The National HVDC Centre

2023 HVDC operators Forum

KEPCO's HVDC Utilization and Operation Plan for Net zero

2023. 6. 14

KEPCO RI (Research Institute)

Senior researcher(Ph.D) HyunKeun Ku

KEPCO KOREA ELECTRIC POWER CORPORATION

CONTENTS

* : Control, Flexibility and Inertia

CONTENTS

* : Control, Flexibility and Inertia

Active Grid Project team

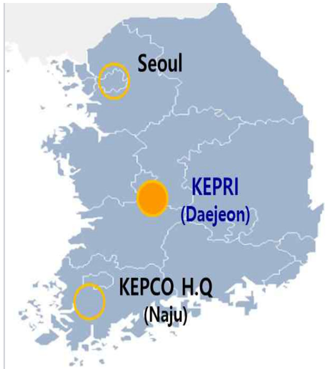
Overview of the Korea Power Grid

KEPCO

... Research Institute (KEPRI)

... Future Grid Research Center

- Grid Flexibility Management Project Team
- Flywheel Inertial Supply Project Team
- IBR Control Project Team
- Active Grid project team



- KEPCO is the sole Transmission Owner (TO) in South Korea (※ KPX is System Operator(SO))
- KEPCO : Planning, Constructing and O&M
  (T/L, S/S, HVDC, FACTS, and ESSs)
- KPX : Operation and market.
- KEPRI is the research institute of KEPCO
  - KEPCO : 24,000 workers
  - KEPRI : 700 researchers

Our Team Research Areas

- Future grid planning, HVDC, FACTS analysis, and its application
- Renewable energy hosting capacity and impact study
- Real Time Simulator(RTDS), HILS for Replica Controller, and other devices

NDC and Trends in Power Policies for Carbon Neutrality

Overview

☐ Continued **Expansion of Renewable Energy Expected** in line with NDC Upward Revision

☐ (9th Basic Plan) for Electricity (hosting) Requires 50.6GW of Renewable Energy Integration

- Commercial operation status : 27.1GW, '22.6

Renewable Energy Share and Capacity by Energy Policy

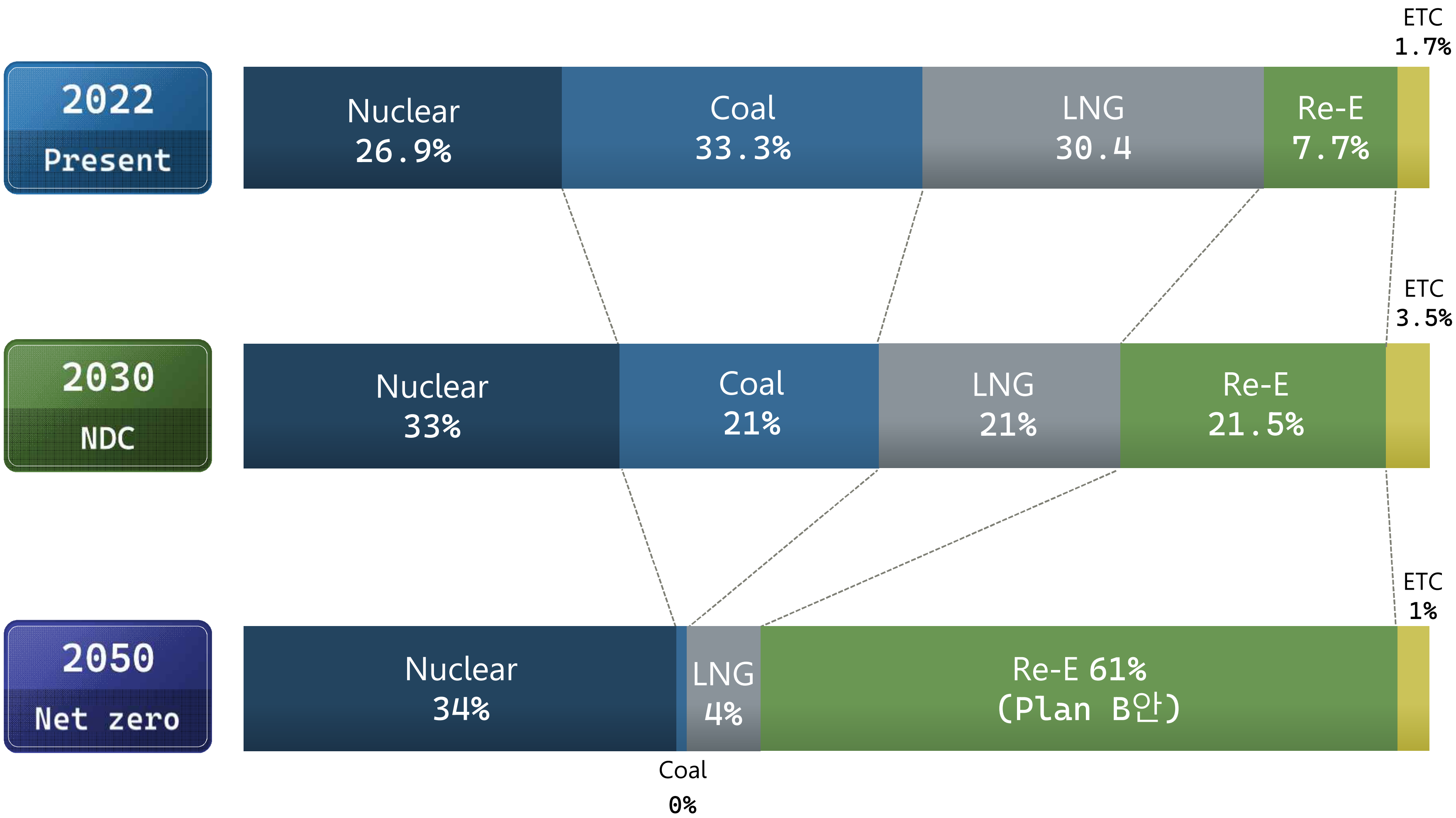
Policy	target	Re-E gen ratio	Re-E capa.	-
8th basic Plan power supply	'30	20%	58.6GW	PV (34GW), Wind(18GW)
9th basic Plan power supply	'34	26.1%	77.8GW	PV(46GW), Wind(24GW)
3rd basic Plan energy	'40	30 ~ 35%	114 ~ 140GW	-
NDC object	'30	20 ~ 30%	61.3 ~ 97.8GW	Nuclear gen 30%↑
2050 Net Zero	'50	61%	613.9GW	**net zero plan B**

→ **Systematic Expansion of Renewable Energy**

→ **Establishment of Timely Stable Power Grid Needed**

2030, 2050 Gen mix ratio Prospects (Estimated)

Overview



Current Status of Domestic Re-E (9th basic Plan)

Overview

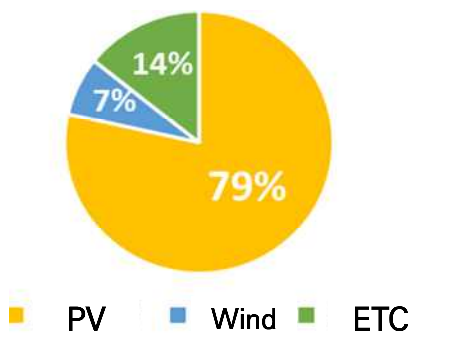
Commercial Operation Status : 27.1GW

Re-E	PV	Wind	Etc	Total
Capacity (GW)	21.2(79%)	2.0(7%)	3.9(14%)	27.1(100%)

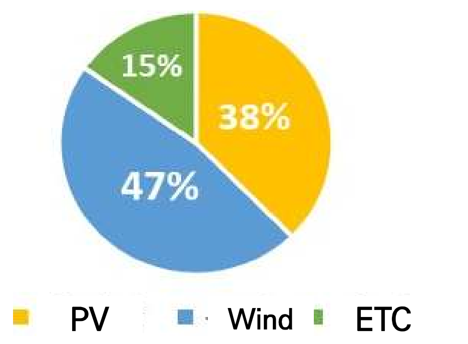
Connection application Status : 30.7GW (excluding commercial)

Re-E	PV	Wind	Etc	Total
Capacity (GW)	+11.6(38%)	+14.9(47%)	+4.7(15%)	+30.7(100%)

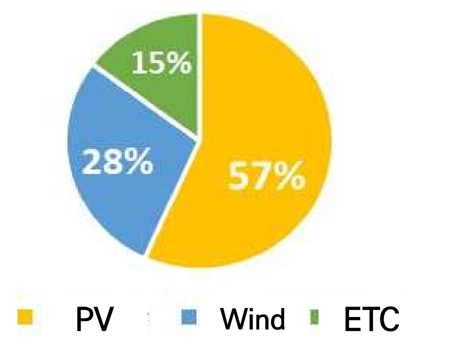
Total commercial



Total application



Sum



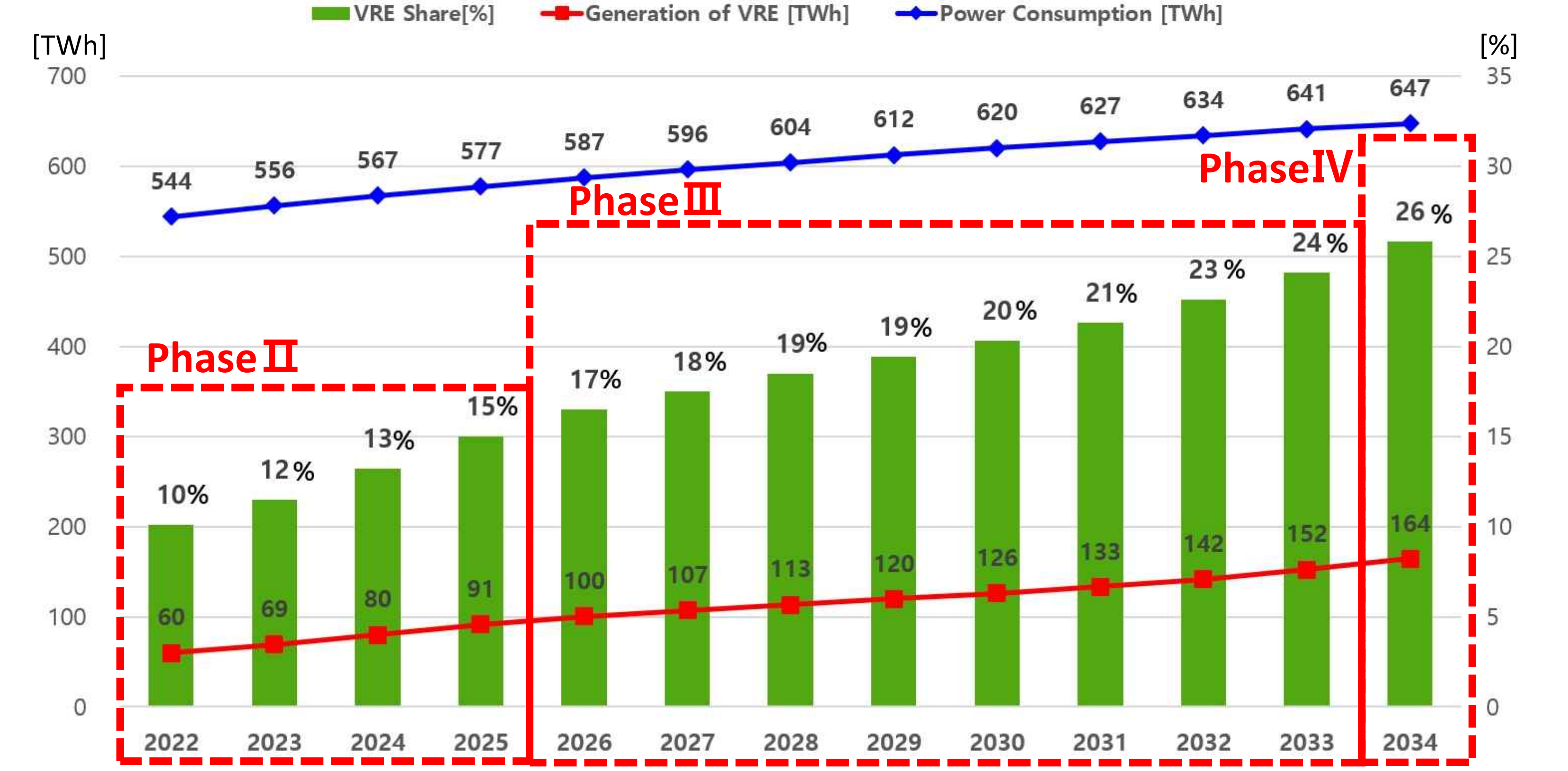
※ ETC : Fuel cell, Hydro, Biomass, Organic...

Forecast for the Proportion of Renewable Energy Generation

Overview

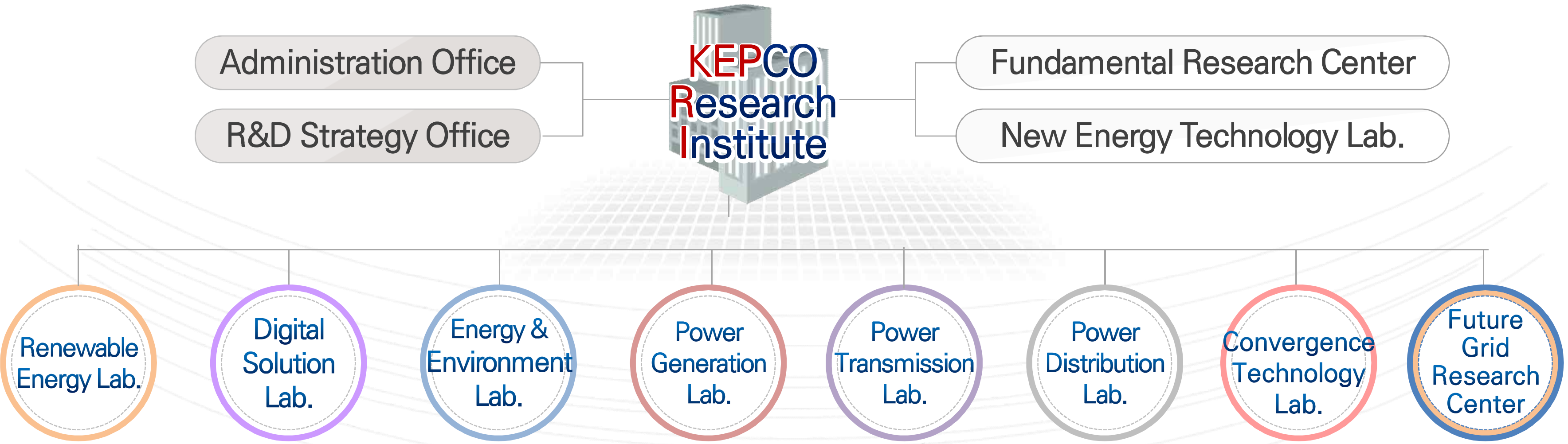
→ : 10%('22) → 20%('30) → 26%('34)

Forecast for the proportion of Re-E ('22~ '34, IEA phase)



KEPRI – organization and human resources

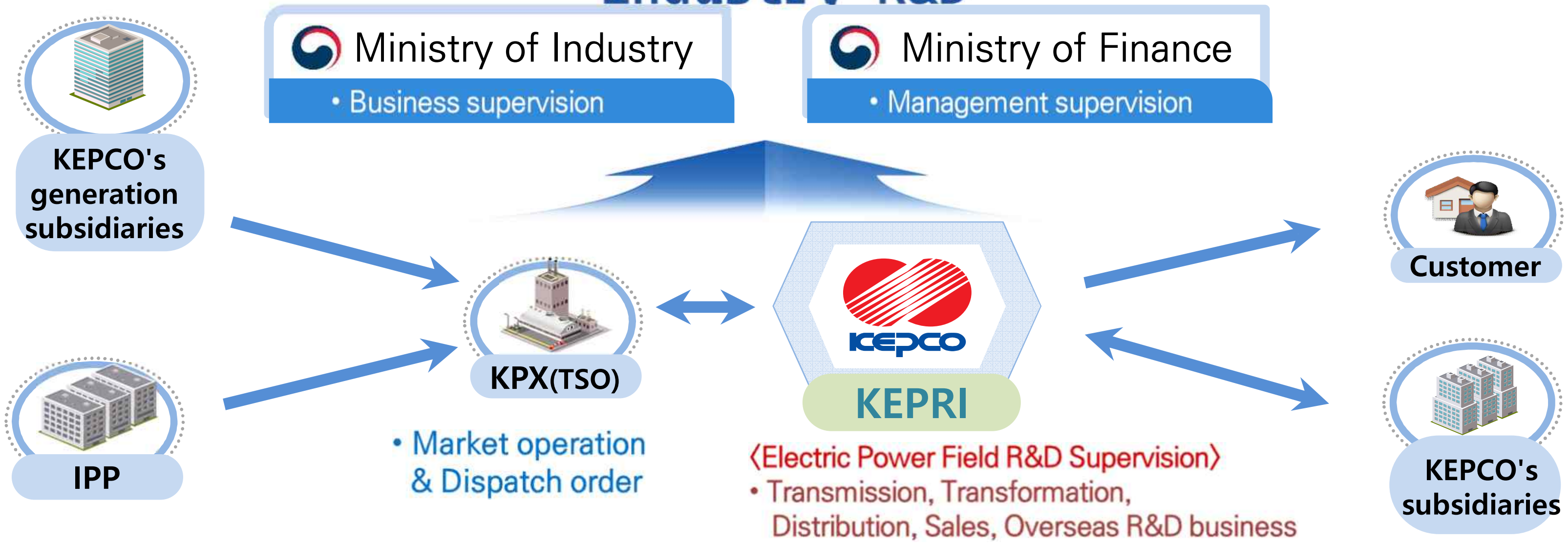
8 Laboratory / 2 Office / 2 Center, 664 People



✔ Human Resource : 664 people [Researcher : 469, Others : 195]

KEPCO Research Institute [Daejeon]	Electric Power Test Center [Gochang]	Fundamental Research Center [Seoul]	New Energy Technology Lab. [Naju]
			

Performing a pivotal role in the Electric power industry R&D



Securing Future Growth Engines

- Leading Carbon Neutrality (Energy Transition) and Digital Transformation
- Development of eco-friendly technology

Contribution to Management

- Gain revenue, cost-saving technology
- Tech-commercialization and resolving issues

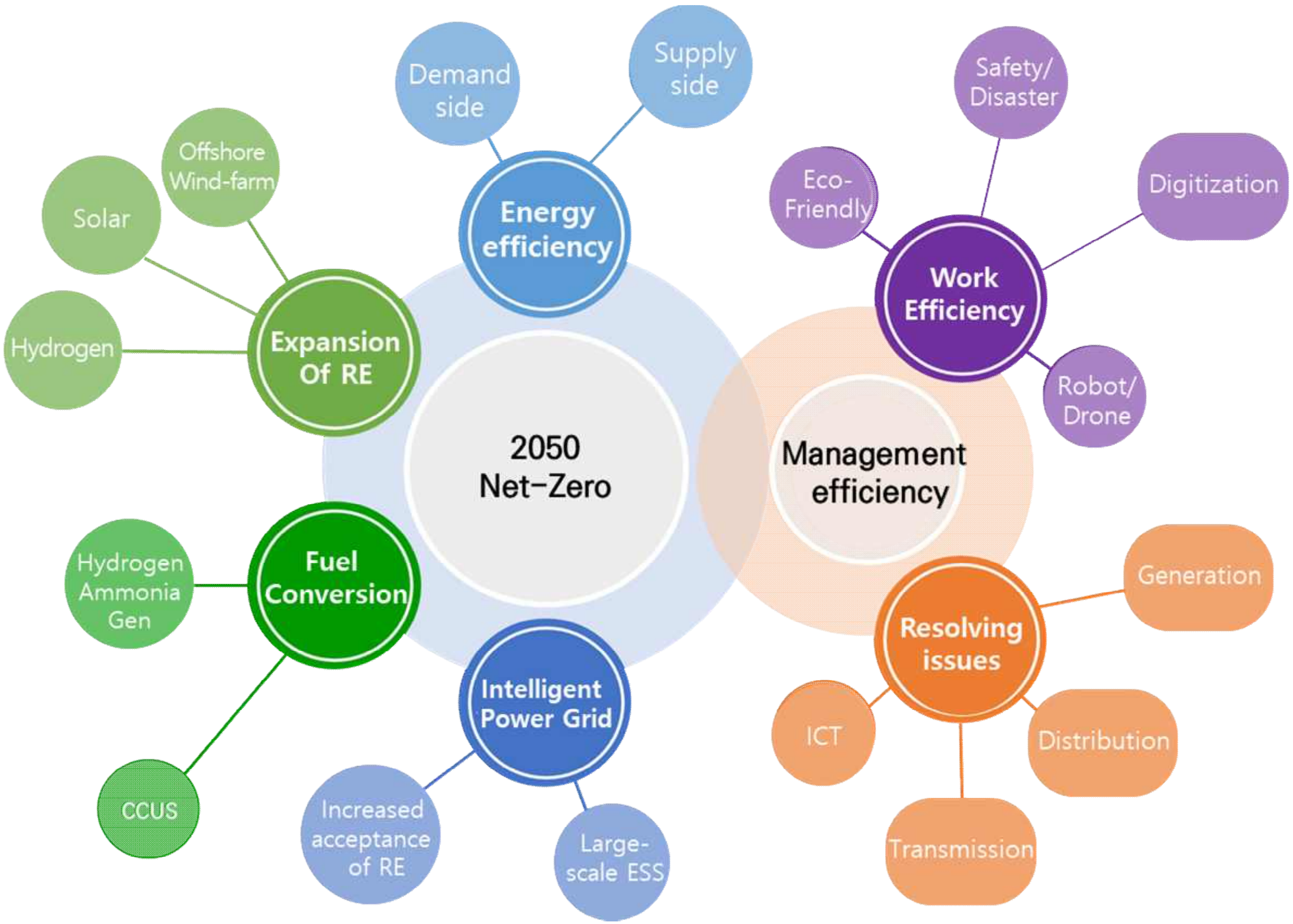
Development of Power supply stabilization Tech.

- Improving the performance of power facilities
- Operation and prevention/diagnosis Tech.

Leading Electric power industry R&D

- Technical cooperation between institutions
- Joint research and Technical support

'22 R&D Investment Plan : 550 Project, EUR 1.76 billion



CONTENTS

Ⅱ CFI* Strategy for Renewable energy penetration in Jeju island

* : Control, Flexibility and Inertia

Status and Prospects of RE in Jeju

☐ (S&D) **Over generation owing to RE penetration increase**(1% load of mainland's)

- RE capacity 871MW(40%) / Jeju Gen cap 2,181MW('21)

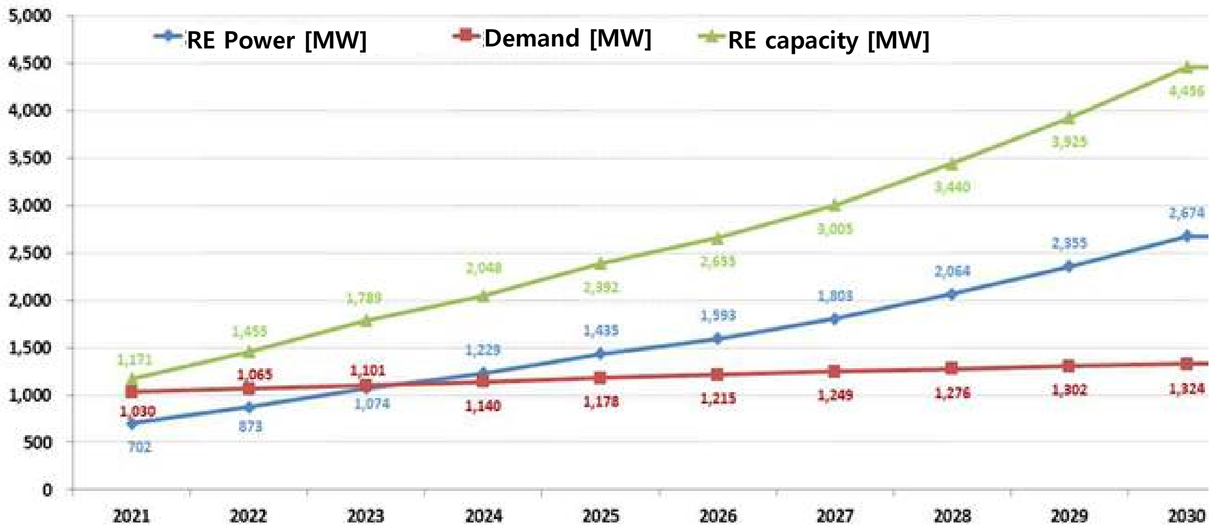
Contents	Max demand	Sources				Remarks
		SG	RE	HVDC	total	
Cap(MW)	1,012('21)	910 (42%)	**871** **(40%)**	400 (18%)	2,181 (100%)	over cap than needed(1169MW)

☐ (RE Pros.) 13% grow by year, **Gen cap with 3 times the demand in 2034**

- Jeju Gen cap(5.7GW*), Demand(1.4GW), RE cap 78.6% of Jeju Gen cap

  * Jenu Gen cap('34) : SG 0.6GW, HVDC 0.6GW, **RE 4.5GW**

- RE share in Jeju(estimated) : 15%('21) → 34%('25) → 71%('30**)**



cf. RE penetration level in main land

- 10%('21) → 16%('25) → 20%('30)

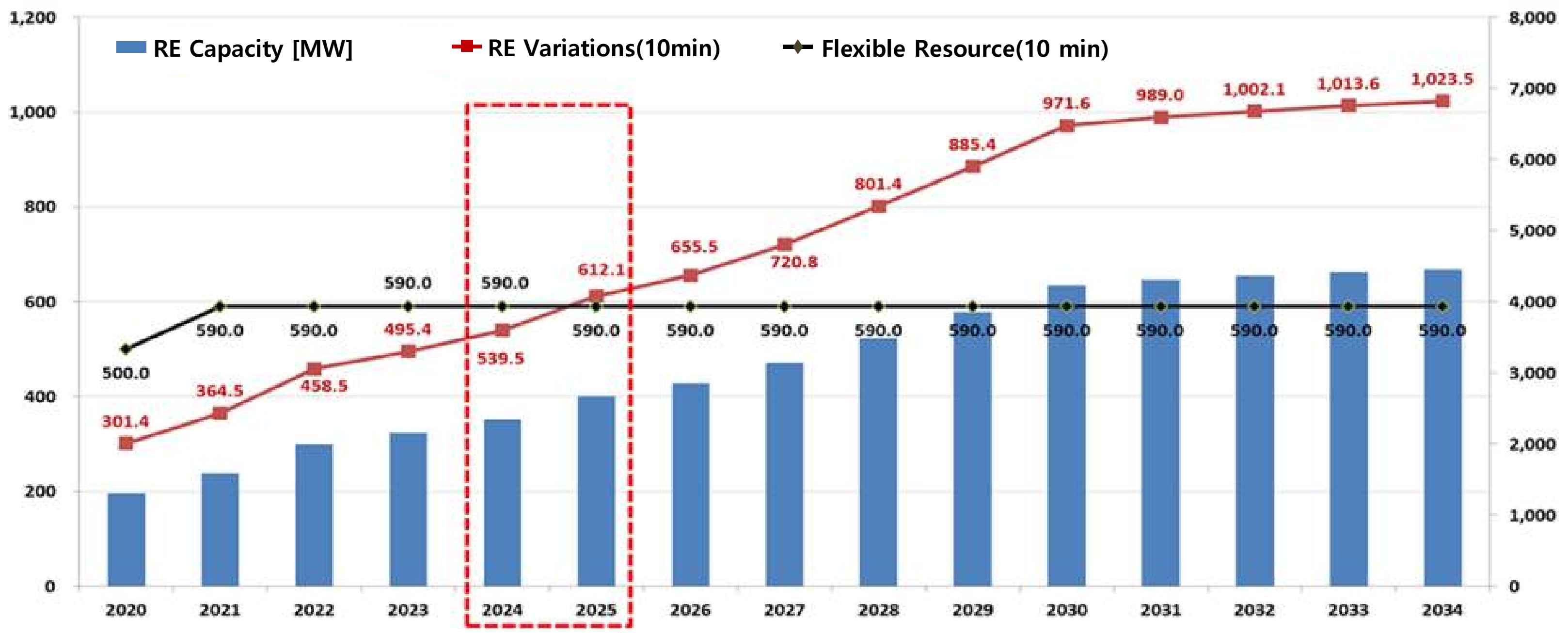
Issues of RE penetration increase in Jeju

□ (Flexibility) 10 min. reserve not enough to compensate RE variation

Contents	2018	2019	2020	2021		2030
RE Capacity [MW]	452	580	774	812	→	3,982
Curtailed Energy[MWh]	1,366	9,223	19,449	10,158		724,272

○ **Lack of Flexibility since 2025** → flexible resource needed

* flexibility increase by SG, ESS, dispatchable RE, RE forecast/monitoring/control, HVDC



Lack of Flexibility

Our Goal for RE in Jeju Grid

Demonstration of CFI (Control, Flexibility, Inertia) in Jeju
to improve the system stability and RE penetration level

	RE output control (**C**ontrol)	Grid flexibility (**F**lexibility)	System inertia (**I**nertia)
Tech	Real-time curtail	ESS for NTAs	Flywheel Sync Condenser GFM for artificial inertia
			
Def	RE output control remotely using RE forecasting and monitoring system	ESS to relieve transmission congestion which may occur according to RE variability	System inertia improvement using flywheel SC and Inverter-based Resources
items	- Forecast and monitor RE - Estimate penetration level - Remote control of RE output (real-time, day-ahead) - Grid code of RE	- NTA ESS control for congestion relief (Non-Transmission Alternatives) - Multi-purpose ESS - Grid Planning considering NTAs	- Demonstration of Flywheel Synchronous Condenser - Design of Flywheel SC - IBR and artificial inertia for RE and ESS

CONTENTS

Ⅲ Korea HVDC projects

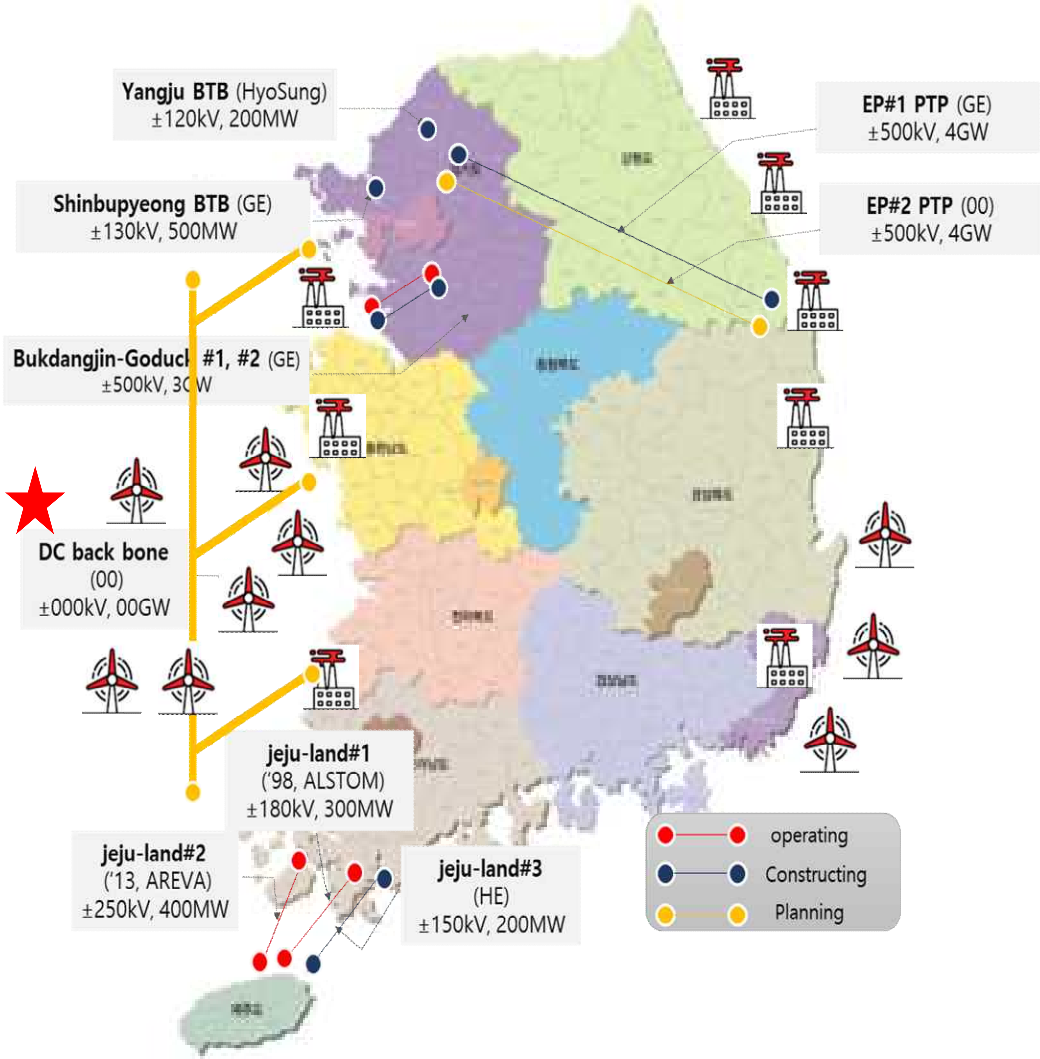
HVDC Projects

Large scale renewable E connection & concentration of power generation
→ Expand transmission lines

Demand high-capacity power transmission and increased stability
→ Increase IBR(HVDC, FACTS, …) facilities

AC-DC complex power grid
→ Advanced operational strategy (control interaction, interoperability)

★ power system analysis
→ System impact analysis, operating system, DC based facilities performance verification



CONTENTS

Ⅳ Research Projects

Overview (Our team)

Research Projects (recent 3y)

□ **Developing** stable **operation strategy and control performance optimization** technology according to the completion of GW-level **Embedded HVDC** and changes in system operation conditions ('20.01 ~ 22.12 / 1.2£M)

□ Optimal **asynchronous power grid division** technology development and operating system design **using VSC HVDC** ('21.01 ~ 22.12 / 0.5£M)

□ Analysis of **renewable energy hosting capacity** and development of **automated stability analysis tool** for long-term transmission grid ('23.02 ~ 25.07 / 0.9£M)

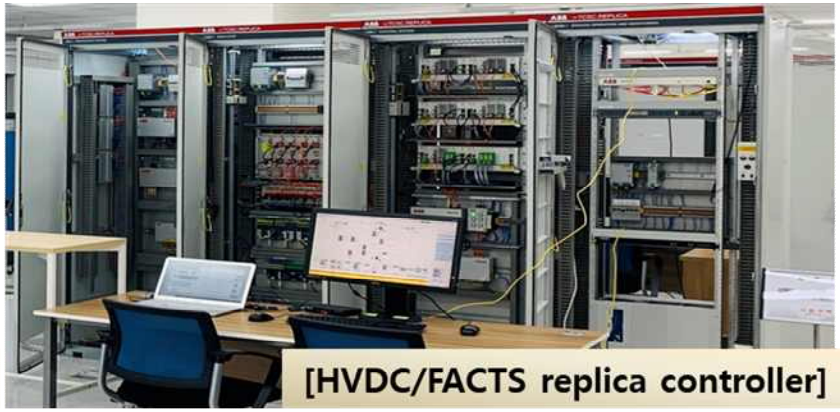
□ Development and demonstration of **online supervisory HVDC control system** ('23.03 ~ 27.02 / 3.9£M)

□ Development and demonstration of **online power generation constraint assessment system** based on dynamic stability ('23.07 ~ 26.06 / 2.3£M)

Our laboratory configuration

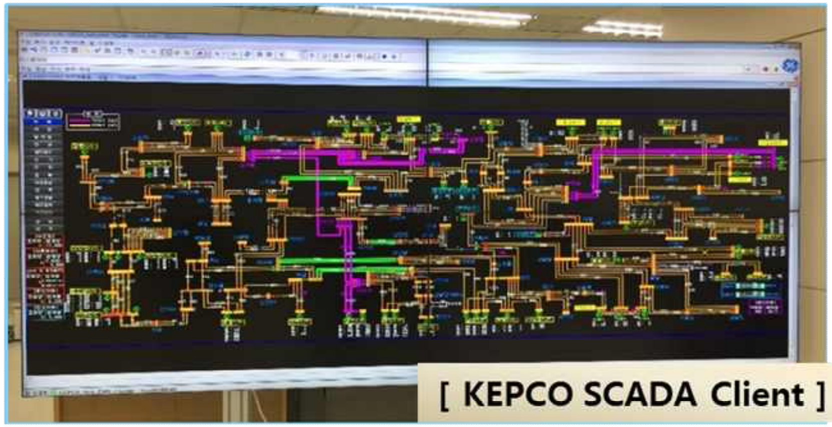
Research Projects

[Real Time Digital Simulator]



[HVDC/FACTS replica controller]

[Replica controller operating]



[KEPCO SCADA Client]

Replica Controller Status

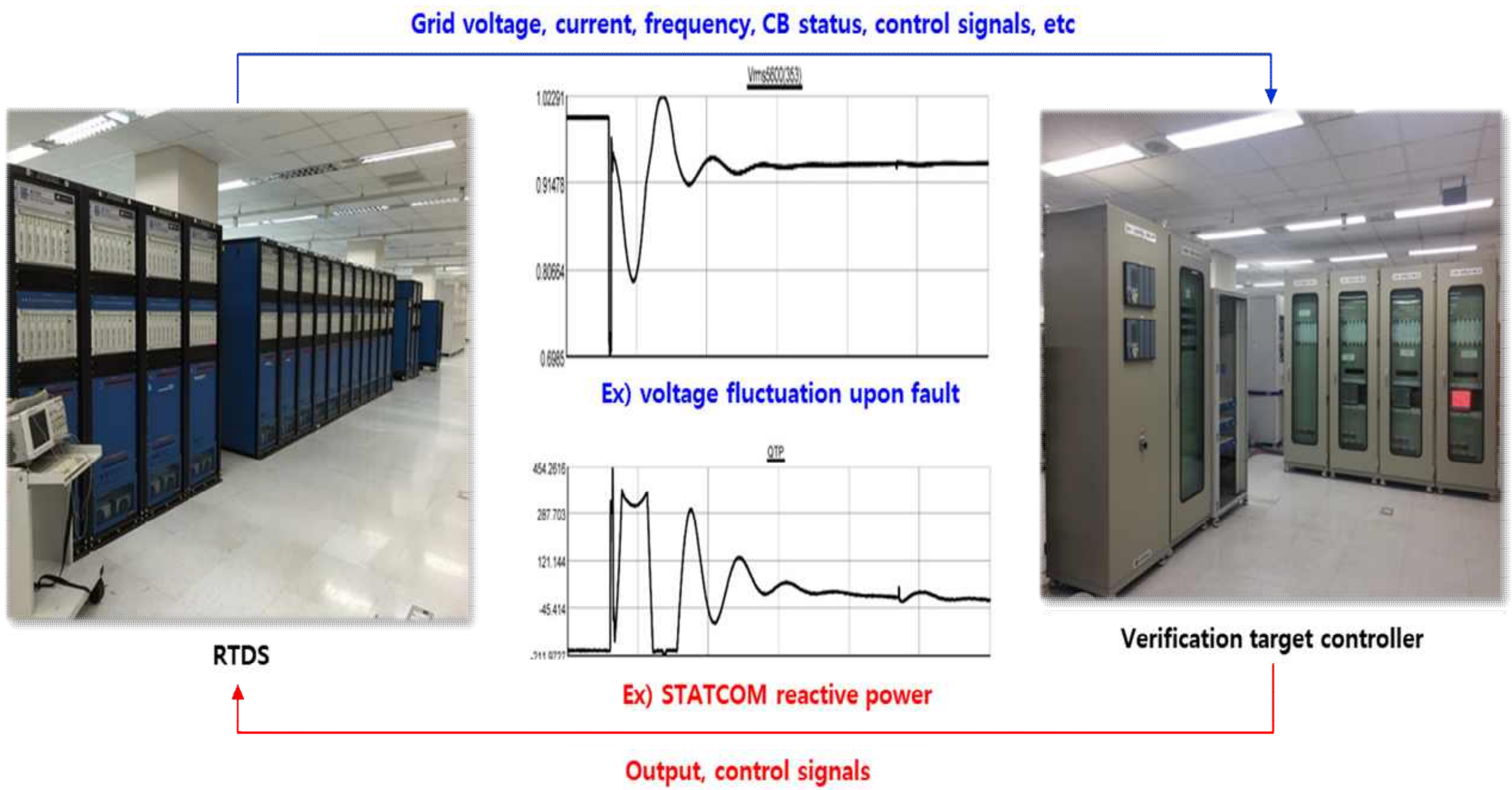
- In operation
  - 2 TCSC Controllers ('19, ABB) ,1 STATCOM ('20, LS Electric)
- To be Installed
  - 1 Bi-pole LCC HVDC Controllers ('22, GE)
  - 1 VSC BTB HVDC Controllers ('24, Hyosung)
  - 1 VSC BTB HVDC Controllers ('24, GE)

Study Cases

- FACTS Dynamic Performance Test ('18~)
- Field fault reproduction and analysis
  - Shinjecheon TCSC gain tunning ('19~21)
  - HVDC/STATCOM interaction test ('21)
  - SSTI analysis ('22~)
  - Domestic BTB HVDC DPT ('23.6~)

Major Performance

HVDC/FACTS Dynamic Performance Test (DPT)



Concept of DPT connection with RTDS and target controller

Deliverable – In house Tool #1

HVDC ELCAT(Entire Life-cycle Analysis Tool)

- Purpose : Automatically analysis in total HVDC optimal power transfer range
- Pre-installation required : PSS/E(over v33.4)
- Data managing : System topology(*.sav, *.raw), Contingency list(*.con), Monitoring(*.sbsxml), Harmonic impedance(*.csv), UIF gen list(*.csv)
- Analysis Modules : SCR, FFTOV, UIF, MIIF, GSE, RPC Harmonic Impedance scanning, Filter performance/rating, Reliability(overload, over/under voltage)

Planning (Specification)

· Select HVDC rating
· Main control scheme
· System strength(SCR)
· Reactive Power Capability
· Harmonic impedance Scan
· Screening interaction

Design Verification

· Temporary Overvoltage
· Filter design
· Main scheme parameter
· Damping control (POD, SSDC, etc)

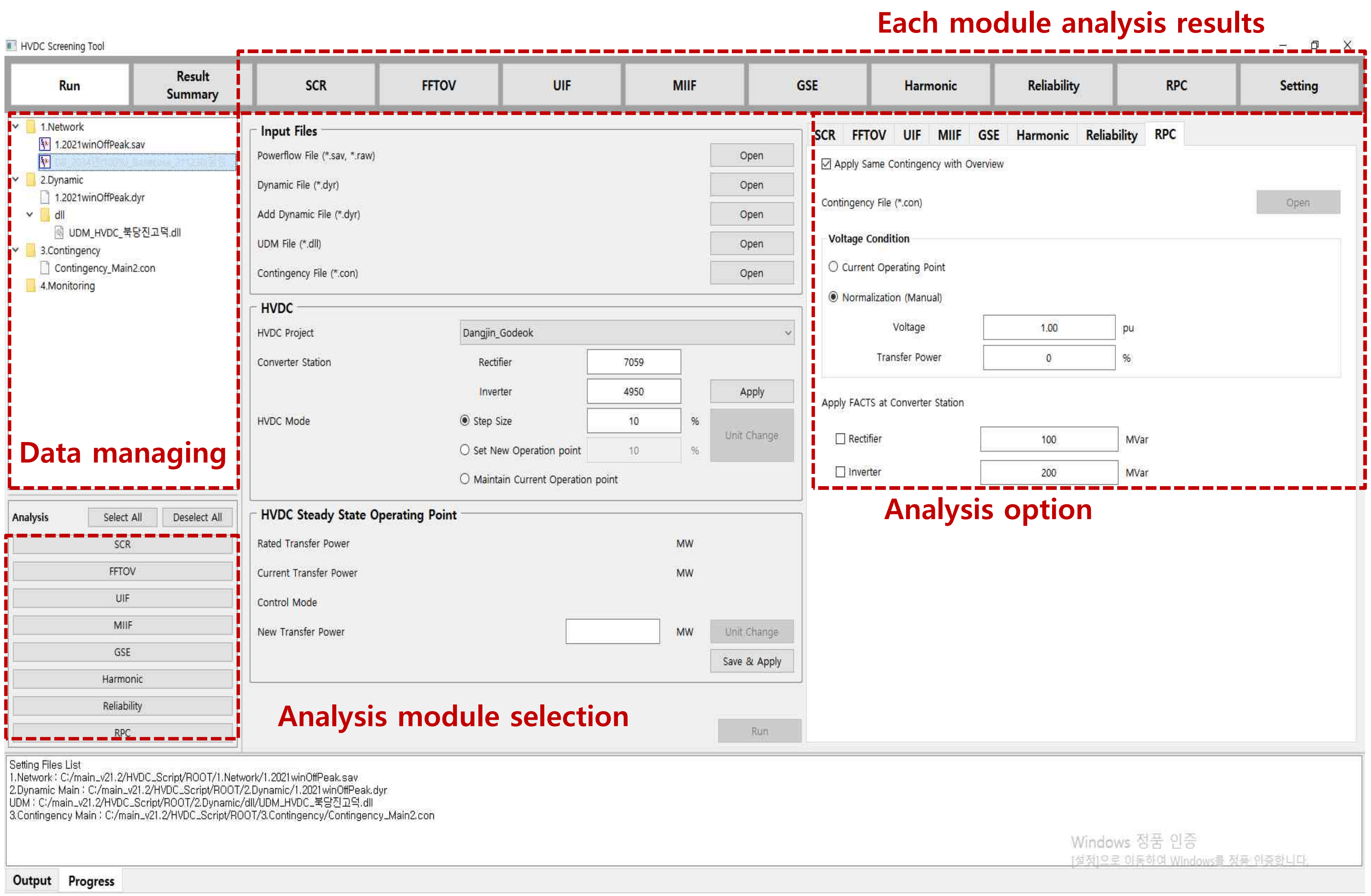
Operation

· System stability
· Facility rating
· Harmonic performance
· Interaction study
· Remedial/mitigation action

Deliverable – In house Tool #1

Research Projects

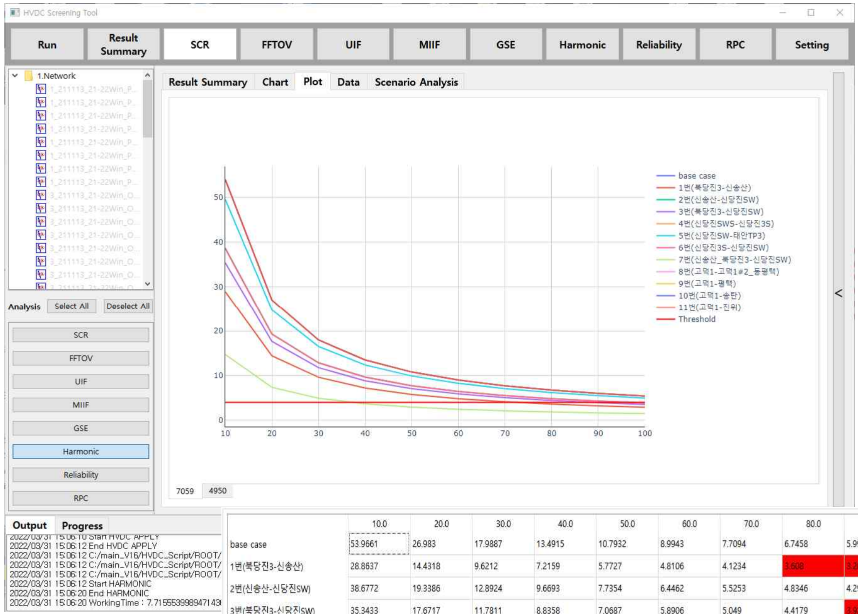
HVDC ELCAT HMI Overview



Deliverable – In house Tool #1

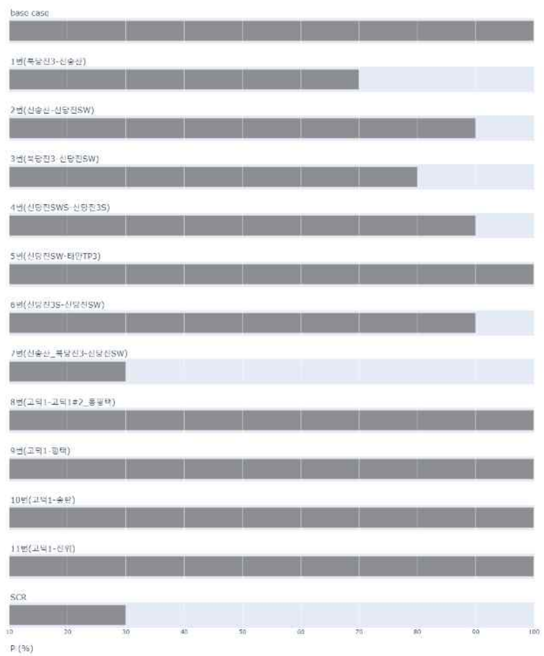
Research Projects

Operation Range Analysis Result



	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0
base case	53.9661	26.983	17.9887	13.4915	10.7932	8.9943	7.7094	6.7458	5.9962	5.3966
1번(북당진3-신송산)	28.8637	14.4318	9.6212	7.2159	5.7727	4.8106	4.1234	3.608	3.2071	2.8864
2번(신송산-신당진SW)	38.6772	19.3386	12.8924	9.6693	7.7354	6.4462	5.5253	4.8346	4.2975	3.8677
3번(북당진3-신당진SW)	35.3433	17.6717	11.7811	8.8358	7.0687	5.8906	5.049	4.4179	3.927	3.5343
4번(신당진SWS-신당진3S)	38.5204	19.2602	12.8401	9.6301	7.7041	6.4201	5.5029	4.8151	4.28	3.852
5번(신당진SW-태안TP3)	49.5209	24.7605	16.507	12.3802	9.9042	8.2535	7.0744	6.1901	5.5023	4.9521
6번(신당진3S-신당진SW)	38.5204	19.2602	12.8401	9.6301	7.7041	6.4201	5.5029	4.8151	4.28	3.852
7번(신송산_북당진3-신당진SW)	14.7183	7.3591	4.9061	3.6796	2.9437	2.453	2.1026	1.8398	1.6354	1.4718
8번(고덕1-고덕1#2_동평택)	53.9651	26.9826	17.9884	13.4913	10.793	8.9942	7.7093	6.7456	5.9961	5.3965
9번(고덕1-평택)	53.9446	26.9723	17.9815	13.4861	10.7889	8.9908	7.7064	6.7431	5.9938	5.3945
10번(고덕1-송탄)	53.9641	26.9821	17.988	13.491	10.7928	8.994	7.7092	6.7455	5.996	5.3964
11번(고덕1-진위)	53.9611	26.9805	17.987	13.4903	10.7922	8.9935	7.7087	6.7451	5.9957	5.3961

HVDC전송가능 영역 평가 툴 HMI화면



상정고장별 HVDC전송가능 영역 분석 결과

Deliverable – In house Tool #2

RTDS Pre/Post Processing Tool

- Purpose : Reducing errors and associations when converting RTDS DB by processing PSS/E DB
- Pre-installation required : PSS/E
- History : Developed ver1 in 2019(Network, Dynamic, RTDS, Miscellaneous)
  Developed ver2 in 2022(DB consistency comparison, Add Dyr default parameters, etc.)

Network

· Data Error Correction (Parameter Range, etc)
· Steady State Check (Topology, Slack, etc)
· Renew Energy Aggregation
· Resource Minimization
· Conversion & Integrity
· Result Verification

Dynamic

· modify Gen X Source
· Control System Limit
· Impedance Correction
· Numerical Stability Correct
· Governor Limit Constraint
· Gen Model Parameter

RTDS

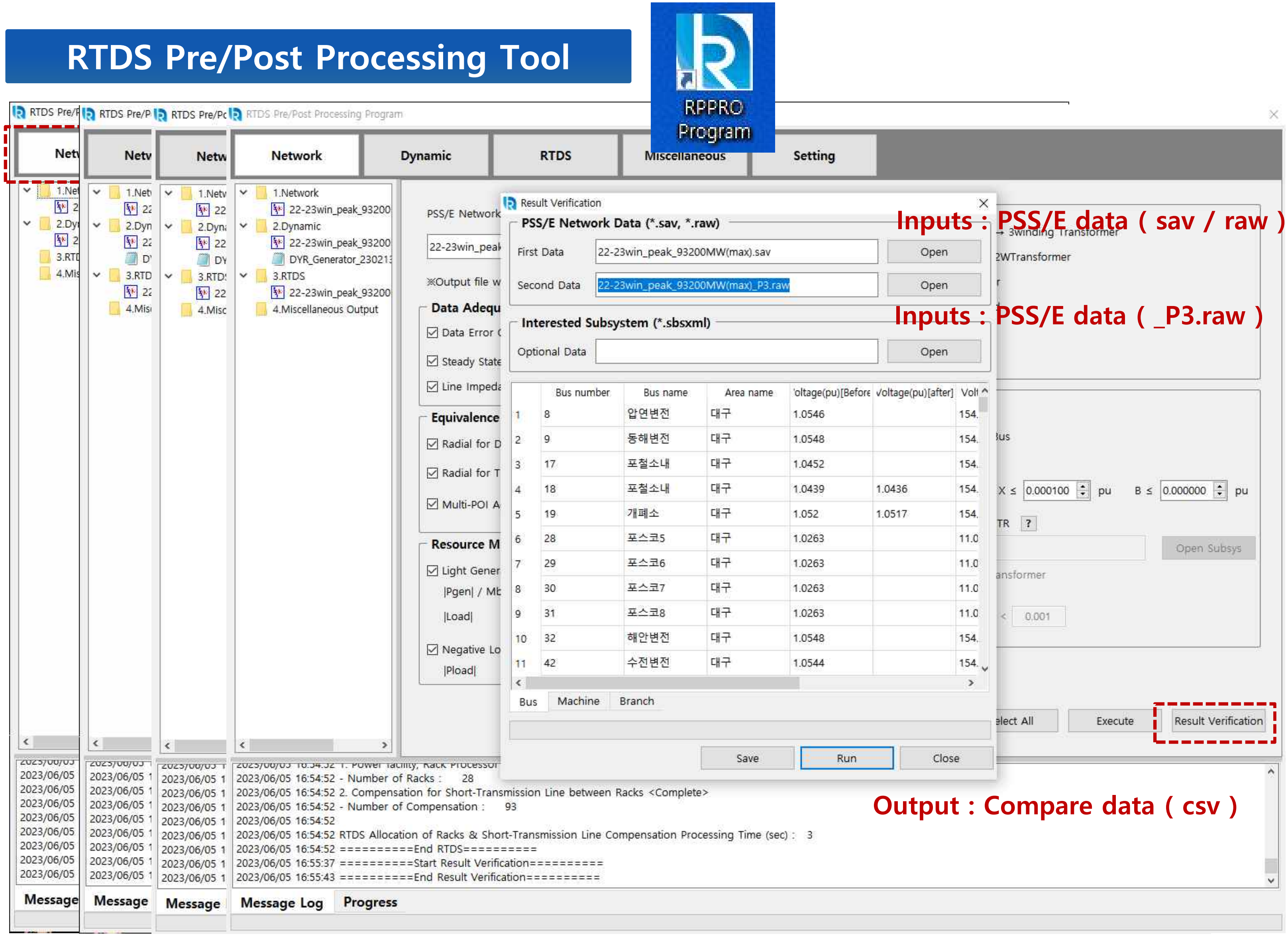
· Short Line Compensation
· Rack and Process Allocation

Miscellaneous

· Conversion Validation
· Generator Dynamic Response
· Modeling
· RTDS case Analysis
· RTDS Rack Manual Allocation
· SSTI Analysis

Deliverable – In house Tool #2 Research Projects

RTDS Pre/Post Processing Tool



Deliverable – In house Tool #2

RTDS Pre/Post Processing Tool

Bus Voltage Gap

	A	B	C	D	E	F	G	H	I
1		Bus numbe	Bus name	Area name	ge(pu)[Be	age(pu)[a	tage(Base	Deviation	Error(%)
2	0	8	압연변전	대구	1.0550095		154		
3	1	9	동해변전	대구	1.0551846		154		
4	2	17	포철소내	대구	1.0455332		154		
5	3	18	포철소내	대구	1.0442708	1.0438194	154	-0.000451	0.0432193
6	4	19	개폐소	대구	1.0523599	1.051905	154	-0.000455	0.0432269
7	5	28	포스코5	대구	1.0266926		11		
8	6	29	포스코6	대구	1.0266926		11		
9	7	30	포스코7	대구	1.0266926		11		
10	8	31	포스코8	대구	1.0266926		11		
11	9	32	해안변전	대구	1.0551847		154		
12	10	42	수전변전	대구	1.0547475		154		

Generator P & Q Gap

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1		Bus numbe	Bus name	Area name	ID	Pmin(MW	Pmax(MW	Qmin(Mva	Qmax(Mva	Mbase	n(MW)(Be	n(Mvar)(Be	Pdev(MW	Qdev(Mvar	Perr(%)	Qerr(%)	Prate(%)	Qrate(%)
2	0	21421	파주열GT1	경기북부	1	115	162	-70	98	220	153.89999	32.44458	1.4210052	0.6064873	0.9233303	1.8693023	0.6459115	0.275676
3	1	21422	파주열GT2	경기북부	1	115	162	-70	98	220	153.89999	32.44458	1.4210052	0.6064873	0.9233303	1.8693023	0.6459115	0.275676
4	2	21423	파주열ST1	경기북부	1	59.700001	172	-70	98	227	163.39999	44.14027	1.5149994	0.57687	0.9271722	1.3069018	0.6674006	0.2541277
5	3	21441	포천GT1	경기북부	1	173	238.00002	-110	155	355	234.8	67.876091	2.2229919	0.9971237	0.9467598	1.4690353	0.6261949	0.2808799
6	4	21442	포천GT2	경기북부	1	173	238.00002	-110	155	355	234.8	10.716651	2.2229919	1.219223	0.9467598	11.376903	0.6261949	0.3434431
7	5	21443	포천ST1	경기북부	1	87	245	-100	137	315.79999	242.40001	13.079314	2.2979889	1.2828865	0.9480152	9.8085151	0.7276723	0.4062339
8	6	21444	포천GT3	경기북부	1	173	236.5	-110	155	355	233.2	10.775355	2.2070007	1.1865625	0.9463983	11.011818	0.6216903	0.334243
9	7	21445	포천GT4	경기북부	1	173	236.5	-110	155	355	233.2	67.879974	2.2070007	0.9958191	0.9463983	1.4670293	0.6216903	0.2805124
10	8	21446	포천ST2	경기북부	1	87	244	-100	137	315.79999	240.00002	13.153669	2.2739868	1.2495651	0.9474944	9.4997456	0.7200719	0.3956824
11	9	21471	포천천연G	경기북부	1	232	290	-129	180	413	275.5	26.445702	2.6260071	1.2101345	0.9531786	4.5759214	0.6358371	0.2930108
12	10	21472	포천천연G	경기북부	1	232	290	-129	180	413	275.5	26.139174	2.6260071	1.2112827	0.9531786	4.6339749	0.6358371	0.2932888

Branch P & Q Gap

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1		From Bus nun	Bus num	ranch nan	m Area na	Area nan	ID	ate A(MVA	MW)[Befo	Mvar)[Bef	(MW)[Afte	Mvar)[Aft	Pdev(MW	Qdev(Mvar	Perr(%)	Qerr(%)	Prate(%)	Qrate(%)
2	0	8	9	압연변전-	대구	대구	1	3.0822439	0.0001154	-9.043303								
3	1	8	9	압연변전-	대구	대구	2	3.0822439	0.0001154	-9.043303								
4	2	8	42	압연변전-	대구	대구	1	7.399601	-0.000173	21.710428								
5	3	8	42	압연변전-	대구	대구	2	4.8277578	-0.000173	21.710428								
6	4	8	130	압연변전-	대구	대구	1	2.8369823	5.7669E-5	-12.66713								
7	5	8	130	압연변전-	대구	대구	2	8.6347141	5.7669E-5	-12.66713								
8	6	9	32	동해변전-	대구	대구	1	0.0820218	-4.562E-6	-0.240652								
9	7	9	32	동해변전-	대구	대구	2	0.0820218	-4.562E-6	-0.240652								
10	8	17	42	포철소내-	대구	대구	1	8.9996424	0.0861515	-48.27401								
11	9	17	8560	포철소내-	대구	대구	1	8.9996424	-0.086152	48.274006								
12	10	18	96	포철소내-	대구	대구	2	7.7598095	0.0634079	-41.62357	0.0633572	-41.58735	-5.07E-5	0.0362282	0.0799604	0.0870376	9.4521E-6	0.0067539

Deliverable – In house Tool #3

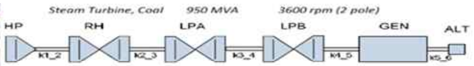
Research Projects

SSTI analysis tool

UIF Study > 0.1 (Unit Interaction Factor) → Damping Analysis (Mech, Elec) → Time Domain Simulation → Mitigation Strategy (Grid Topology change, SSDC Tuning)

① Gen-turbine data → ② Mech. damping analysis ③ Vendor's UDM + RTDS large scale power grid model → ④ Elec. Damping analysis → ⑤ Compare

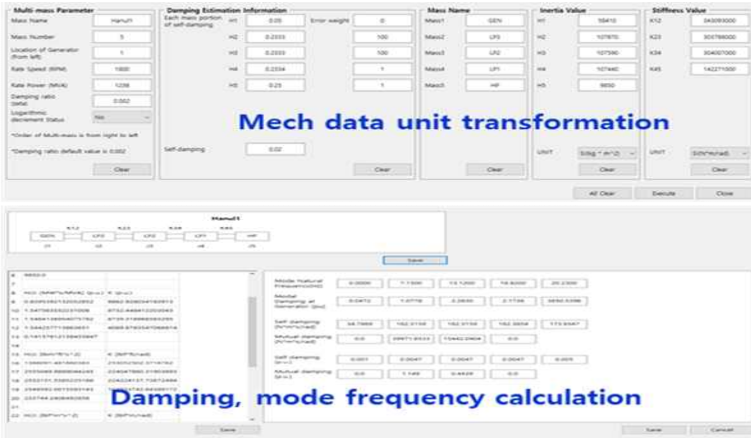
4 masses – turbine Gen



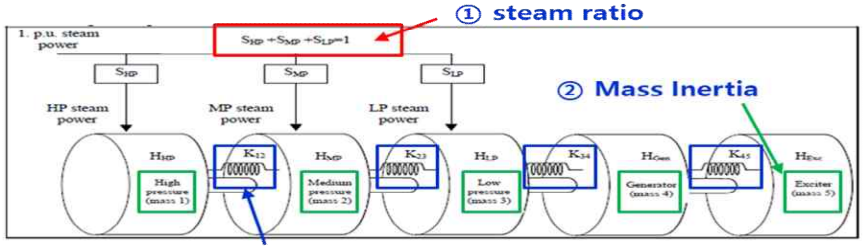
Torsional Input Data

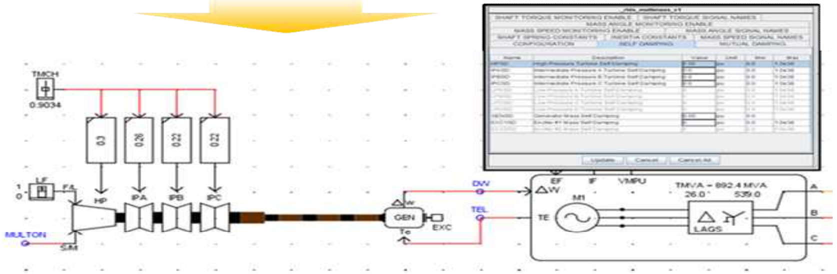
#	Mass Name	Inertia [lbm-ft²]	Shaft Section	Shaft Stiffness [Mlbf-in/rad]
1	HP	30308	k1_2	435.620
2	RH	51840	k2_3	796.186
3	LPA	204900	k3_4	1322.983
4	LPB	213821	k4_5	1309.156
5	GEN	211325	k5_6	34.324
6	ALT	3051		

Mechanical data



In house tool





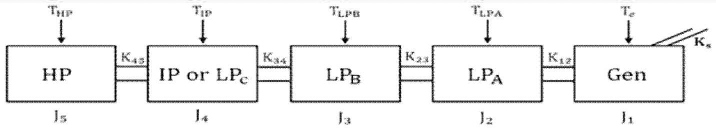
Put RTDS multimass gen data

Deliverable – In house Tool #3

Research Projects

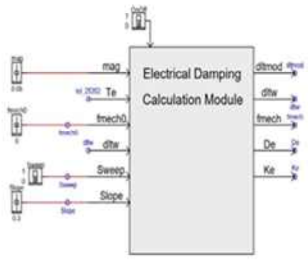
SSTI analysis tool

Turbine Inertia(J), Spring constant(K) (site acquisition / design data) → Mode frequency & Mech damping Based Modal analysis → Elec damping based Perturbation Simulation → SSTI analysis ($D_e + D_M > 0$) → Time domain Simulation



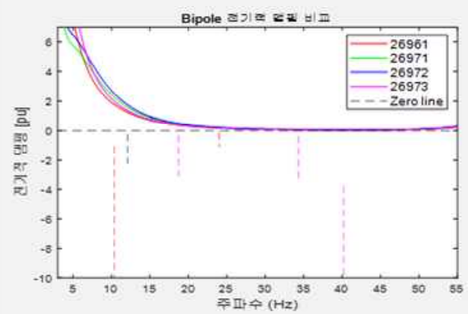
$$\begin{bmatrix} J_1 & 0 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 & 0 \\ 0 & 0 & J_3 & 0 & 0 \\ 0 & 0 & 0 & J_4 & 0 \\ 0 & 0 & 0 & 0 & J_5 \end{bmatrix}\begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{\theta}_3 \\ \ddot{\theta}_4 \\ \ddot{\theta}_5 \end{bmatrix} + \begin{bmatrix} K_{12} & -K_{12} & 0 & 0 & 0 \\ -K_{12} & K_{12}+K_{23} & -K_{23} & 0 & 0 \\ 0 & -K_{23} & K_{23}+K_{34} & -K_{34} & 0 \\ 0 & 0 & -K_{34} & K_{34}+K_{45} & -K_{45} \\ 0 & 0 & 0 & -K_{45} & K_{45} \end{bmatrix}\begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} -T_e \\ T_{LPA} \\ T_{LPB} \\ T_{IP} \\ T_{HP} \end{bmatrix}$$

$$\therefore J\ddot{\theta} + K\theta = T$$ State equation

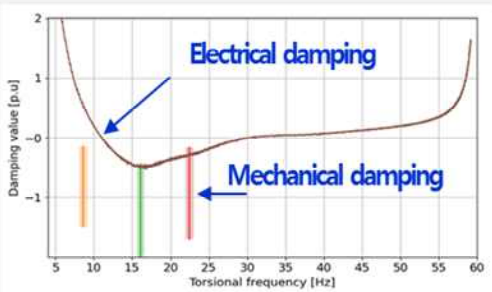


Electrical damping analysis

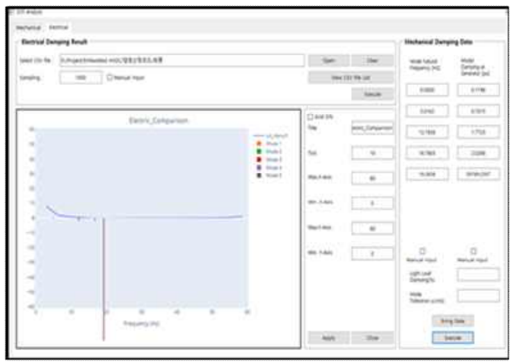
Mechanical damping analysis



HVDC ↔ near CC SSTI analysis results



HVDC ↔ near CC SSTI analysis results



In house tool

Deliverable – In house Tool #4

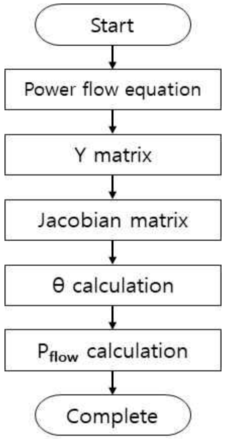
Research Projects

Long-term power system analysis tool

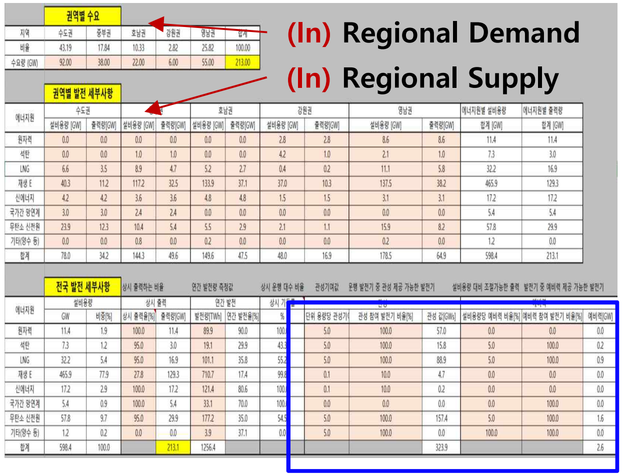
☐ Analysis of Interregional Power Exchange and Transmission Capacity in the long-term power System (Limited Information)

Carbon emission reduction target → Calculation of annual total power generation → Estimation of installed capacity → Allocation of power by region → Power flow analysis between regions → Early-stage AC/DC regional grid planning

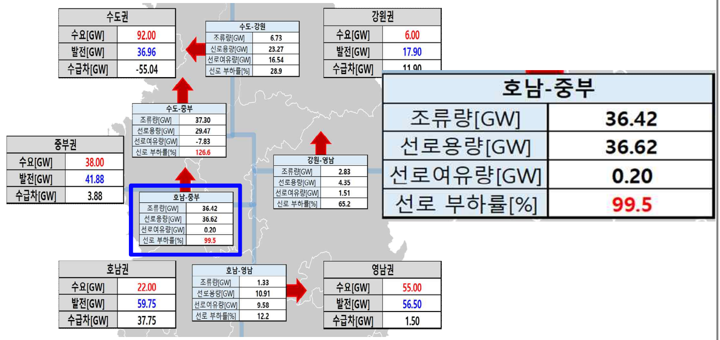
Allocation of power by region → Estimation of inertia/reserve capacity → Development of frequency management strategy



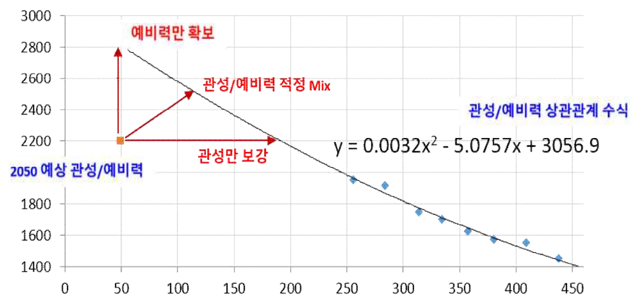
$$P_k = \sum_{\substack{j=1 \\ j \neq k}}^{N} B_{kj}(\theta_k - \theta_j)$$



[DCPF based inter-regional power flow analysis]



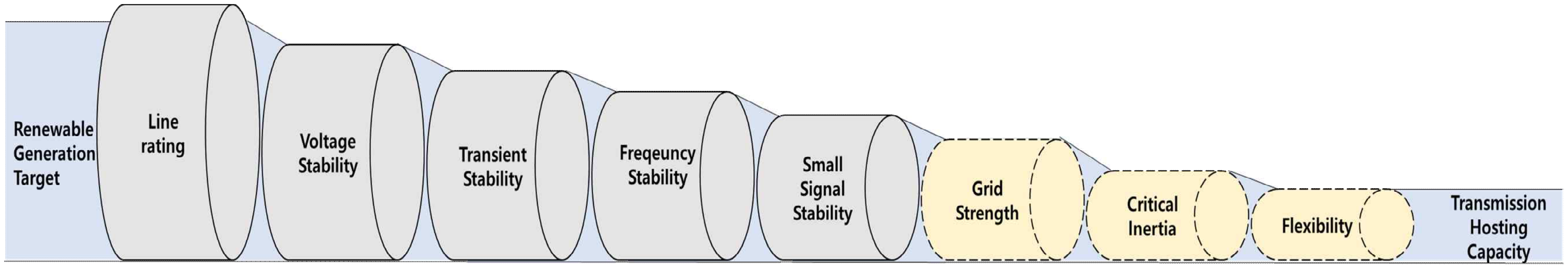
[2050 inter regional power flow (prediction)]

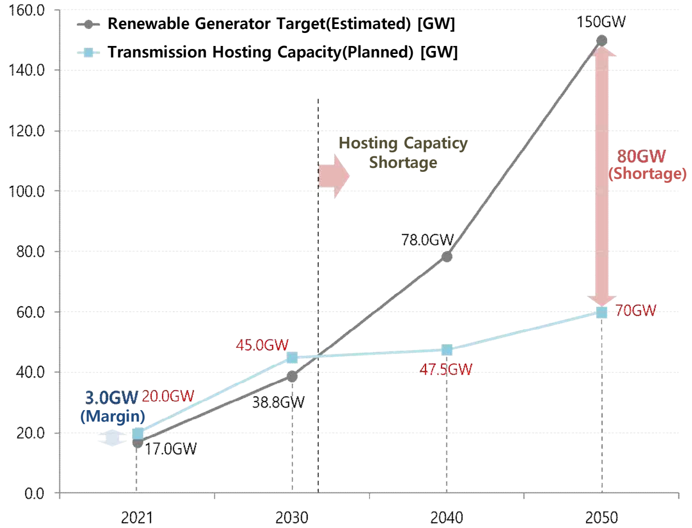


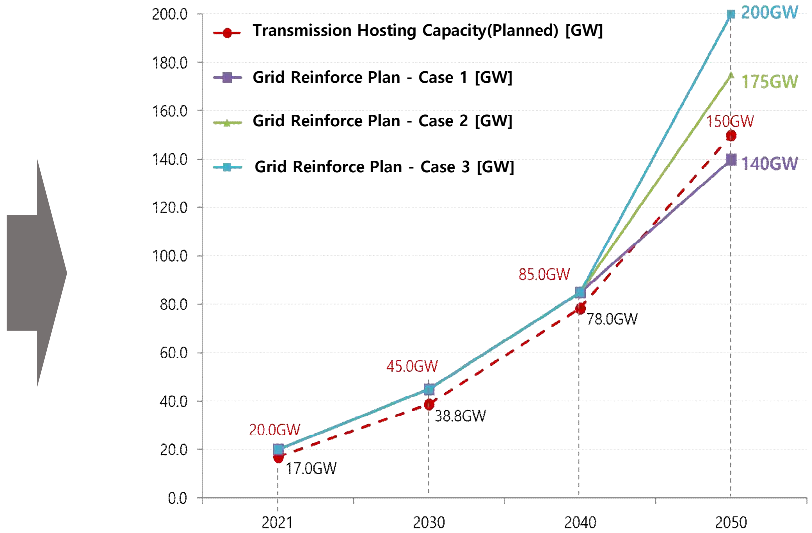
[2050 Inertia / Reserve capacity (prediction)]

Renewable Transmission Hosting Capacity

On-going Research Projects



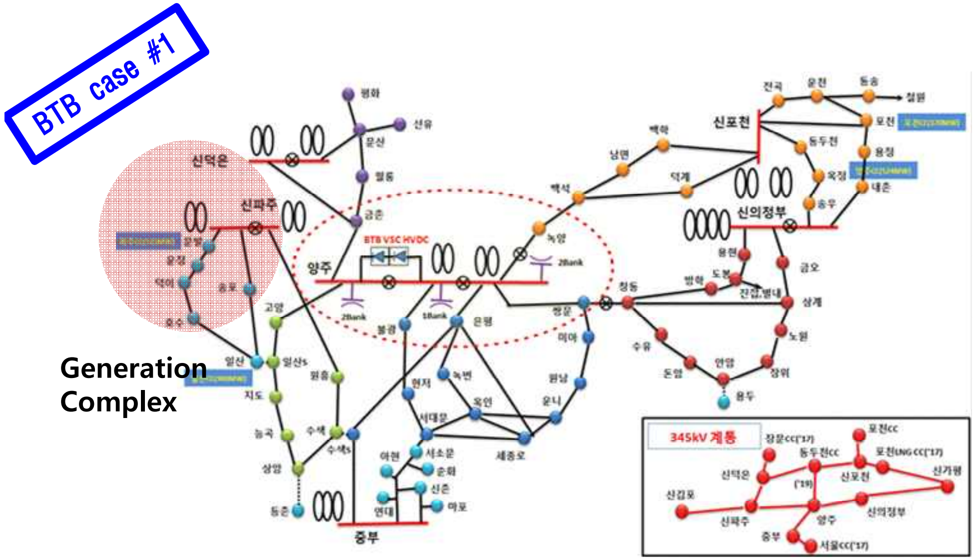




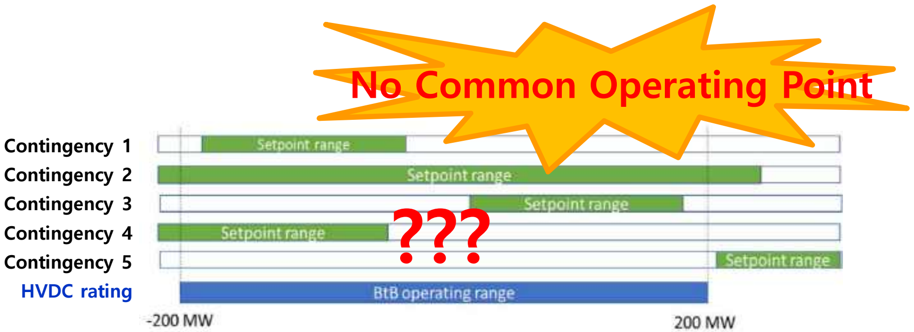
- Transmission Hosting Capacity – Advance stability analysis method for IBR base grid
- Analysis effect on improvement of Hosting Capacity for the draft reinforcement plans

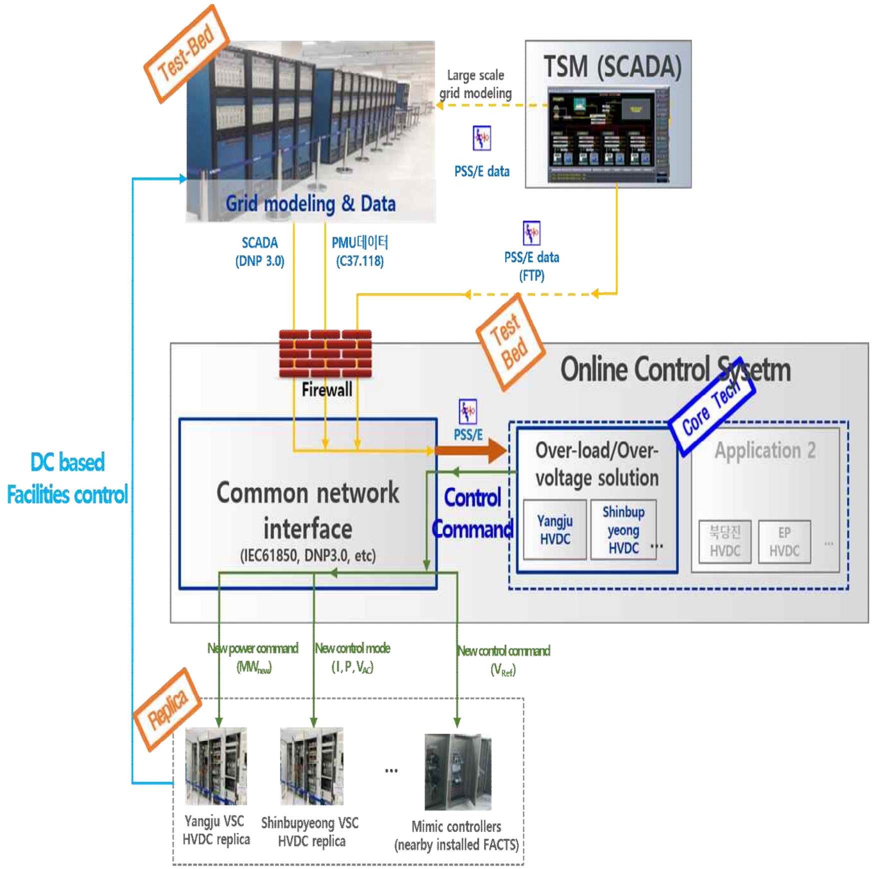
Multiple HVDC system online control system

On-going Research Projects



[GyoungGi Province power system]



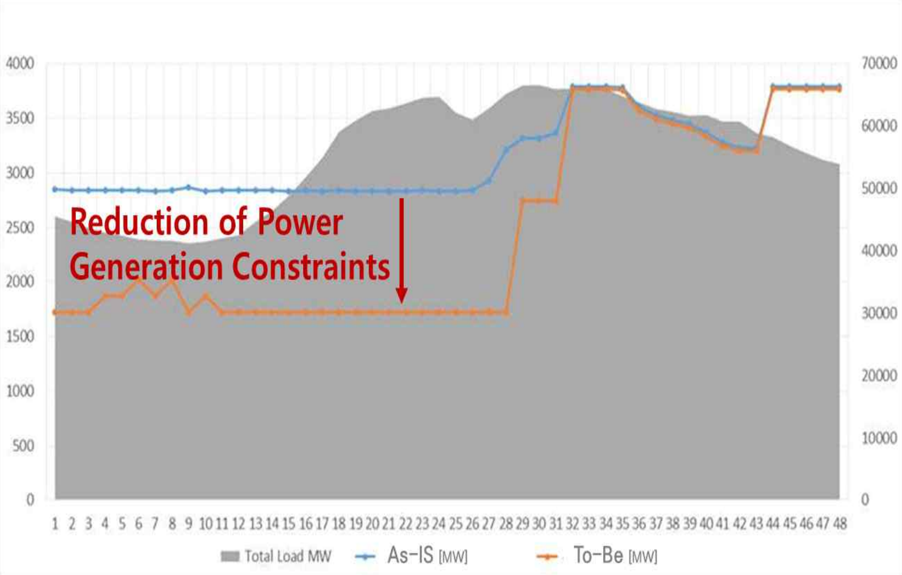


[Configuration of proposed HVDC on-line control System]

- Changing DC Power capacity/direction due to some contingencies, according to generators operating conditions and load level
- No common DC operating area → Operation strategy is very complicated
- Need to change the flow level using the HVDC online control system

Generation Constraint Assessment

On-going Research Projects



- **Coal generation is reduced by the constraint shown in the figure above, and instead, LNG power generation is increased**
- **The cost difference in the figure above is $1.3M due to the difference in fuel cost**
- **Delay of transmission line construction became a global trend due to various issues, it is becoming very important to accurately calculate power generation constraints**

As-Is

- Korea ISO has applied generation constraints to satisfy reliability standards
  - In particular, constraints amount on the east and west coasts are a lot due to a transient stability
- Peak and off-peak prediction data for a specific period are simulated in advance to derive power system stability limits, and generation constraints are applied based on this

- Excessive generation constraints are applied

To-Be

- Improve the ability to respond power system disturbance by on-line dynamic security assessing
- Find the conditions daily that can maintain power system stability with minimum constraint

- Lower SMP/reducing constraints cost and increase power system stability

CONTENTS

V Discussion

Thank you for your attention!!!