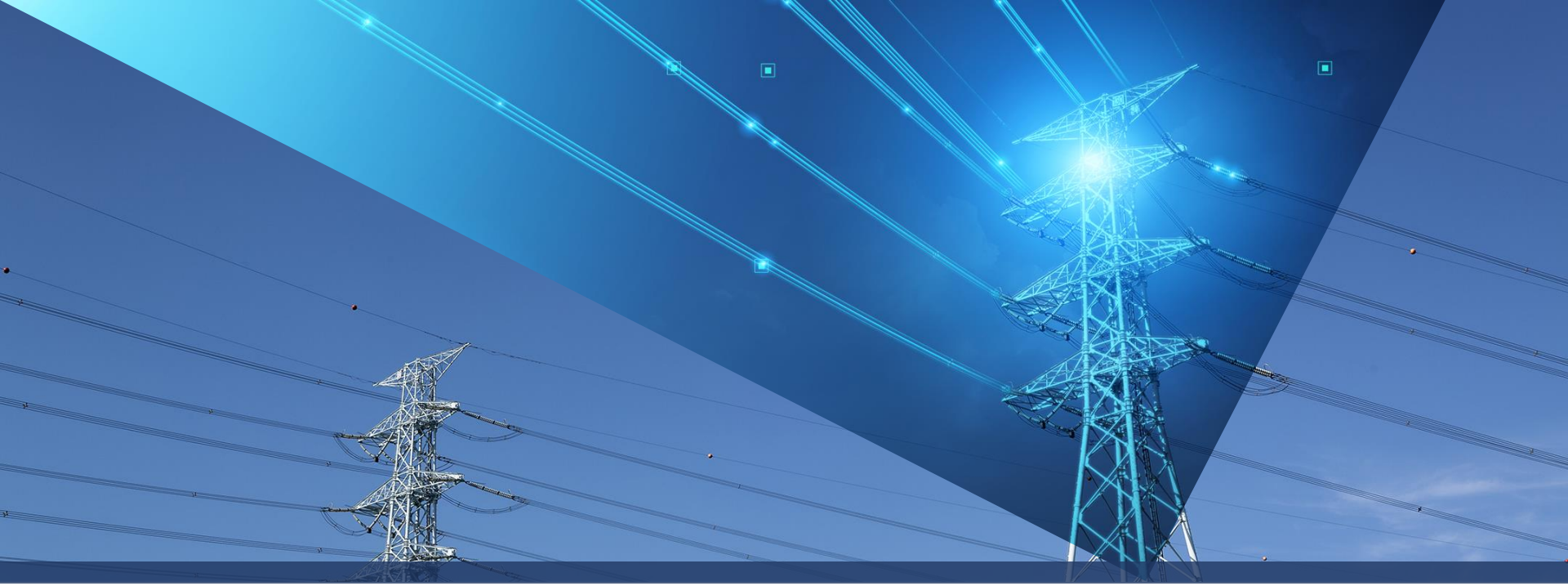


Evolution of Infrastructure in Korea

- High Voltage Engineering Technology -

2023.08.28

Ja-Yoon KOO
Emeritus Professor, Hanyang University

Comments on the title

Korea is a latecomer to the global movement to electrify industrial activities.

- **Its businesses & universities have long been followers rather than leaders.**

Given this history

The resulting shortage of leading-edge knowledge and experience among the related institutions

- **Preparing a memorial lecture on the subject has proven to be difficult.**

Short-Bio of Prof. Emeritus J.Y. KOO

Activities in Korean Society

- 1988.03 – 2016.02: Professor at Hanyang University (Prof. Emeritus)
- 2014.09 – 2018.02: Outside Board member of KEPCO
- 2013.02 – 2017.01: Chairman of Korean National Committee of CIGRE
- 2012.01 – 2012.12: President of Korean Institute of Electrical Engineers
- 2010.06 – 2013.06: Chairman of KOREC (Korean Electricity Regulatory Commission)

International Contributions

- ELECTRA Editor (since October 2022)
- Chair of ISTC of 2019 Jicable (International Conference on Insulated Power Cable)
- CMD 2014 Chairman (International Conference on Condition Monitoring and Diagnosis)
- ISH 2013 Chairman (International Symposium on High Voltage Engineering)

Activities within CIGRE

- Awardee of 2021 CIGRE Honorary Member (2021 August)
- 2020.08 – Present: CIGRE Technical Committee Elected Member
- 2004.08 – Present: CIGRE Administrative Council Member
- 2014.08 – 2006.07: CIGRE Steering Committee Elected Member
- 2004.08 – CIGRE Distinguished Member Award
- 2004.08 – 2006.07: CIGRE Technical Committee Elected Member
- 2004.08 – 2006.07: AORC-CIGRE Chairman
- 2000.08 – 2008.07: Regular Member of SC-D1
- 1988.08 – 2000.07: Regular Member of SC-21
- 1986.08 ~ 1988.07: Observer Member of SC-21 & SC-15

CONTENTS

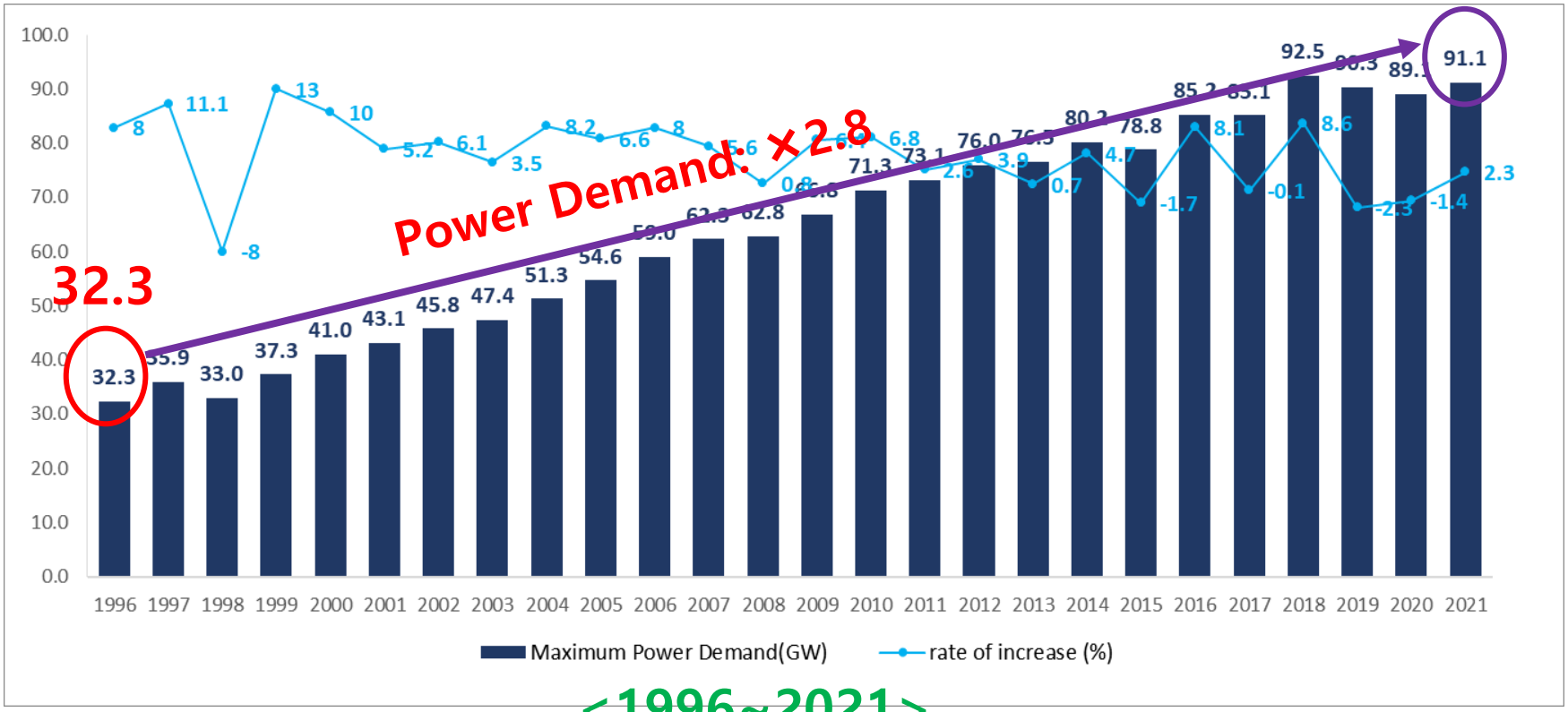
Part 1

KEPCO Research Institute (KEPRI)

- KEPCO Power Testing Center at Gochang -

Why Large-scale Transmission in Korea?

Evolution of annually consumed electricity in Korea

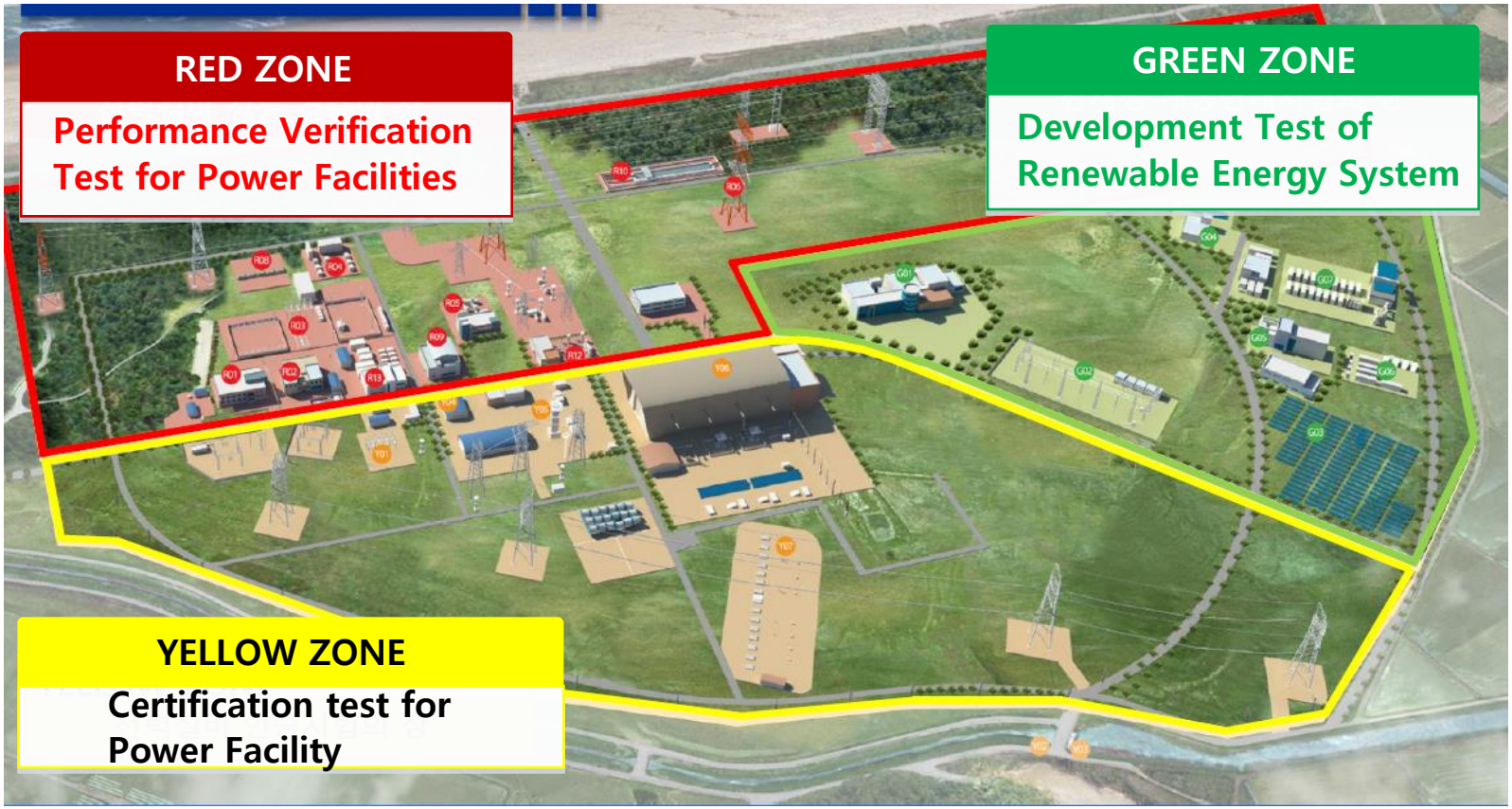


<1996~2021>

*Korea Power Exchange

☑ High voltage and Large current technology are required to cope with the rapid expansion of the Korean energy market. ➔ **765kV T/L**

Purpose of Gochang Testing Center



- To verify the specification and standards related to the power apparatus operating at 765kV transmission line
- To resolve local complaint caused by the transmission line in HVAC & HVDC

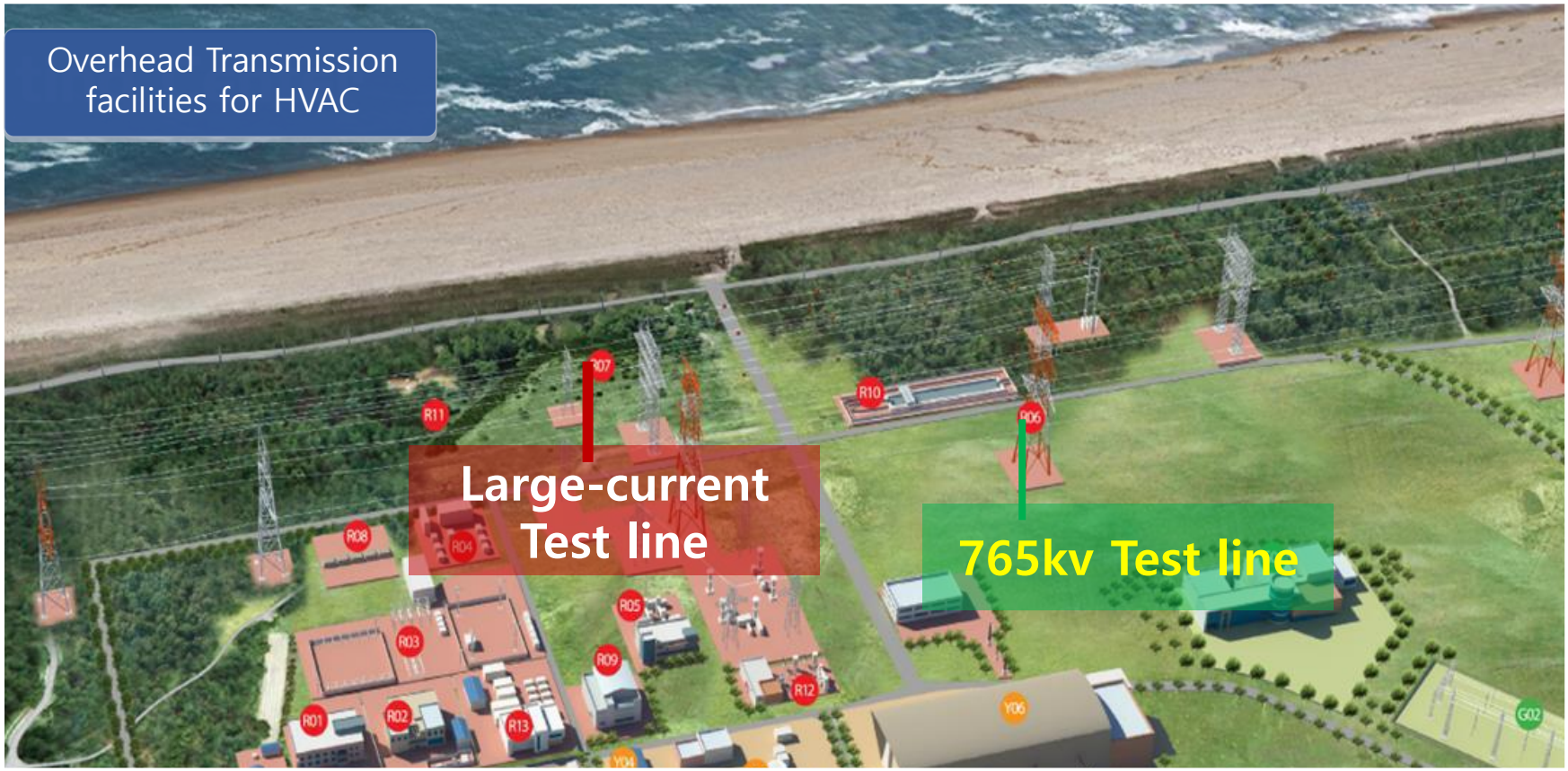
Part 1.1

HVAC Test Facilities

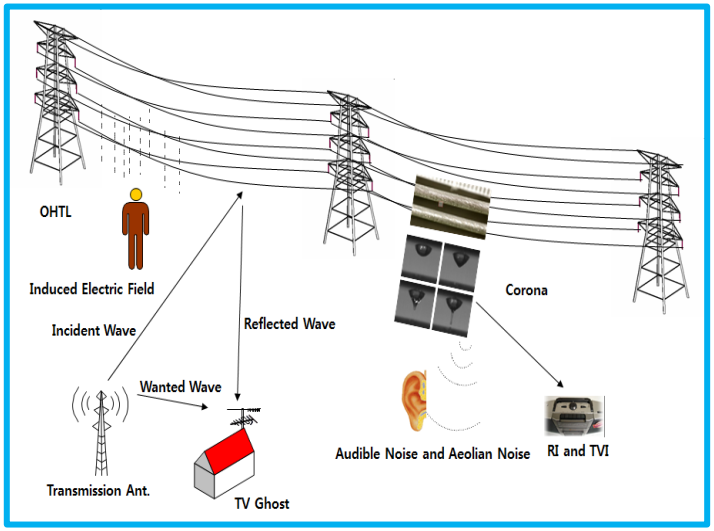
AC Overhead Line Test

Test Line & Facilities for 765kV Overhead T/L

- 765kV Vertical Double Circuit Test **(August,1993)**
- Large Current Test using AC 6,500A Generator **(July,2002)**



Main Concerns

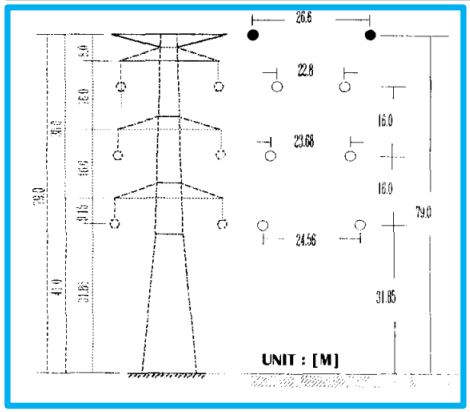


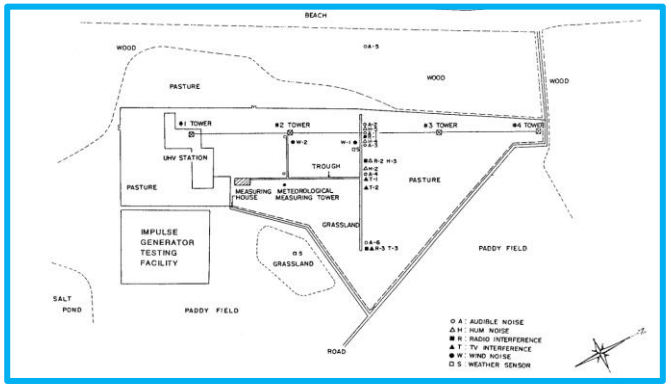
- ☑ Localization and commercialization of power equipment
- ☑ Long-term aging test for Transmission insulator under the cooperation with EPRI, ESKOM
- ☑ Live line maintenance technology
- ☑ Assessment on the electrical safety and environmental effects under 765kV Transmission Line

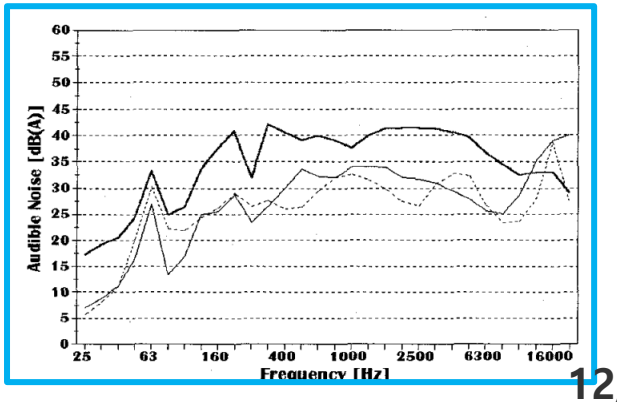
Investigation: Audible Corona Noise

6-Cardinal Bundle conductor at live line **(16 months)**

- L50 AN(audible noise) test at 15m from the outermost phase of 6-Cardinal Bundle conductor:
  48.8 dB(A) in Rainy day / 42.1 dB(A) in Fair weather.
  - The measured AN(L50) on the foul weather is very close to the one calculated using EPRI tool.
  - **Our design satisfies** the **Korean criteria (50 dB(A))** at specified distance.
  - **In Foul weather**, it would be better to reduce appropriately transmission voltage respecting required admissible AN level.







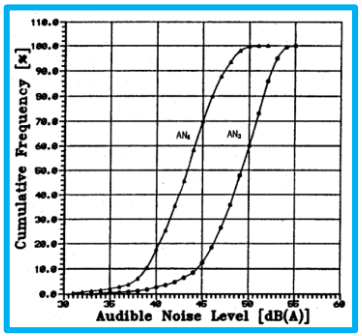
Investigation: Radio Interferences & Electric field

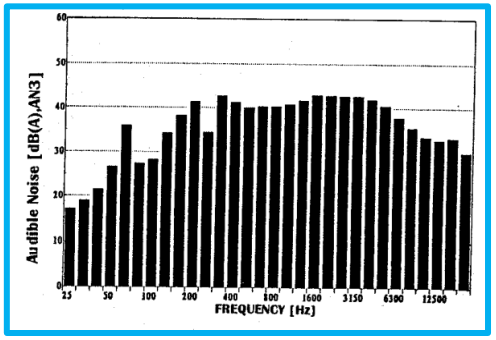
Long term test at Live line **(16 months)**

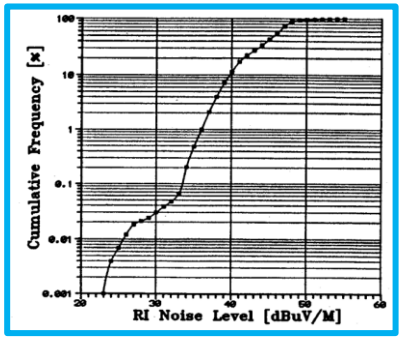
- **RI(L50)** measured in foul weather: 45.7 dB(μV/m)
  → **1.3 dB(μV /m) lower** than Korean requirement
- Electric Field at 28m under the live line:
  - International specification: 5kV/m.
  - Our measurement: 3.5kV/m

The results (AN, RI, Electric field) show suitability

6-Cardinal Bundle Conductor for 765kV Double Circuit T/L







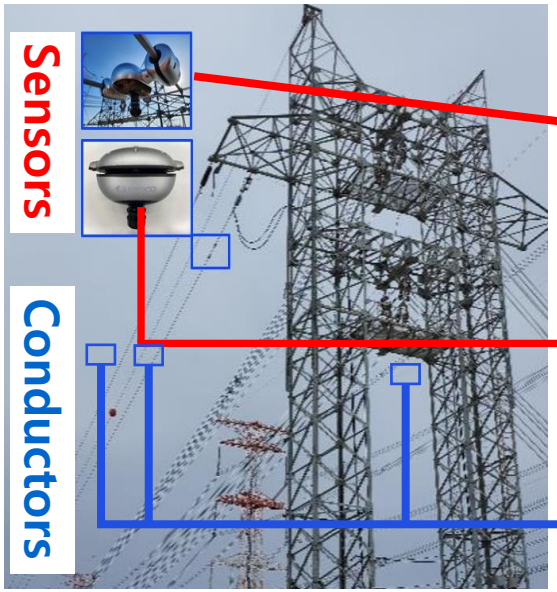
Remark: Safety for Workers

To secure work safety for live line workers

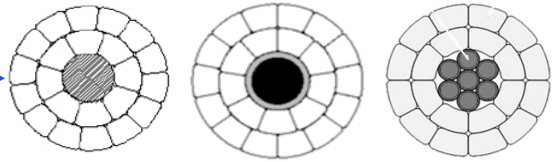
- ☑ Investigation on the Flashover path
- ☑ Necessary tools by our design for double circuit line
  - ➔ Applicable also to single circuit live line

Remark: Long term Investigation for Line rating increase

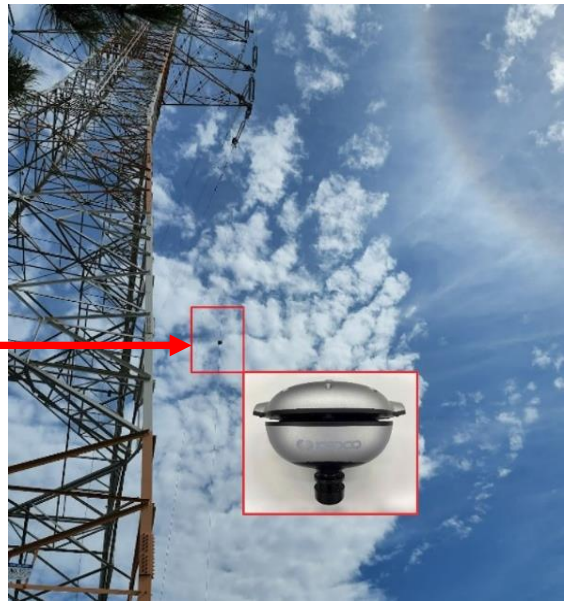
Novel Conductor & Sensor Development



Conductors at HVAC Test line



ACCC LSCC HCSC



Sensors at 154kV Commercial T/L

- ☑ Investigation on the effect of large current and tensile characteristics
  - ➔ Novel conductor is chosen to avoid new T/L construction
- ☑ Development of sensor for FDLR (Forecasted Dynamic Line-Rating)
  - ➔ Commercial service in 2024

Our achievement

765kV Double Circuit T/L using 6-Cardinal Bundle conductor

- ➔ **Transmission capacity up to 12GW**
- ➔ **World's First commercial service in 2003**

Our design, today

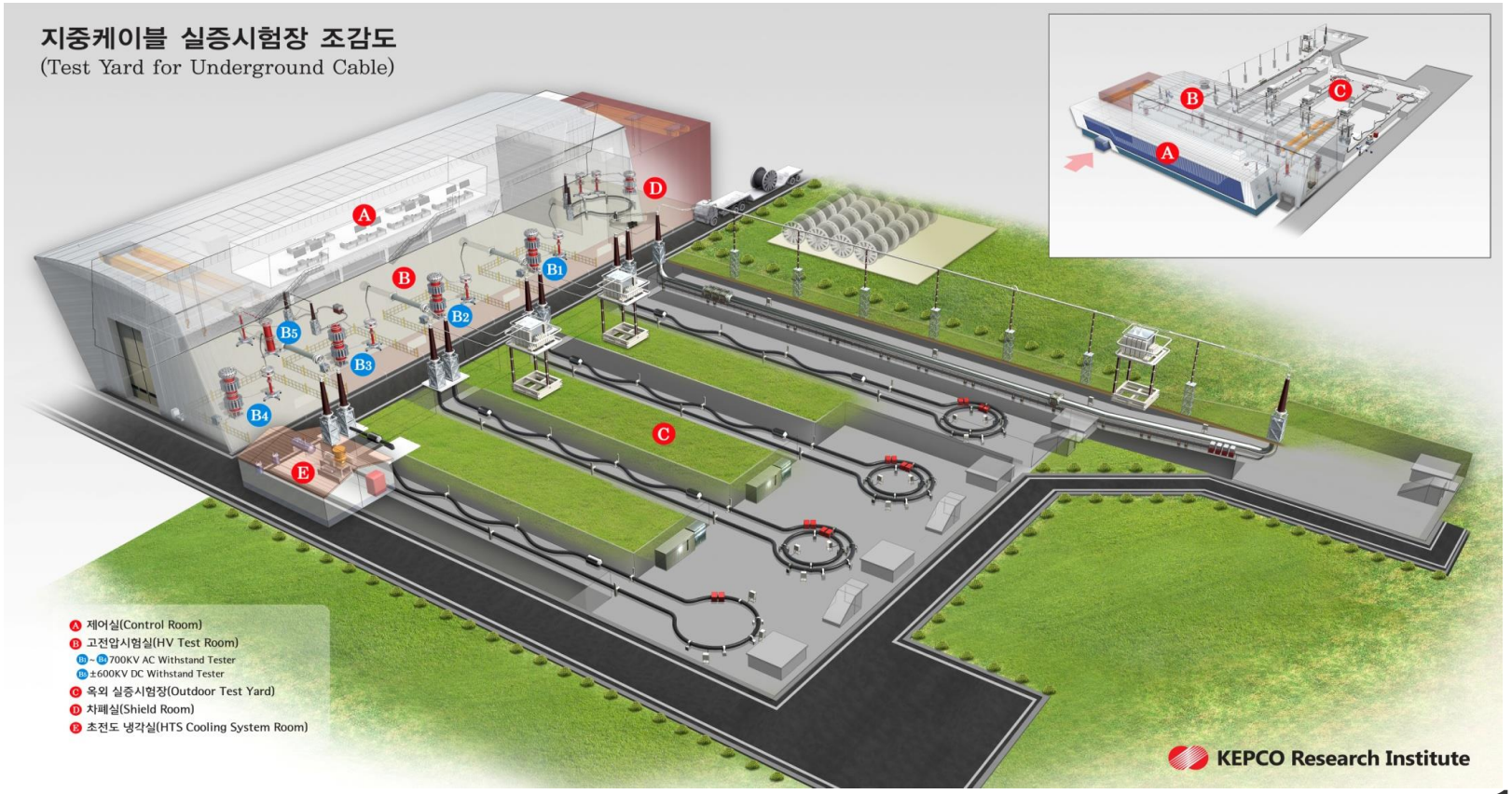
Recognized as an **excellent choice** for other utilities facing:

- ☑ **The challenges** caused by long - standing social grievances
- ☑ Limited ROW available for new transmission lines

AC Underground & Submarine Cable Test

Overview of Test Laboratory **(June 2010)**

- Control Room (L×W×H=72m×10m×14m)
- HV Test hall (L×W×H=86m×35m×25m)
- Outdoor Test Yard (5 test tunnels : length 310m)



Main Facilities

[Overview of Test Hall]

[Test hall]

[Shield room]

[Test tunnel]

[Control room]

Core Testing Equipment

700kV 14A Generator
(Resonance type)

700kV 6A Generator
(Resonance type)

800kV 10A Generator
(Winding type)

4MV Impulse
Generator

6kA AC current
source

Shield Room
<1pC

Related Specification

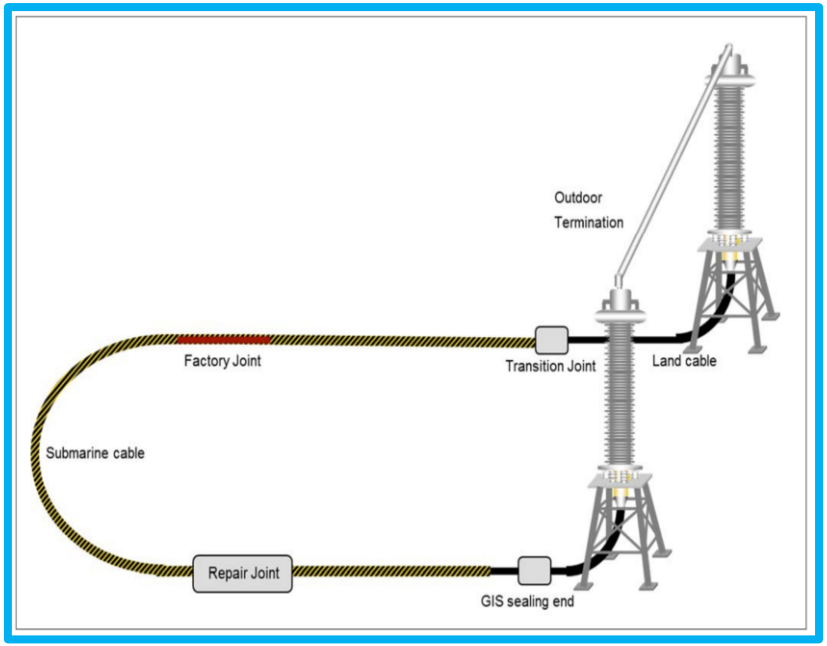
Equipment	EA	Specification
HVDC Voltage generator (resonance type)	2	700kV, 14A 700kV, 6A
HVDC Voltage generator (winding type)	1	800kV, 10A
Impulse generator	1	4MV
AC current source	5	6kA
Wall Bushing	4	LI 800kVp
Water Termination System	1	600kV
DAS & Morning System	1	-
Faraday(shield) Room	1	Background noise ≤ 1pC

Remark: AC 400kV Submarine cable system

Pre-qualification test (CIGRE TB 490 /**18 months**)

- AC 400kV XLPE 1C x 2,500㎟ cable 110m,
  Transition Joint **(TJ)**, Repair Joint **(RJ)**, Factory Joint **(FJ)**, EBG, EBA

  → Successfully completed and Certified by KEMA **(August 2022)**



Part 1.2

HVDC Test Facilities

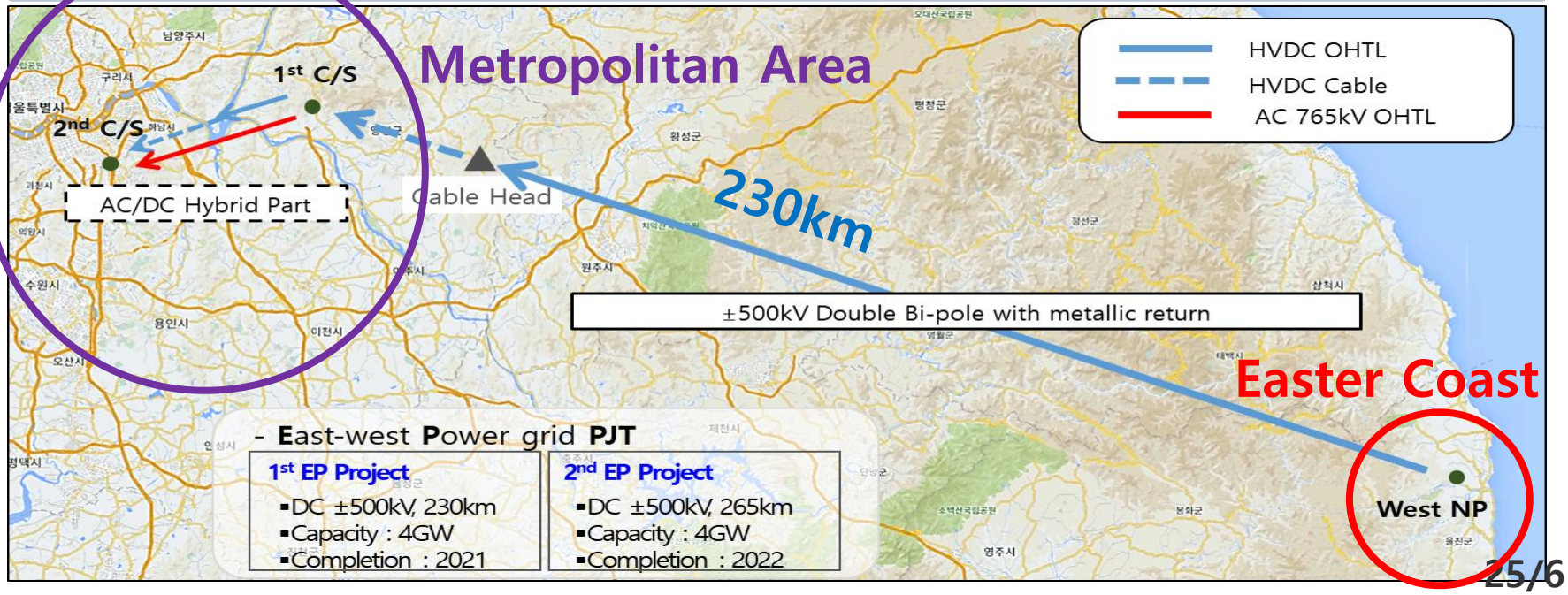
DC Overhead Line Test

HVDC Overhead Transmission line in Korea

East-West Power Grid Project (8GW)

☑ To transport electricity generated at Shinhanul NP from the east coast area to the metropolitan area through a new overhead transmission line **by 2025**

2 HVDC ±500kV Bi-pole , T/L 230km, Metallic return (Tower 440)



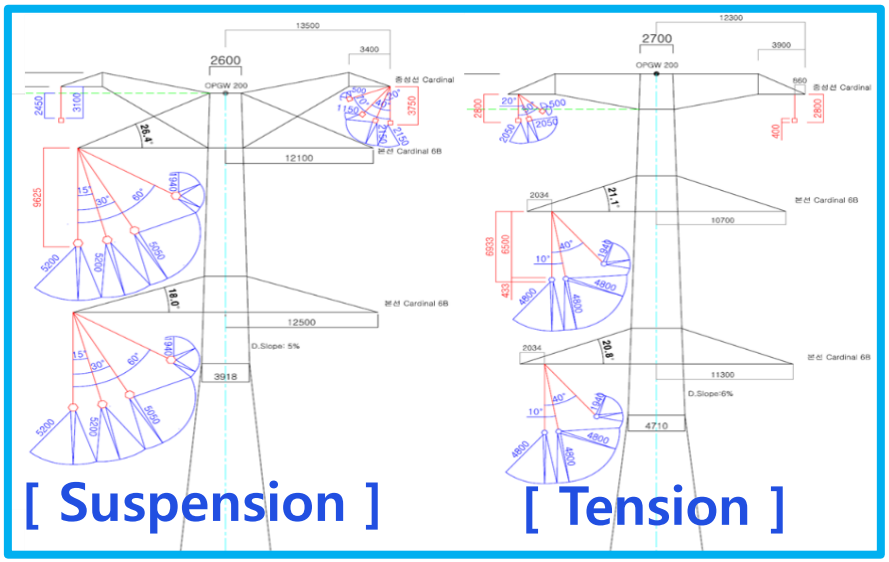
± 500kV HVDC Full Scale Test Line

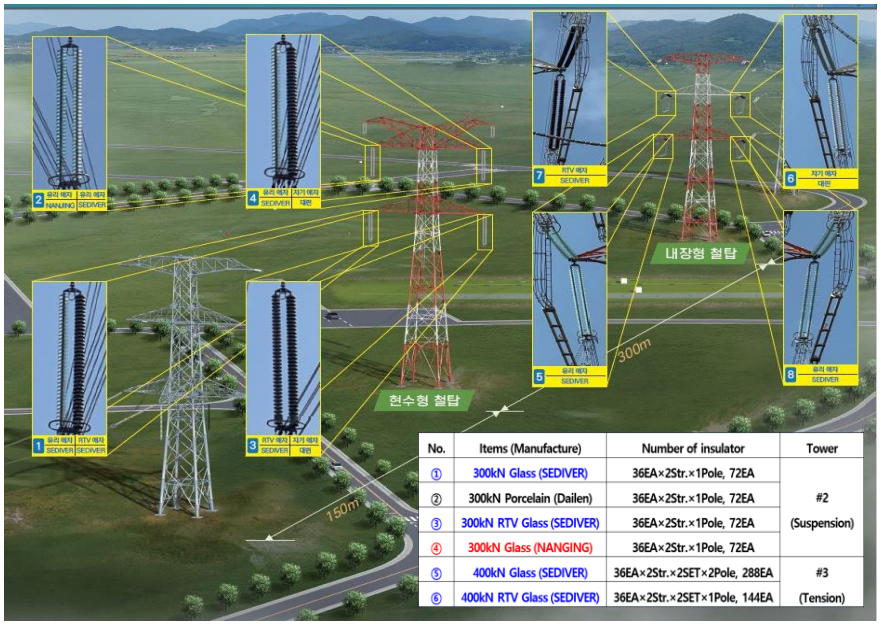
Purpose

- To determine HVDC insulation coordination relevant to actual tower configuration
- To analyze the environmental effect of Double Bi-pole T/L prior to commercialization
- To develop relevant accessories and maintenance technologies

Main concerns

HVDC Towers **(2 Tower types)**





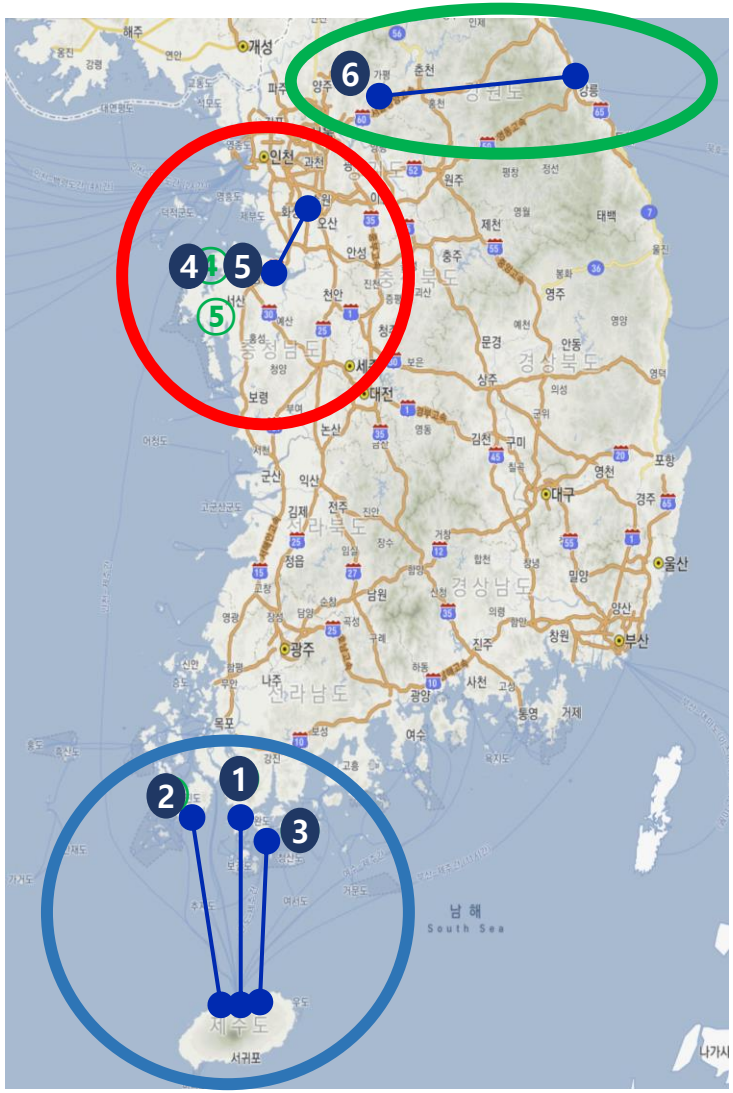
No.	Items (Manufacture)	Number of insulator	Tower
①	300kN Glass (SEDIVER)	36EA×2Str.×1Pole, 72EA	#2 (Suspension)
②	300kN Porcelain (Dailen)	36EA×2Str.×1Pole, 72EA	
③	300kN RTV Glass (SEDIVER)	36EA×2Str.×1Pole, 72EA	
④	300kN Glass (NANGING)	36EA×2Str.×1Pole, 72EA	
⑤	400kN Glass (SEDIVER)	36EA×2Str.×2SET×2Pole, 288EA	#3 (Tension)
⑥	400kN RTV Glass (SEDIVER)	36EA×2Str.×2SET×1Pole, 144EA	

- ☑ To investigate Electromagnetic field intensity & Corona noise
  - ➔ Domestic electrical environment requirements are verified
- ☑ To evaluate the performance and reliability for both Glass and RTV Silicon coating insulators to replace porcelain insulators

DC Underground Cable Test

HVDC Cable Projects in Korea

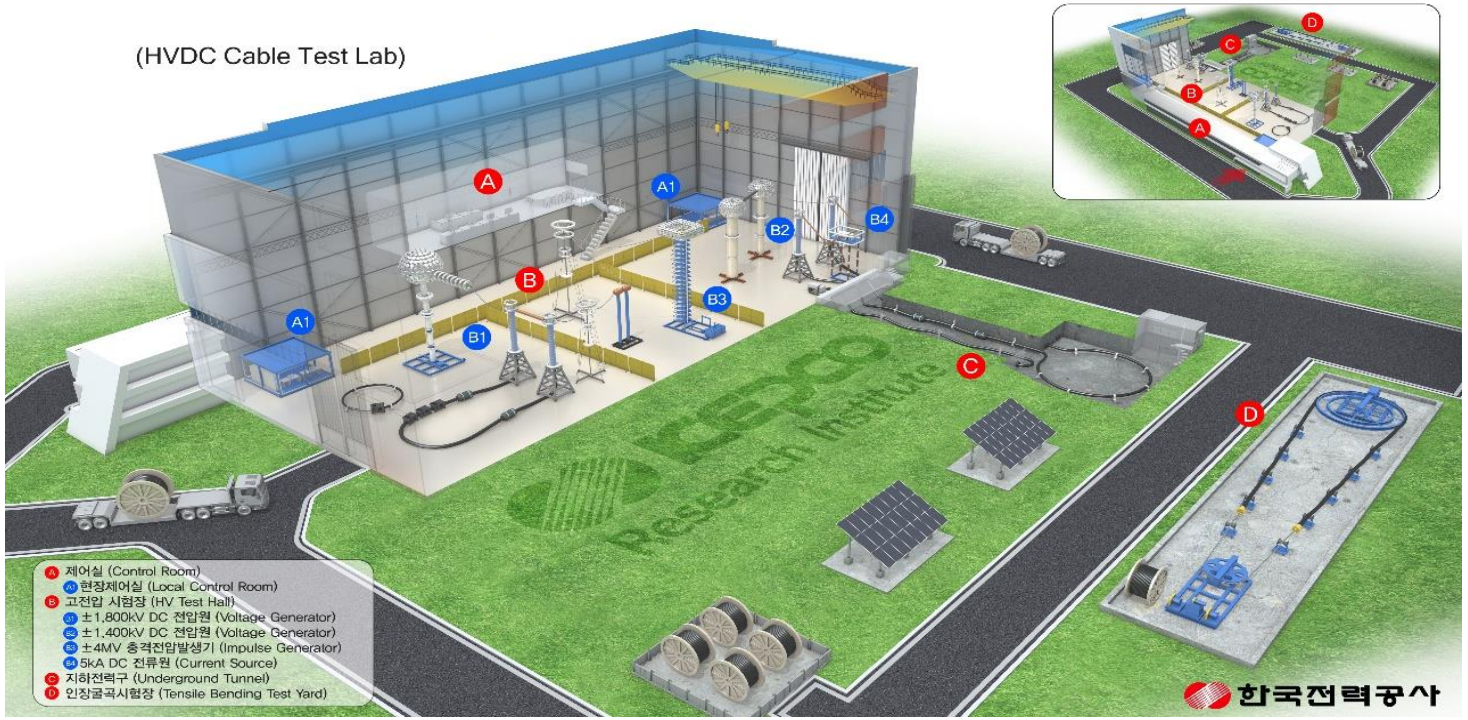
1. **±180kV** HVDC Jeju-Haenam **(since 1998)**
   MI cable, **150MW x 2pole**, 101km
2. **±250kV** HVDC Jeju-Jindo **(since 2013)**
   MI cable, **200MW x 2pole**, 113km
3. **±150kV** HVDC Jeju-Wando **(2023 ~)**
   XLPE cable, **100MW x2pole,** 89km
4. **±500kV** Bukdanjin-Godeok HVDC **(#1, 2020 ~)**
   MI PPLP cable, **1.5GW x 1pole**, 34.2km
5. **±500kV** Bukdanjin-Godeok HVDC (**#2, 2023~)**
   MI PPLP cable, **1.5GW x 1pole,** 34.2km
6. **±500kV** HVDC (to be completed: **2026)**
   XLPE cable + Overhead transmission
   2GW x 4pole, 230km from the East Coast



HVDC Cable Test Laboratory (2021 October)

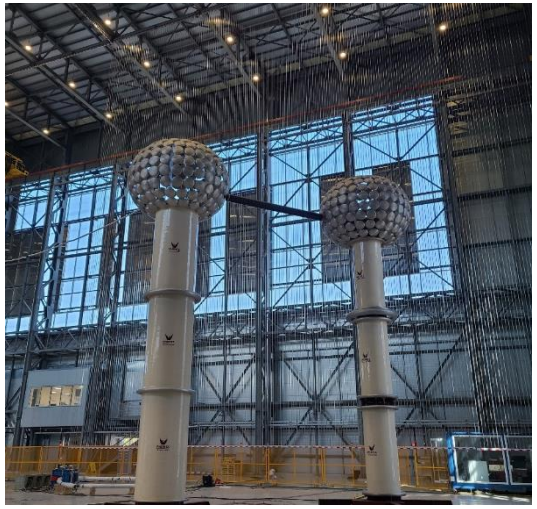
Overview

- ☑ Main control room, 2 Local control room
- ☑ HV Test hall (3 test sections, test tunnel, ducts) / 80m×50m×38m
- ☑ Outdoor tensile bending test yard (length 45m)



Core equipment for testing HVDC cable

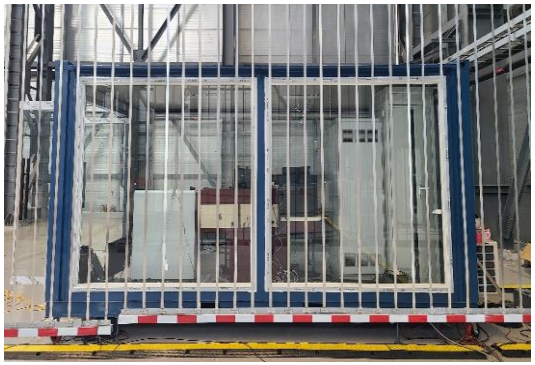
±1800kV DC Generator



±1400kV DC Generator

±600kV DC Generator

4MV Impulse generator



Local control room

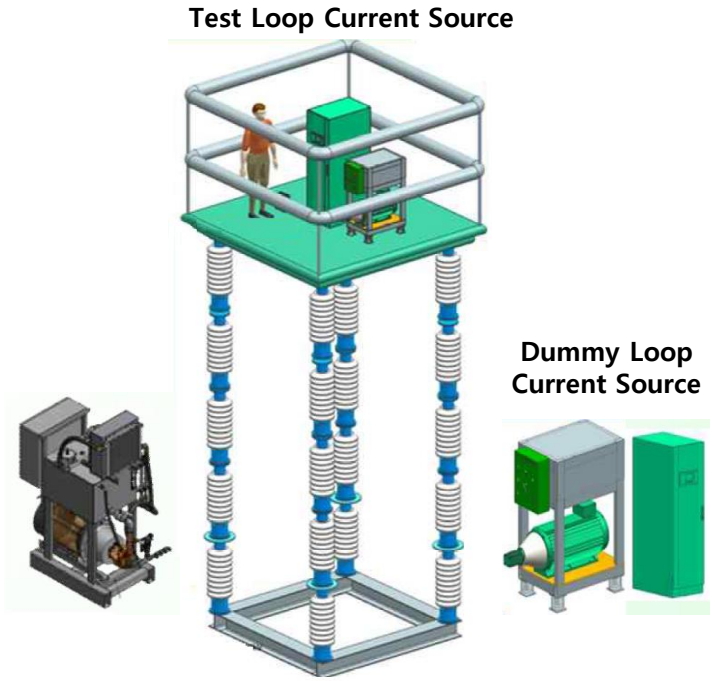
6kA AC current source

Related specification

Equipment	EA	Specification
HVDC Voltage generator	3	±1,800kV 10mA ±1,400kV 20mA ±600kV, 50mA
Impulse generator	1	4MV 600kJ
DC current source	1	5kA 6V
AC current source	2	6kA 20V
Shielding curtain	1	-
Tensile bending test equipment	1	100ton
DAS	1	-

Additional facility: DC Current source

- ☑ Direct application of DC current instead of induction current
- ☑ Possible to ensure the required reliable performance during test



Application for Type & PQ Test

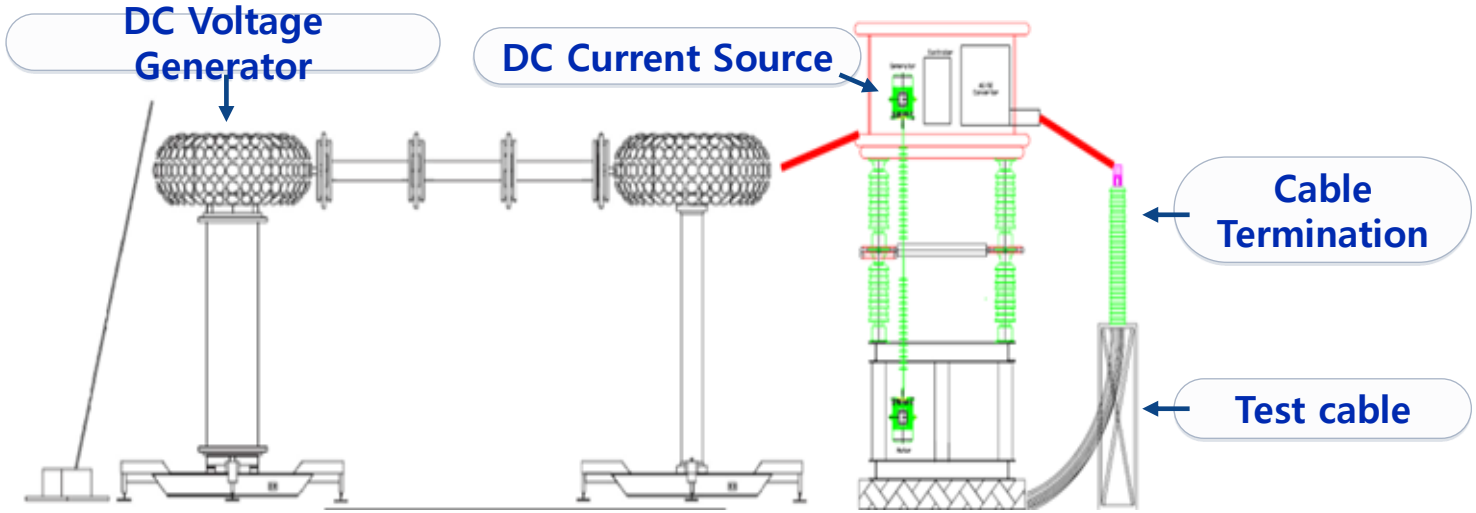
HVDC Submarine cable **(CIGRE TB 496)**

☑ **Conventional method**

- **Induction current** is used for load current in HVDC cable Type and PQ test
  - → Temperature control of the cable conductor is difficult due to the induction of the armor layer. Therefore, the armor layer must be removed.

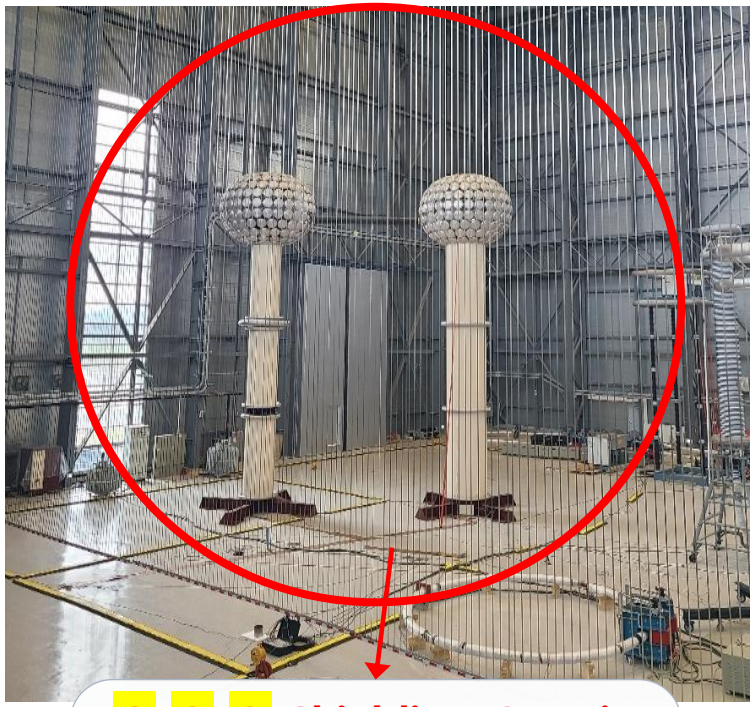
☑ **KEPRI's method**

- **Direct current application** to cable conductor **using DC current source**.
  - → Easy control of conductor temperature without removing armor layer.
  - → **Possible** to put the complete submarine cable **with armor** into test.

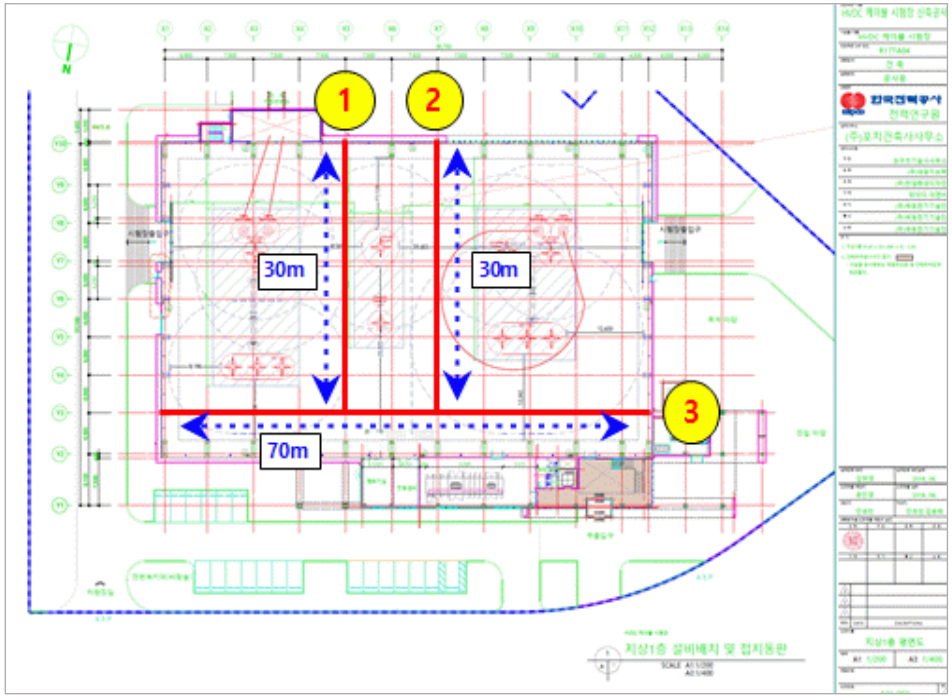


Additional facility: Shielding Curtain

- **Easily separate** test hall into three parts
  - ➜ Possible to run **two tests at the same time**

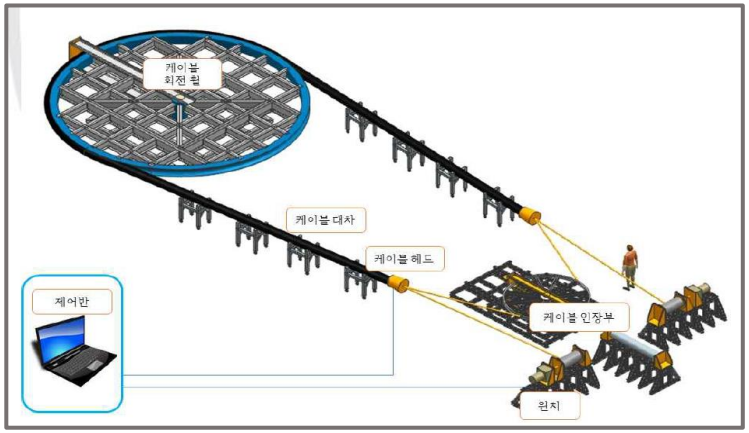


① ② ③ Shielding Curtain



Additional facility: Tensile Bending equipment

☑ Weights of **up to 100 tons** using three types of wheels



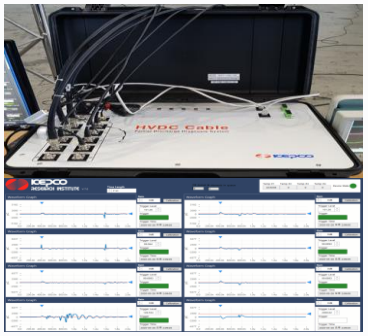
Achievement: Real-time PD Diagnosis system

Mi-PPLP HVDC Land Cable (±500kV DC)

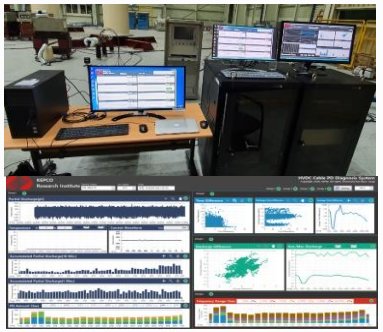
World's First commercial application

→ Land HVDC Cable installation (Duct & Tunnel)

Measurements



Pattern Analysis



Diagnosis

Achievement: Real Time Fault Location System

Application to HVDC Submarine & Land Cable in Korea

☑ 2 Independent & Complementary functions

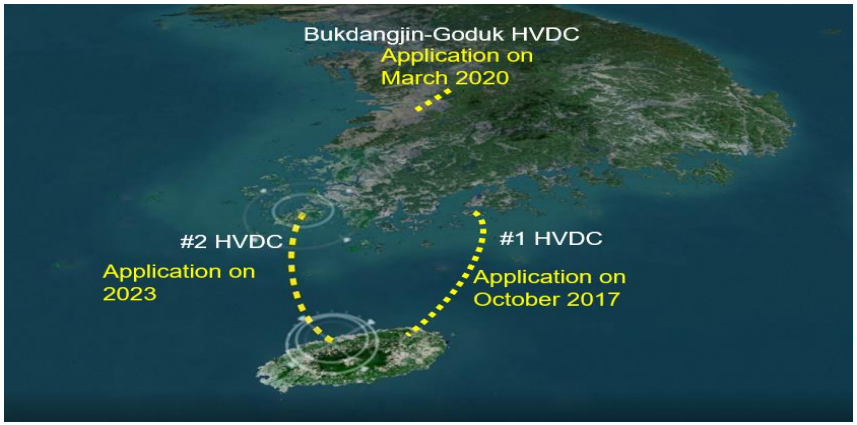
- **Trigger monitoring**: **Abnormal signals** from the weak spots ➔ When they are above the trigger level, corresponding to fault current, sensors installed at both end of cable detect them..
- **Real Time monitoring** : **DC load current** & **Fault current** are detected by the sensors simultaneously
  ➔ Fault location is recognized when these signals are above the trigger level respectively

☑ Commercial service at 3 long distance HVDC Line

- **±180kV** HVDC submarine cable, **October 2017**
- **±500kV** HVDC land cable , **March 2020**
- **±250kV** HVDC submarine cable, **2023**

No faults till now

[Real Time Fault Location System S/W]



[Application of Real Time Fault Location]

Accredited Laboratory for Cable Testing

No. 105 (1/9)

CERTIFICATE OF ACCREDITATION

Name of Laboratory : KEPCO Research Institute

Representative : Kim, Ssang-Su

Address of Headquarters : 167, Samsung-Dong, Gangnam-Gu, Seoul, Korea

Address of Laboratory : 105, Moonji-Ro, Yusong-Gu, Daejeon, Korea

Duration : April. 4 , 2009 ~ April. 3, 2013

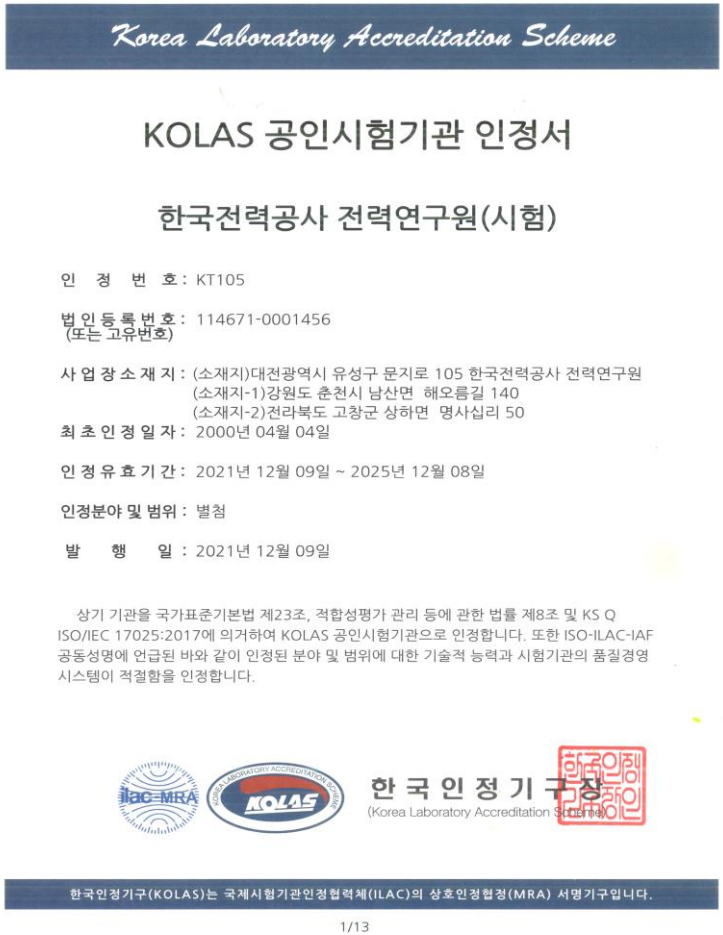
Scope of Accreditation
(Scope of Accreditation is described in the accompanying Annex)

This testing laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025 : 2005. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer to joint ISO-ILAC-IAF Communique dated 8 January 2009).

March 2, 2011

Huh. Kyung

Administrator,
Korea Laboratory Accreditation Scheme(KOLAS)



Korea Laboratory Accreditation Scheme

KOLAS 공인시험기관 인정서

한국전력공사 전력연구원(시험)

인 정 번 호 : KT105

법인등록번호 : 114671-0001456
(또는 고유번호)

사업장소재지 : (소재지)대전광역시 유성구 문지로 105 한국전력공사 전력연구원
(소재지-1)강원도 춘천시 남산면 해오름길 140
(소재지-2)전라북도 고창군 상하면 명사십리 50

최초인정일자 : 2000년 04월 04일

인정유효기간 : 2021년 12월 09일 ~ 2025년 12월 08일

인정분야 및 범위 : 별첨

발 행 일 : 2021년 12월 09일

상기 기관을 국가표준기본법 제23조, 적합성평가 관리 등에 관한 법률 제8조 및 KS Q ISO/IEC 17025:2017에 의거하여 KOLAS 공인시험기관으로 인정합니다. 또한 ISO-ILAC-IAF 공동성명에 언급된 바와 같이 인정된 분야 및 범위에 대한 기술적 능력과 시험기관의 품질경영 시스템이 적절함을 인정합니다.

한국인정기구장
(Korea Laboratory Accreditation Scheme)

한국인정기구(KOLAS)는 국제시험기관인정협력체(ILAC)의 상호인정협정(MRA) 서명기구입니다.

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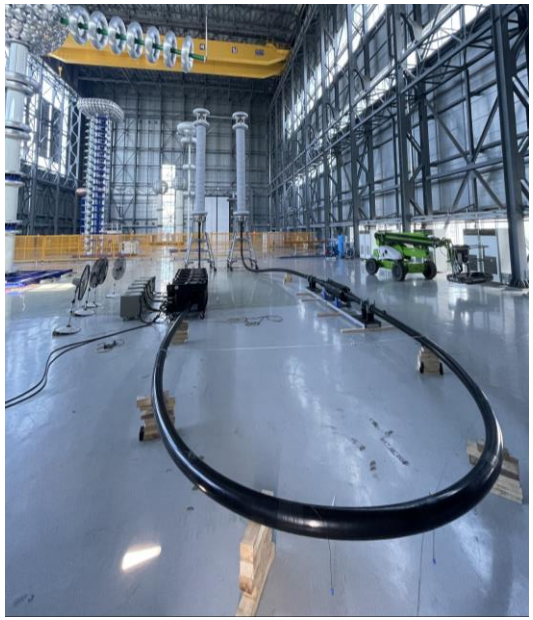
Standards & Accredited Tests by KEPRI

Standards	Subject	Accredited Tests
IEC 60230	Impulse Tests on Cables and their Accessories	Switching/Lighting Impulse
IEC 60885-3	Electrical Test Methods for Electric Cables	Partial Discharge measurement under AC
IEC 60840	**Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) –Test methods and requirements**	**HVAC Cable Type & PQ Test**
IEC 62067	Power cables with extruded insulation and their accessories for rated voltages above 150kV (Um = 170 kV) up to 550 kV (Um = 550 kV) –Test methods and requirements	HVAC Cable Type & PQ Test
CIGRE TB 852 (TB 496)	**Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 800kV**	**HVDC Cable testing**

Remark: Support for domestic manufactures

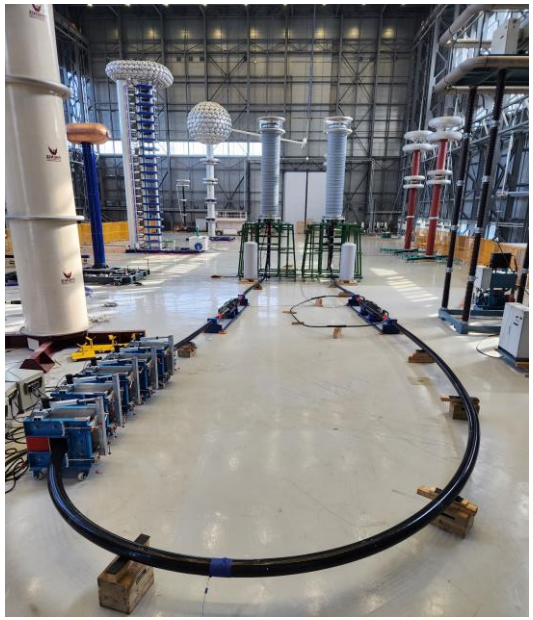
HVDC XLPE Land cables

- ☑ **±500kV** HVDC LCC XLPE Land Cable
- ☑ **±525kV** HVDC VSC XLPE Land Cable
- ☑ **±320kV** HVDC VSC XLPE Land Cable



±500kV LCC

±525kV VSC



±320kV VSC

Part 1.3

Concluding Remarks

Envisaged activities for HVDC cable system

Standardization of Space Charge Measurement

- Space charge accumulation in the insulation of XLPE HVDC cables
  - → Shorten equipment lifespans or cause breakdown
  - → **Space charge measurement system** & **Certification test techniques** will be standardized for commercial services.

Real Time Fault location detecting system

- Upgraded system will be integrated to **HVDC line (Overhead + XLPE cable/ 230km)** → This will transport **8GW** from the Ester coast to Metropolitan area **in 2026**.

Part 2

Korea Electrotechnology Research Institute (KERI)

at Changwon

About KERI

Founded in 1976

Non-profit independent organization

- ☑ To promote domestic electrical engineering
- ☑ To serve international testing and certification

10th STL member (since 2011)

Short-circuit Testing Liaison (STL)

Establishment (1976)

1st and 2nd research building construction

HP & HV testing facility(1982)

HP & HV testing facilities and started testing & certification service

Voltage source for 3 phase synthetic tests(1992)

First- upgrade of HP & HV testing facilities

Testing Infra for Heavy electrical equipment (1992)

The second-upgrade of HP & HV testing facilities

Part 2.1

8000 MVA-Class High Power Laboratory

Construction of HPL (4000 MVA/ 1982~2005)

<Initial Facility>

4000 MVA-class HPL (1982)

- ☑ Short-circuit generator & Short-circuit transformer
  - ➔ **Single-phase synthetic** testing facility and others

< Improvement >

3-Phase Synthetic testing facility

- ☑ New construction **(1992)**
- ☑ Upgrade testing voltage and power capacity **(2005)**

< Enhanced Capability >

Short-circuit breaking Test

- ☑ **Three-phase** circuit breaker (170 kV, 50 kA) **(1993)**
- ☑ Gas-insulated high-voltage **half-pole** circuit breaker (800kV, 50kA) **(1998)**
- ☑ Gas-insulated high-voltage **full-pole** circuit breaker (800kV, 50kA) **(2005)**

Expansion of HPL (8000MVA/ 2011~2016)

To meet the domestic growing demand of short-circuit testing

☑ **2 Short circuit generators** are constructed (**4000 MVA & 150 M USD**)

➔ **8000 MVA** are available to test breaker (800kV, 80kA) **(since 2016)**

2011
Project
4000MVA

2012~2013
Design and order for testing facilities

2014
Construction

2015
Completion of main facilities

2016
Completed
8000MVA

Schematic of HPL (8000MVA)

In 2005

G1 **4000MVA**

In 2016

Expansion in 2 steps

G2 **2000MVA**

G3 **2000MVA**

TC1
- Internal arc test
- Short-time withstand Current test

TC2
- Short-circuit test
- Load test MV Switchgears
- Transformers

TC3
- MV Switchgears
- Transformers

TC6
- Short Time withstand current test
- Short-circuit test
- Load test

TC7
- Short-circuit test
- Load test

TC8
- Internal arc test
- Short-circuit test
- Synthetic test(MV)
- Load test

TC4(HV/EHV/UHV)
- Short-circuit test
- Synthetic test
- Load test

Voltage source of Synthetic test

TC5(HV/EHV/UHV)
- Short-circuit test
- Synthetic test / Load test
- Short Time withstand current test
- HVDC test

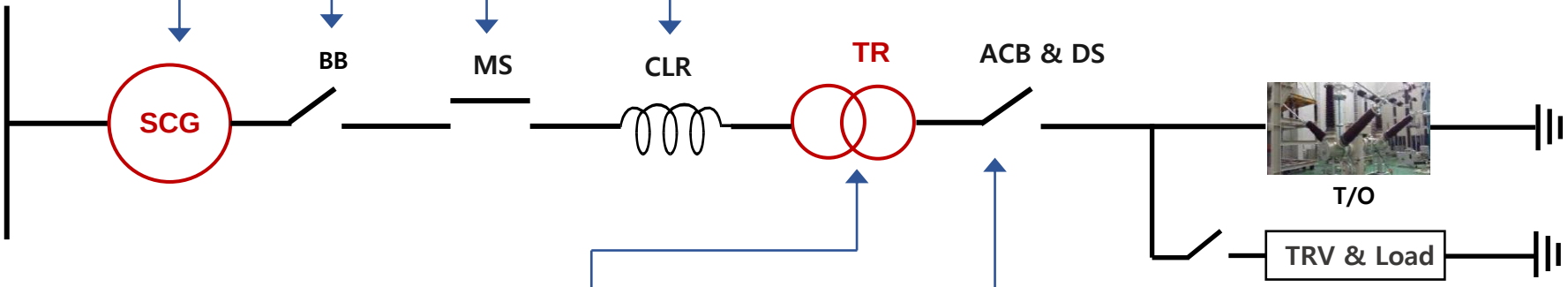
Overview of Test Facilities

Short-circuit Generator(SCG)

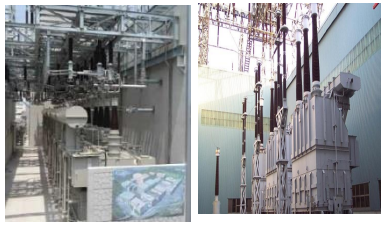
Back-up Breaker(BB)

Making Switch(MS)

Current limiting reactor(CLR)



Control & Monitoring system

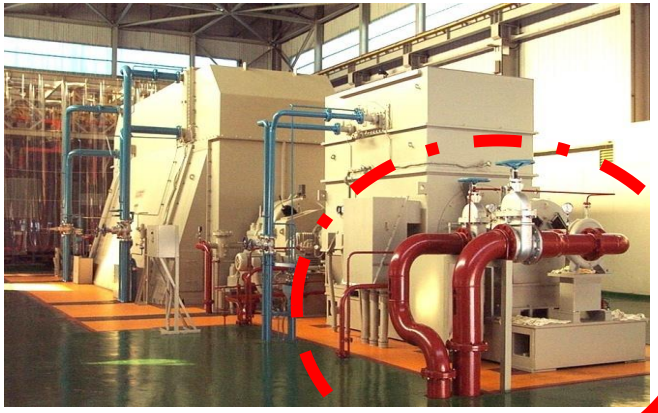


Testing Transformers(TR)

Auxiliary CB(ACB) & Disconnectors

TRV & Load circuits (R, L, C bank)

Components of Short-circuit generator (SCG)



4000 MVA(G1), 1 unit

2000 MVA(G2 & G3), 2 Units

Back-up Breaker for SCG

Driving motor system (V.V.V.F)

Excitation system

Testing Transformers (TR)

Short Circuit Current

Short-Circuit Transformers

Primary voltage : 18 kV
Secondary voltage : 24 ~ 96 kV

Primary voltage : 15 / 18 kV
Secondary voltage : 4 ~ 48 kV

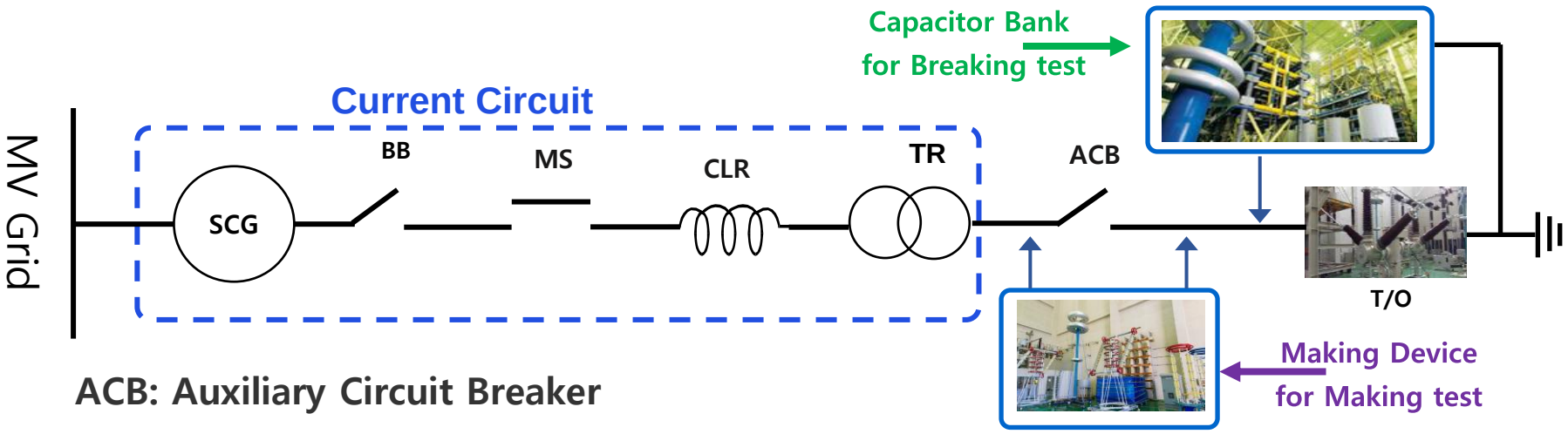
Short time & Peak Current

LVHC Transformers

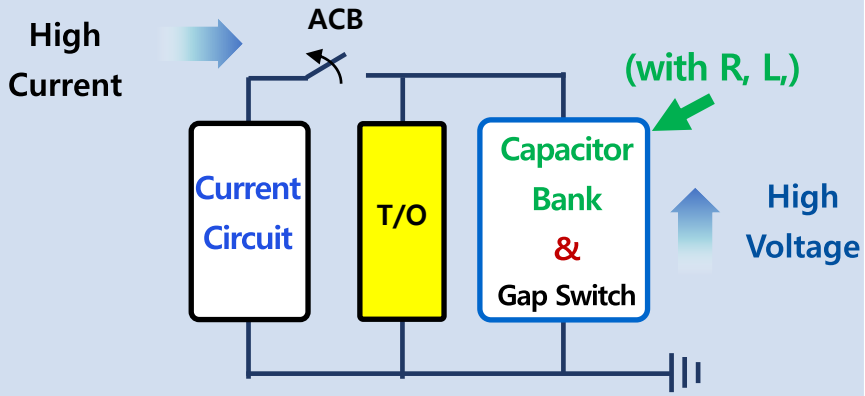
	LVHC1	LVHC2
Pri. Voltage	18 kV	18 kV
Sec. voltage	250~1000 V	500~1000 V

Primary voltage : 18 kV
Secondary voltage : 500 V ~ 1 000 V

Synthetic Test: Breaking & Making test for CB



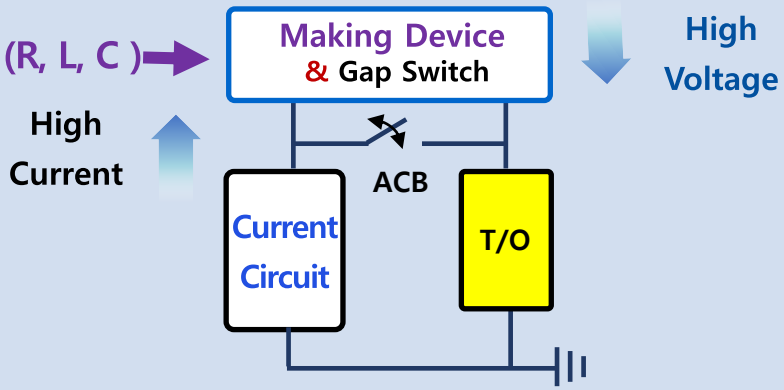
T/O: Breaking test



① Interruption of T/O during short-circuit
② Capacitor bank operates
③ C Bank Voltage applied across on T/O
④ ACB opening

Operation Sequence

T/O: Making test

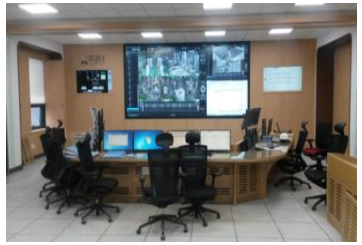
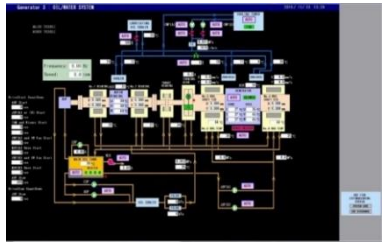
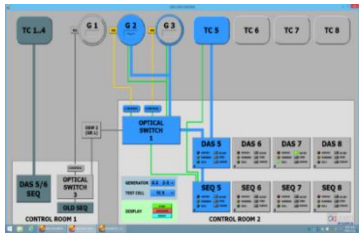


① Voltage of MD applied on T/O during closing operation
② Pre-arcing across the contact gap of T/O
③ Making device operates and Current circuit connects
④ ACB closing

Operating system for High Power Test

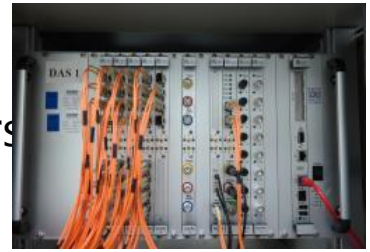
Electrical Control & Monitoring System (ECMS)

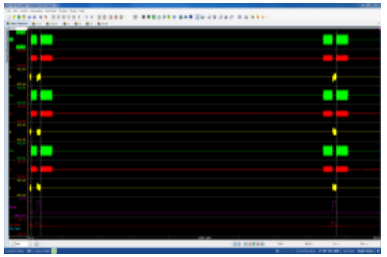
- Short-circuit generators
- Testing circuits
- Test bay

Data Acquisition System (DAS)

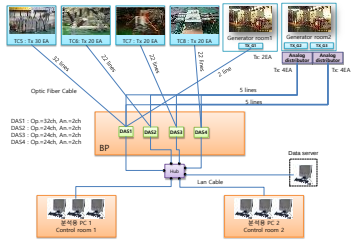
- Signal transmission through optical fibers
- High sampling rate for TRV





Other auxiliary System

- 128 Ch. of CCTV system & High Speed Cameras

Control Rooms & Test bays

3 Control Rooms

8 Test Bays

- 2 Test Bays for HV & UHV
- 6 Test Bays for MV
- Reinforced Concrete

9 Assembly Halls

HV & UHV Test Bay

MV Test bays

Assembly Halls

Part 2.2

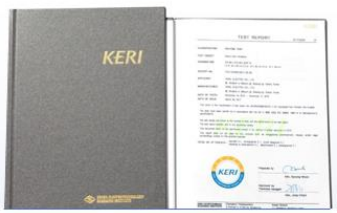
Concluding Remarks

Key roles: Testing & Certification

Independent third party

- Testing services in compliance with ISO/IEC 17025.
- High-quality, reliable, and impartial testing services.
- Accredited institute by ACCREDIA, KOLAS
- STL type test certificates in compliance with recognized international standards and STL guides
- Overseas agents : Japan, Thailand, China, Russia, Taiwan, India, Indonesia and Vietnam
- Upgrade of relevant testing facilities for High Voltage and High-power equipment
- International collaboration among testing organizations through global forums : Task force, technical committee, management committee, and working group

Type Test Certificate



Test Report

Report of Performance

Core activities in the Future

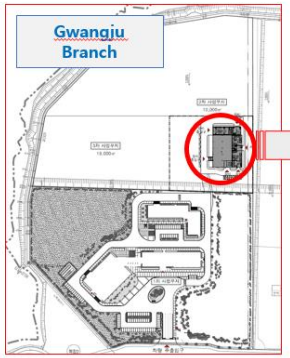
Future projects

- ☑ HVDC cables testing
- ☑ Secondary energy-storage technologies: Redox flow batteries (RFB)
- ☑ Leading-edge testing services beyond high-power and high-voltage equipment.

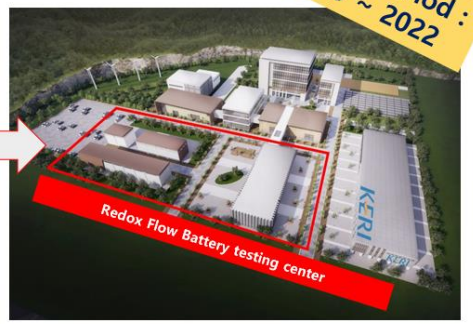
Battery testing

Construction of T&C Infrastructure for Redox Flow Battery testing

Project period : 2019 ~ 2022



High Voltage Laboratories, Gwangju Branch



KERI will provide RFB & Li-on battery testing services for Performance test (1MWpeak) and Stability test (100 kW level).

HVDC cable testing

Construction of T&C Infrastructure for HV-class DC Power Apparatus

Project period : 2020 ~ 2023

High Voltage Laboratories, Changwon

KERI will provide electrical equipment certification services for HVDC Cable type test and PQ test (500 kV level).

Conclusion

- VISION in Korea -

HV & HP Technology

Vision of H.V. Engineering in Korea

☑ **A leading partner** enabling to conduct relevant tests and investigations on the futuristic apparatus to be operated in distribution and transmission grid.

☑ **A provider** enabling to propose any cutting-edge design for UHV apparatus to be operated in the future AC and DC grid by reinforcing test infrastructure.

☑ **A promising contributor** to the global carbon neutrality goal by providing novel technology employable to the renewable energy engineering.

Thank You
for
Your time

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