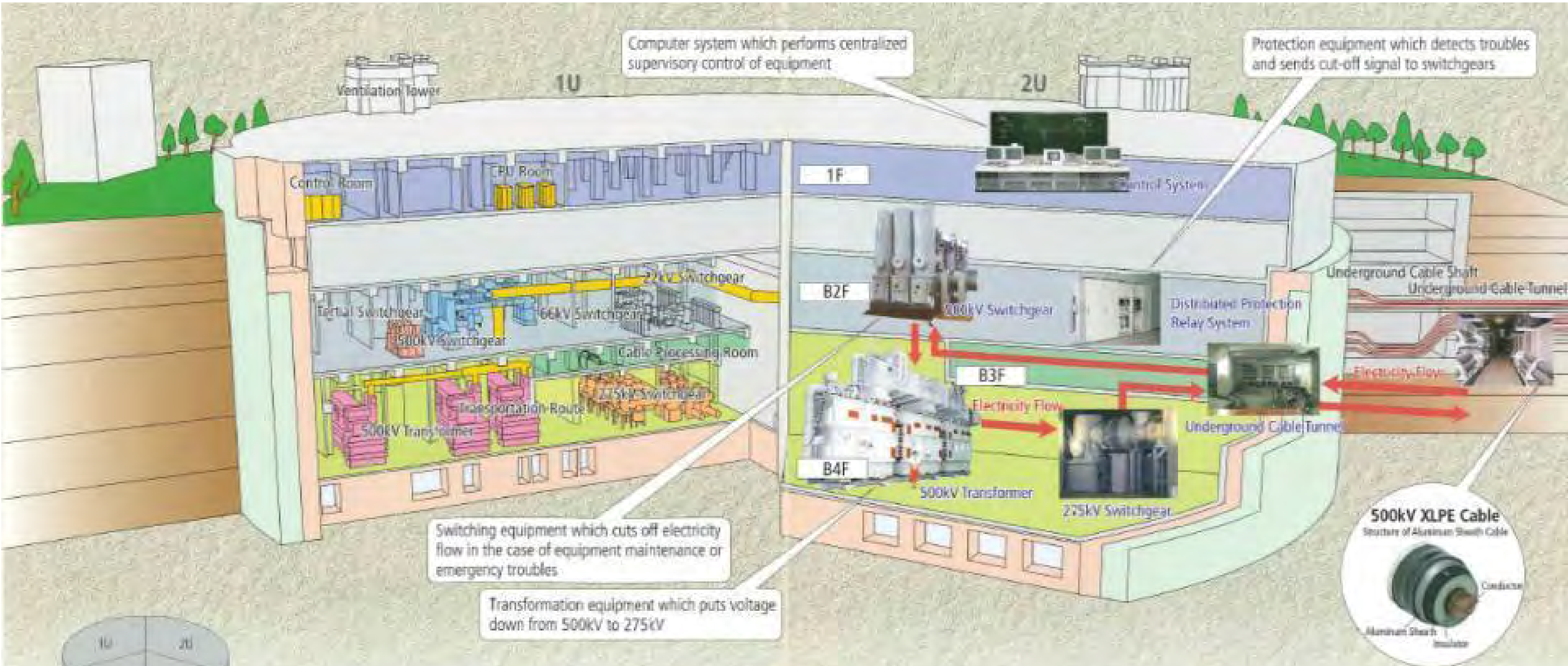
550kV Underground Substation (1)

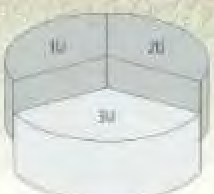


- A Circular form building was adopted to save construction costs. (Building volume: 1/3 of Tokyo Dome)
- The building is divided into 3 sector parts and equipment is installed in each part.

550kV Shin-Toyosu Substation

550kV Underground Substation (2)





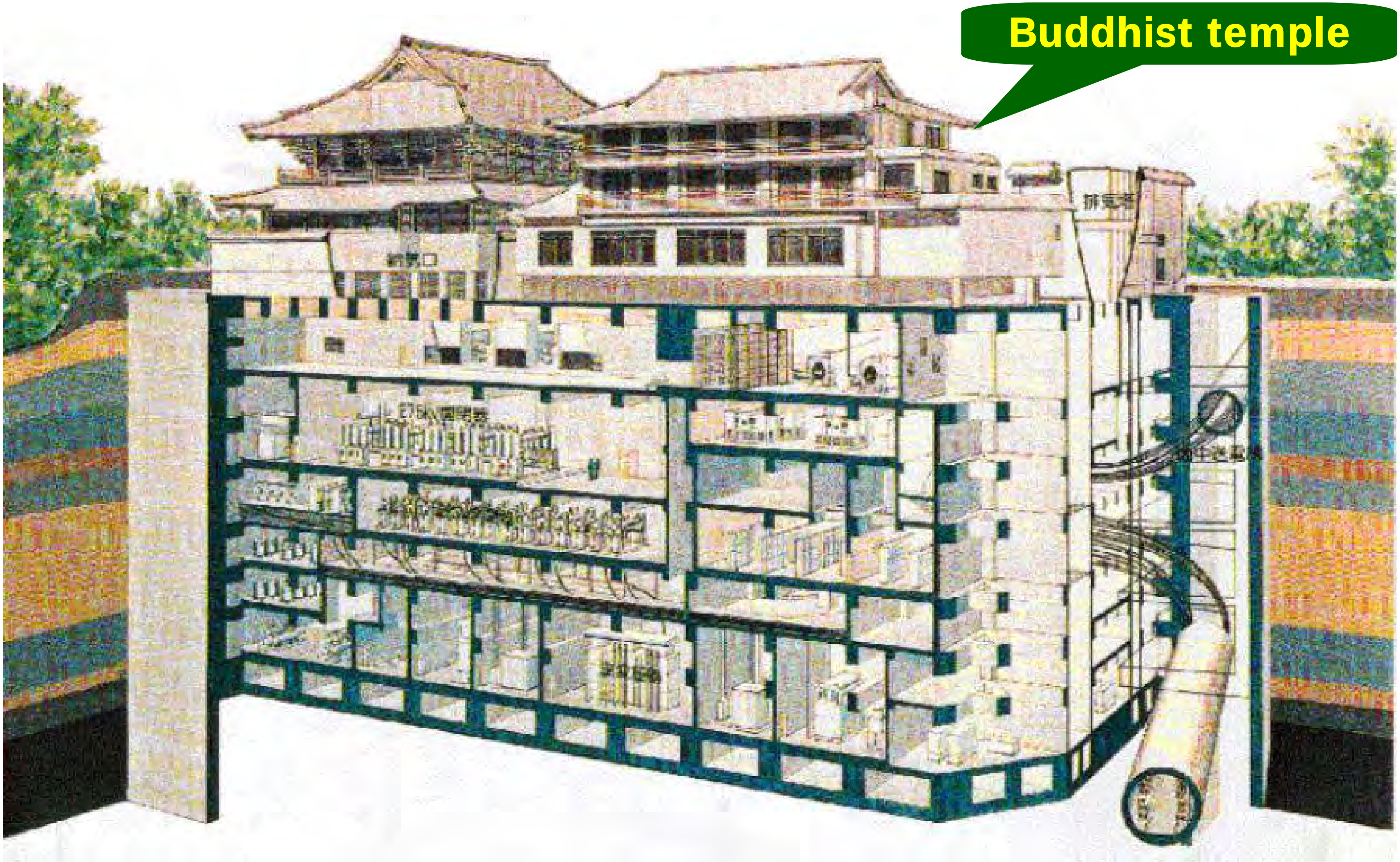
Sectional View


Substation Groundwork


Transformer Installation


500kV GCB(Gas Circuit Breaker)Installation

275kV Underground Substation

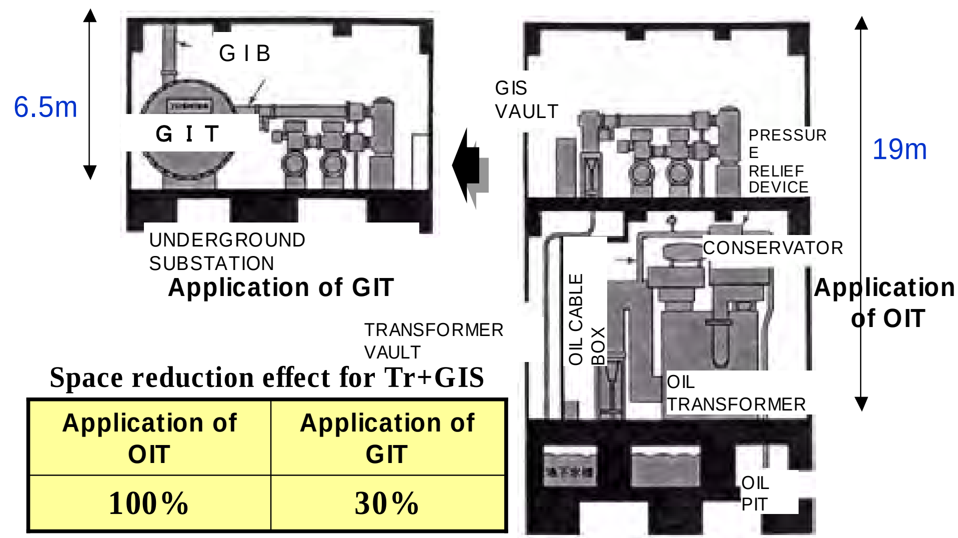


275kV Takanawa Substation

275kV Gas Insulated Transformer

275kV-300MVA GIT

- **Non flammable**
- **Space reduction**



Space reduction effect for Tr+GIS

Application of OIT	Application of GIT
100%	30%

Examples of Study Items of Tokyo Underground Cables

April 2010

Tokyo Electric Power Company

Typical Study Items for Underground Cables

1. Series resonance overvoltage
2. Parallel resonance overvoltage
3. Oscillatory overvoltage by islanding
4. Voltage Variation
5. Reactive Power Compensation
6. Switching overvoltage
7. Lightning overvoltage
8. Auto-reclose system

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4. Voltage Variation

Compensation rate of a cable is low as a design or due to an outage of a shunt reactor.

↓

The cable is a reactive power source.

↓

Sudden loss of the cable can cause voltage variation.

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5. Reactive Power Compensation

- Appropriate amount of shunt reactors will be found from the voltage profile in off-peak demand
- If the length of the cable is very long, necessity of shunt reactor stations (or switching stations) along the length of the cables will be found from the following aspects:
  - ✓ Voltage around the center of the cable
  - ✓ Active power loss in the cables
  - ✓ Impact on the transmission capacity

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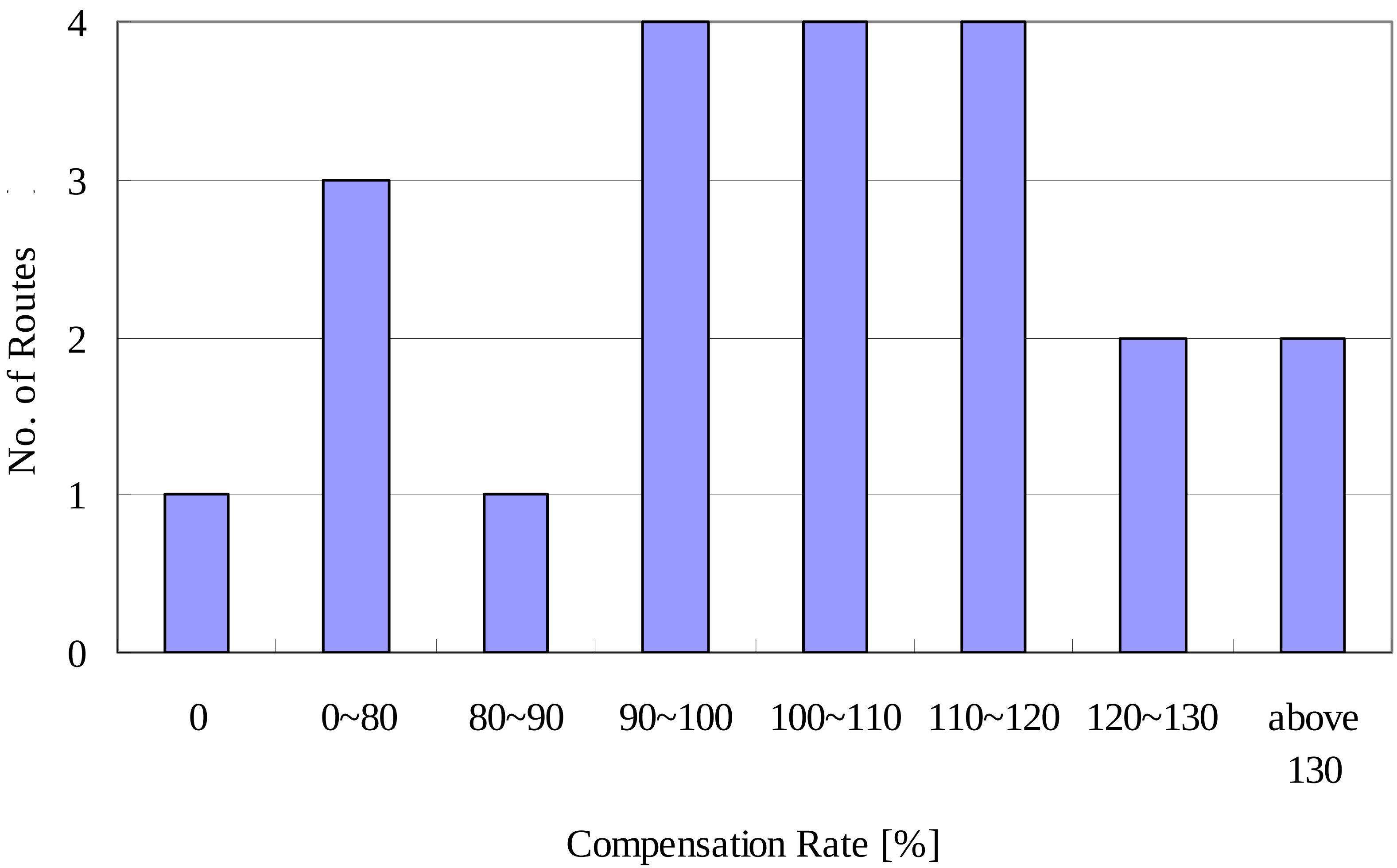
5. Reactive Power Compensation: Compensation Rates of EHV Cables in TEPCO



Most shunt reactors are automatically switched at scheduled times to control system voltages.

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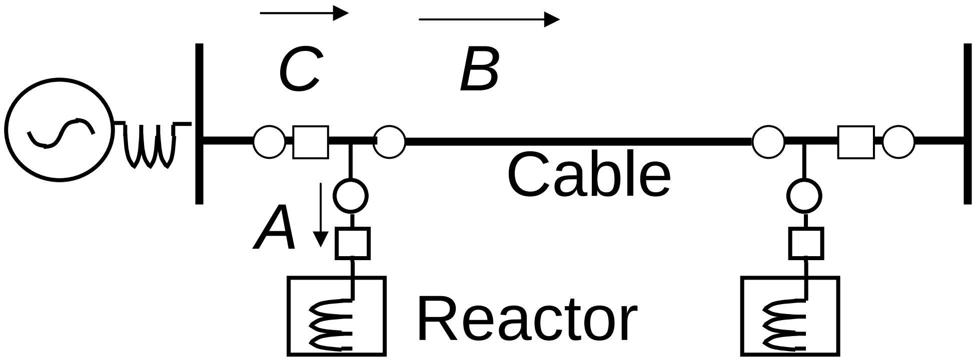
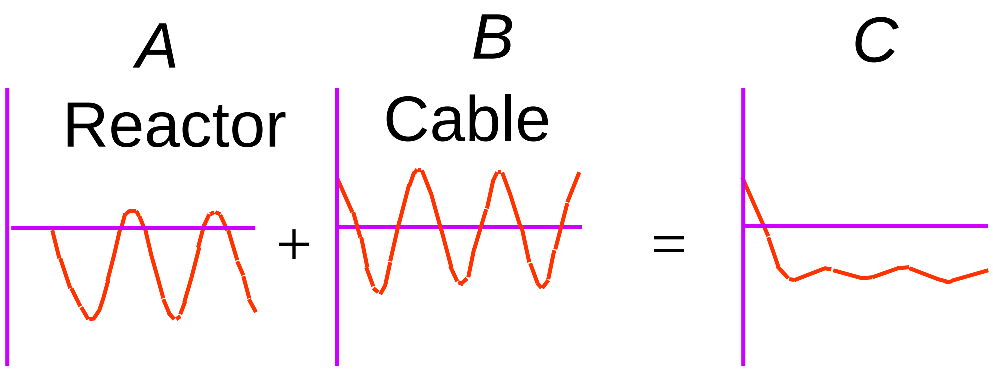
5. Reactive Power Compensation DC Offset Current



Close *C* under a no load condition with a shunt reactor

Current on *C* has dc-component for several seconds.

If a fault occurs during this periods, circuit breaker cannot interrupt fault current.



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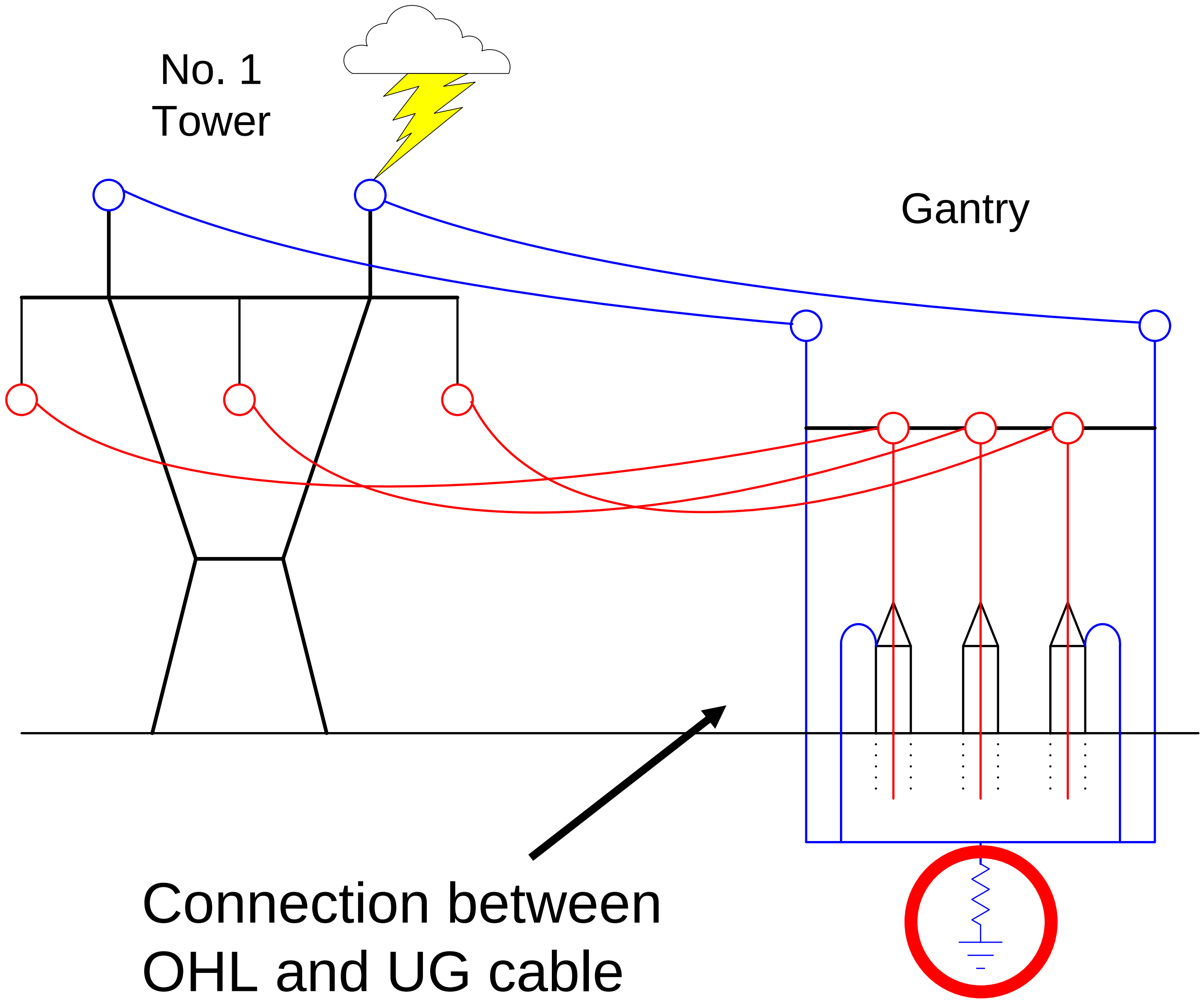
7. Lightning Overvoltage



Sheath overvoltage can be severe due to high grounding resistance of the gantry.

Evaluation of sheath overvoltage with SVL (sheath voltage limiter) is necessary.

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