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KEPCO KOREA ELECTRIC POWER CORPORATION

Recent Progress and Research Activities on HTS Power Cable Application in KEPCO

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CONTENTS

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History of HTS Cable Projects

R&D → Demo (in grid) → D/B

2001 2007 2011 2012 2013 2014 2015 2016

DAPAS

22.9kV 50MVA

154kV 1GVA

KEPRI

22.9kV Cable
Operation & Long term evaluation

22.9kV 50MVA 410m

22.9kV 120MVA 100m

22.9kV Demo.

Icheon Project (08.11~13.10)

Fault diagnosis method
Long term operation

Icheon II (14.06~17.10)

JeJu Project (11.07~16.10)

80/154kV Class Demo.

AC 154kV Cable, 1km

DC 80kV Cable, 0.5km

KEPCO LS

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23kV HTS Cable Demonstration in Icheon

Icheon Substation
AC : 22.9kV, Capacity: 50MVA, Length : 410m

Control Center

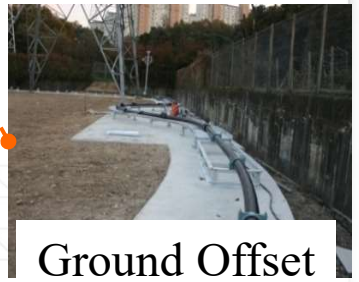
SFCL

Joint

Snake Installation

Termination

Cooling System



Ground Offset

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154kV HTS Cable Demonstration in Jeju

- The demonstration project to install 154kV HTS cables was conducted at Jeju HVDC and Superconductivity Test Center.
- DC 80kV HTS cable was also installed to test the performance on the same place.

Jeju Island
Hawaii of
S.Korea

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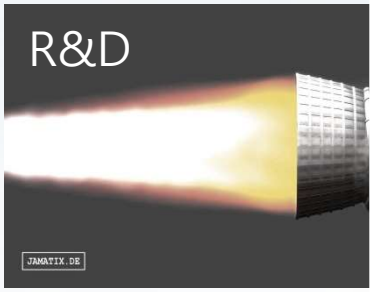
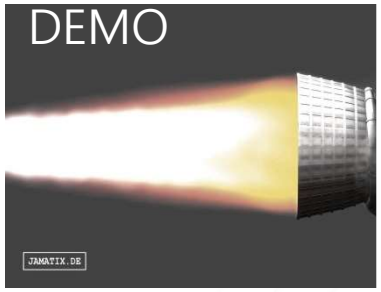
Development of HTS Cable Cooling System





3kW@66.4K, 2006~2008

Decompression System

- **Icheon** 22.9kV 50MVA
- **(6.5kW@69K, 2011)**

6kW@66.4K, 2008~2012

Decomp.+ Stirling System

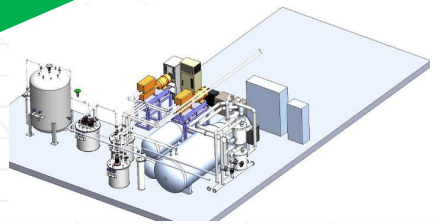
- **Icheon** 22.9kV 120MVA
- **(6kW@69K, 2013)**

[DC] 3kW@69K 2008~2012

[AC] 12kW@69K 2013~2016

Stirling + Brayton Sys.

- **JeJu** DC80kV **(6kW@69K, 2014)**
- **JeJu** AC154kV 600MVA **(12kW@69K 2016)**



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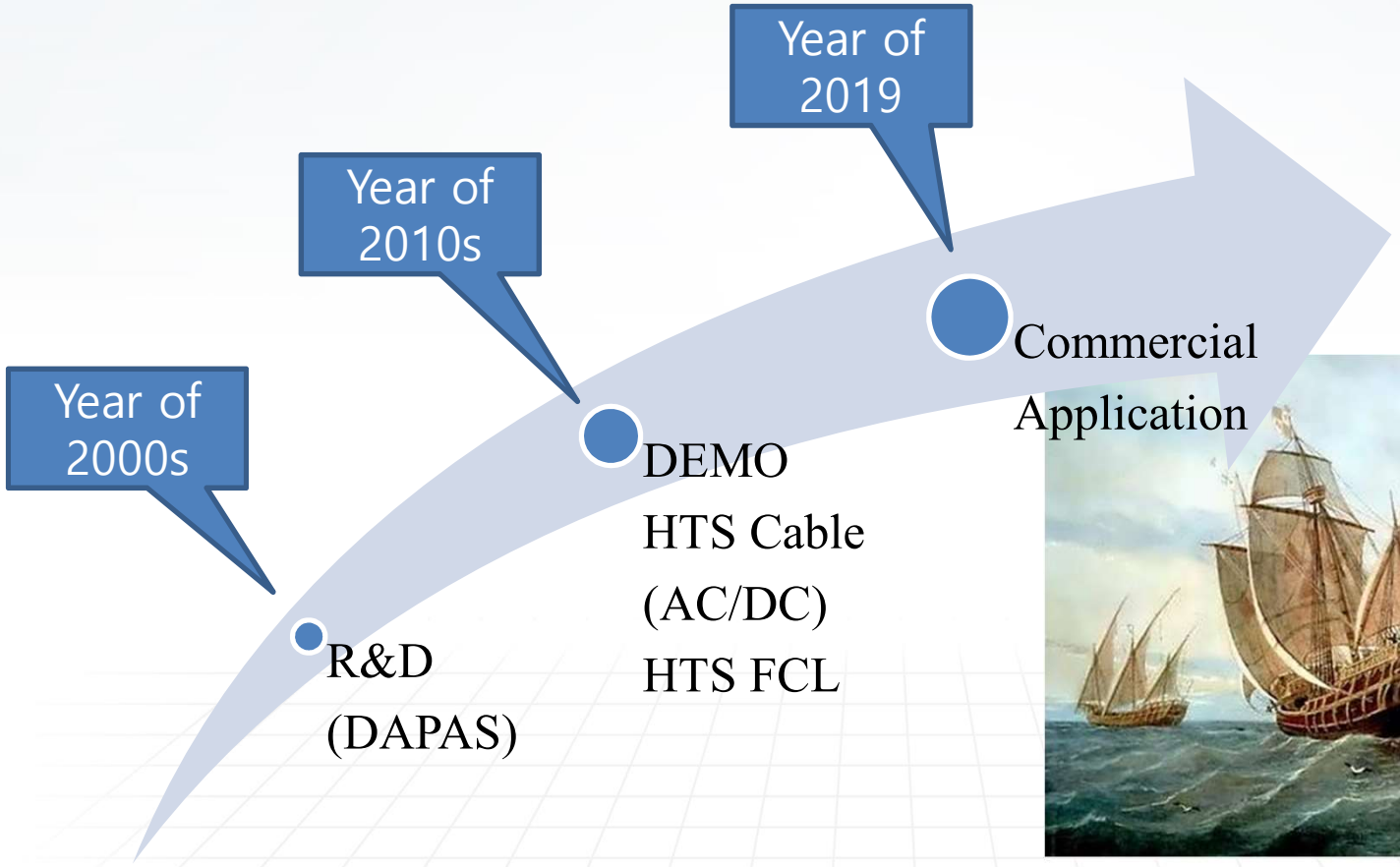
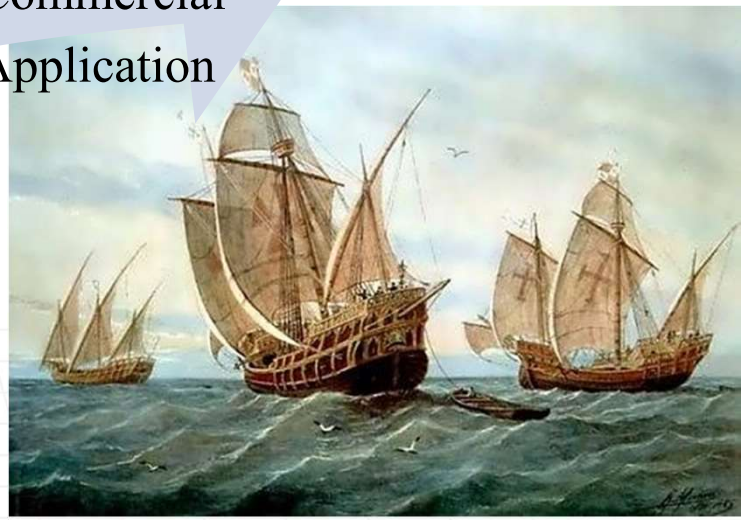
History of HTS Cable Projects in KOREA

- Korea began research on the development of superconducting cables in the early 2000s.
- The development and verification tests of the HTS cables for AC and DC from 23kV to 154kV have been very successful through the various demonstration projects.





[Ref. http://Landoflegendslv.com]

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Opening Ceremony for the HTS Industrialization

- KEPCO declared to lead the industrialization of HTS in an opening ceremony in Mar. 2016.
- **The 1st commercial application of HTS cables, "SHINGAL Project" was developed** with the support of high executive levels.

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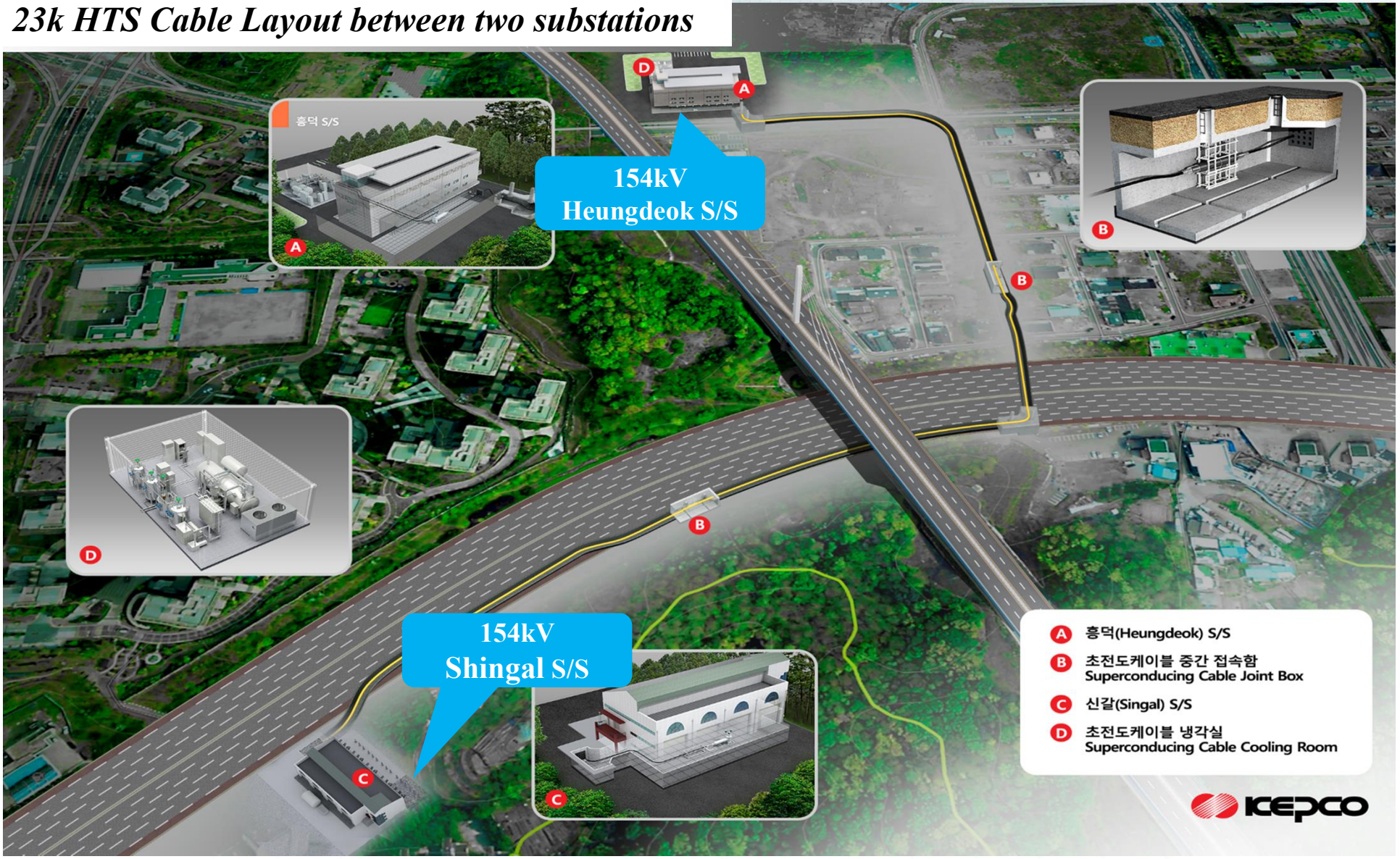
"Shingal" Project : 23kV HTS Cable Installation

23k HTS Cable Layout between two substations



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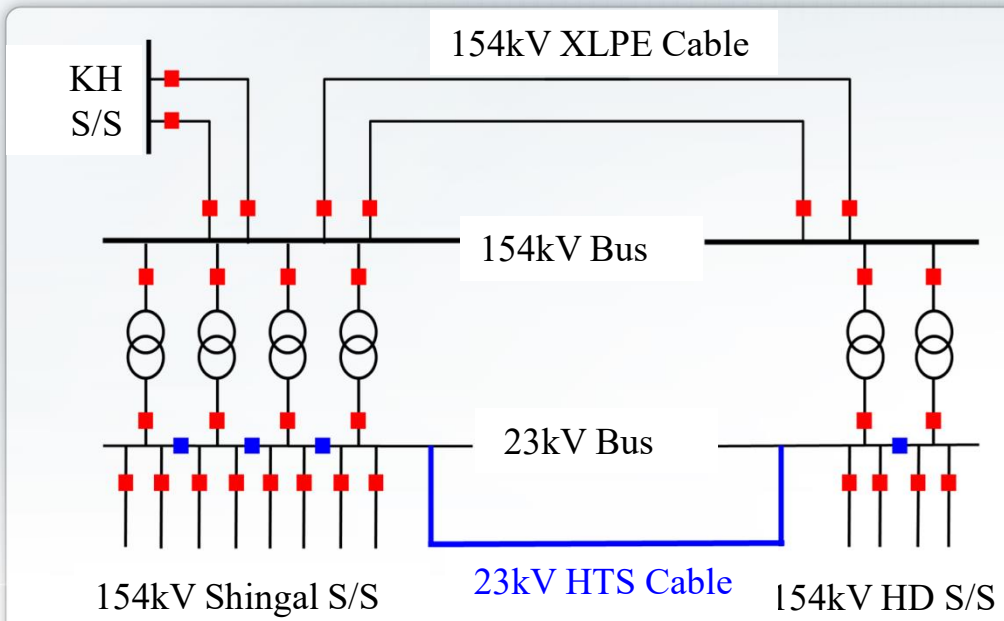
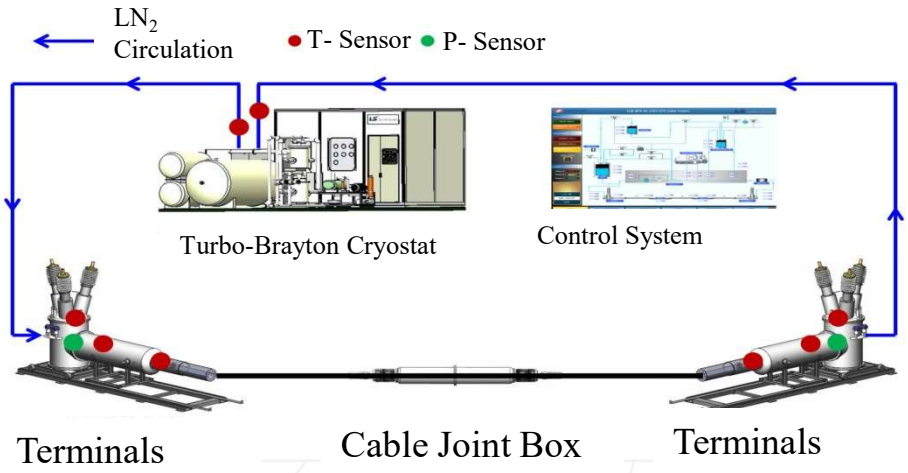
"Shingal" Project : 23kV HTS Cable Installation





Period : Nov. 2016 ~ Jun. 2019

System : AC HTS 23kV 50MVA 1km-cct

Cooling : 7.5kW @69K
- LN_2 Circulation cooled by Turbo-brayton Cryo-cooler and Decompression type refrigerator

Budget : USD 15M (100% funded by KEPCO)

Purpose : Sharing power supply capacity by connecting 23kV HTS cable between two substations

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"Shingal" Project : 23kV HTS Cable Installation

- The type test of the 23 kV HTS cable system is underway at the Gochang test center of KEPCO
  - Duration : Aug. 2018 ~ Nov. 2018
- Based on CIGRE TB 538 (2013), IEC 60840, and IEC 61462, KEPCO has established its own type test guidelines; KEPCO GS 6145-0088

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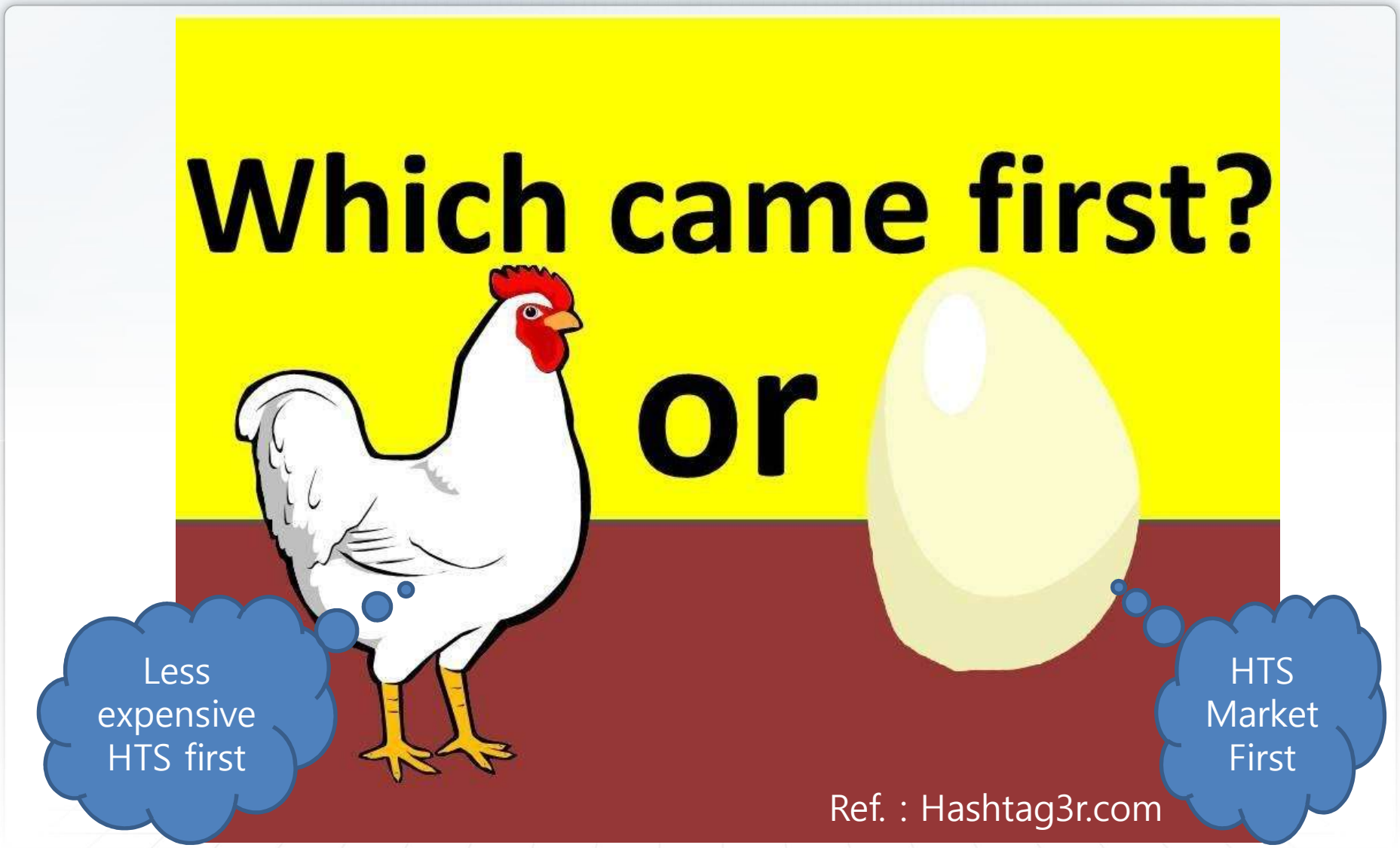
"Shingal" Project : Type Test

Items			July				August				September				October				November				Remarks
			1wk	2wk	3wk	4wk	1wk	2wk	3wk	4wk	1wk	2wk	3wk	4wk	1wk	2wk	3wk	4wk	1wk	2wk	3wk	4wk	
Pre	Cable housing																						
	Assemble																						
	Vacuum																						
Type Test	Pressure Test and Cool-down																						
	Pressure Down and loss Measurement																						
	Load Cycle Voltage Test																						
	AC Voltage Test Lightning Impulse Partial Discharge Test																						
	Thermal Cycle Test	Warm-up																					
		1st Cool Down																					
		1st Load Cycle																					
		Warm-up																					
		2nd Cool Down																					
		2nd Load Cycle																					
		Warm-up																					
	Visual Inspection																						

Currently, The thermal cycle test is underway

Paradigm Change of Power System



Paradigm Change of Power System

Pumped

AC

765kV

ESS

HVDC

HTS

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Paradigm Change of Power System

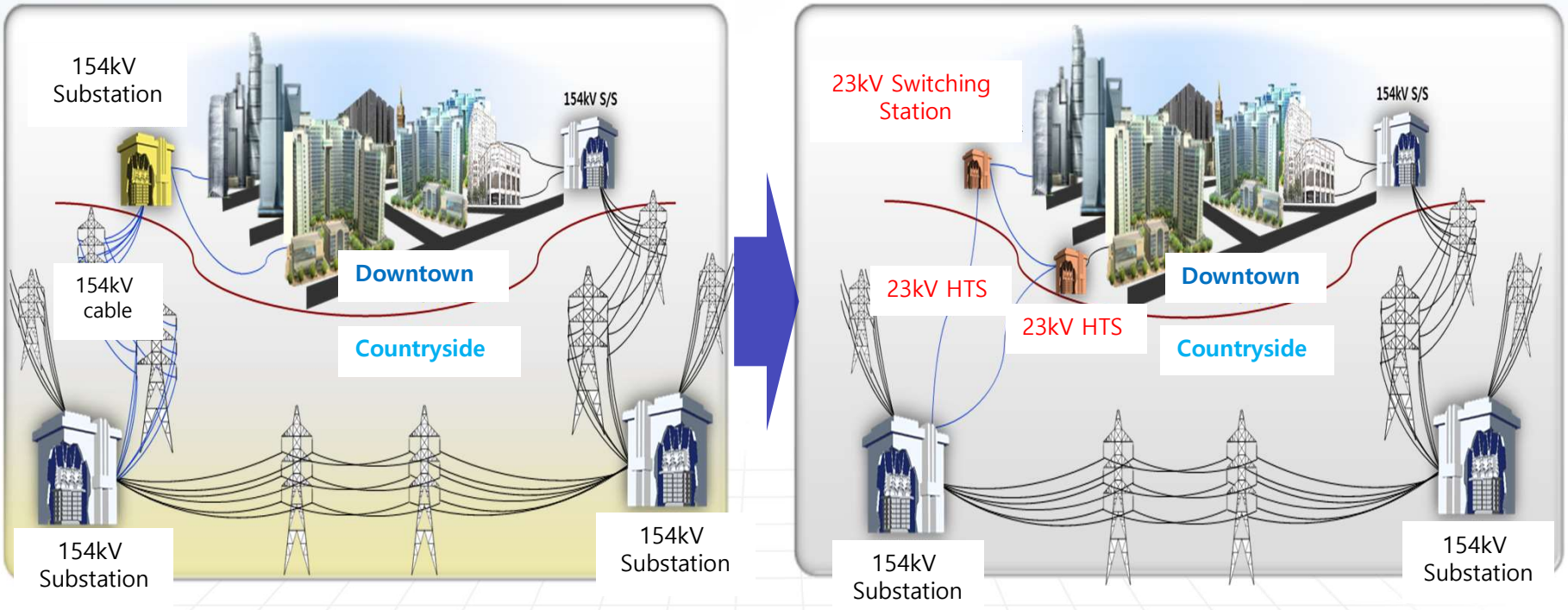
- The HVDC connection with North Korea will be necessary considering the national security and the reliability of power system issues among others.
- This peaceful scenario will be able to envision a Super Grid which connects Korea with its neighboring big countries, such as China, Russia, and Japan.

Ref. http://www.vox.com

Ref. http://www.toonpool.com

Paradigm Change of Power System

- The left figure shows the conventional method used to install substations in urban areas, and the right figure illustrates the concept of a hybrid power system combined with 23kV HTS power cables.
- The 23kV switching stations linked with HTS cables can perform the same tasks rather than constructing new substations that require a large-scale space.



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Paradigm Change of Power System

No more High
Voltage Cables
No more EMF

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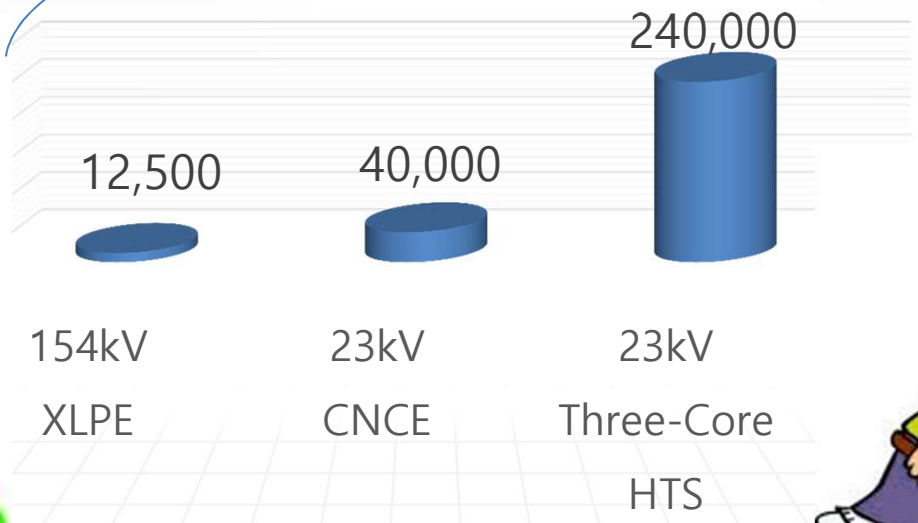
The HTS Cable is Ready? How Economical?

- From a view point of transmission planning, we have two issues for the broader application of the HTS cables to power systems.
- One is the price reduction of HTS cables and the other one is the length of them.



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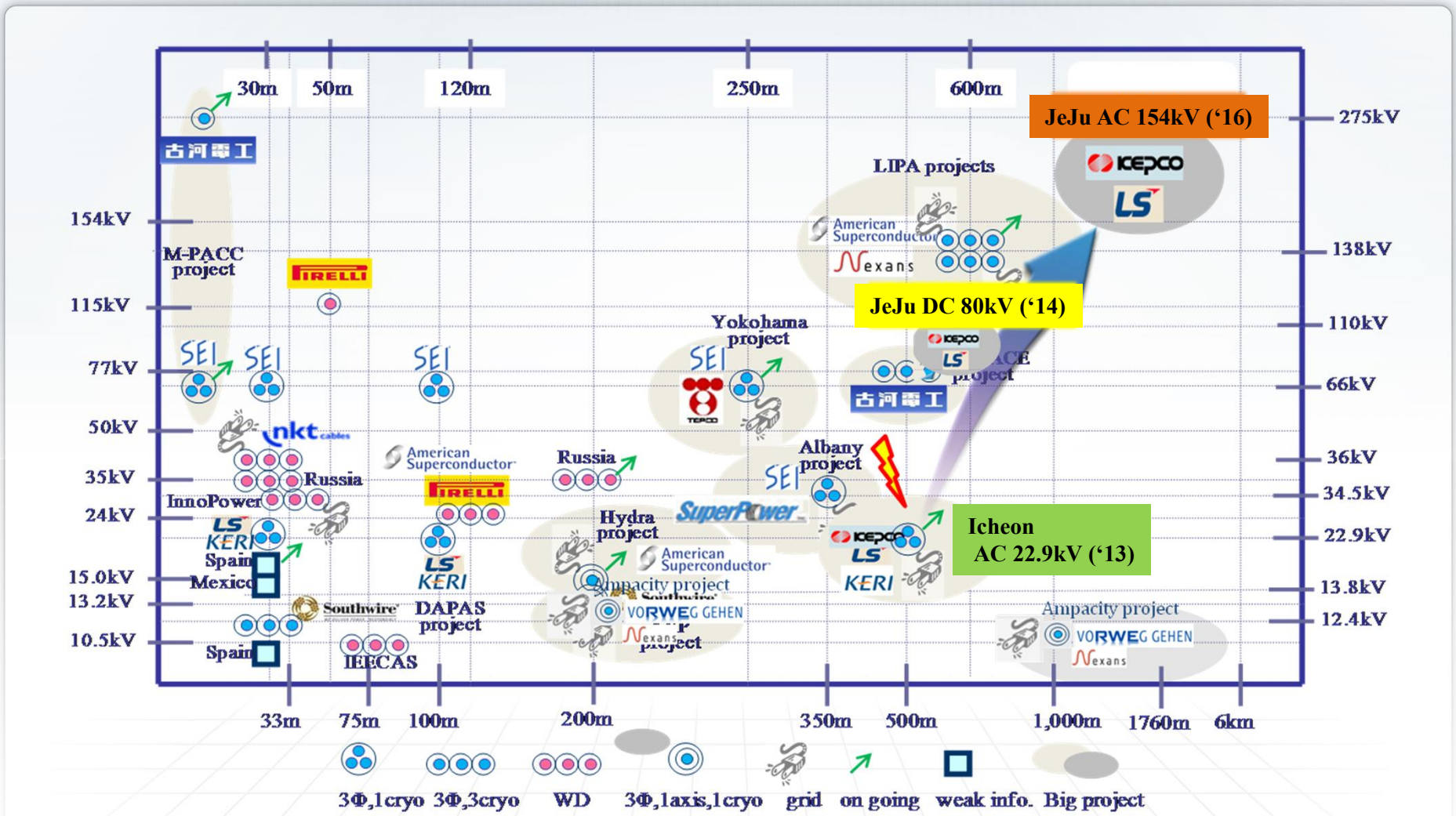
Worldwide development and demonstration of HTS Cables

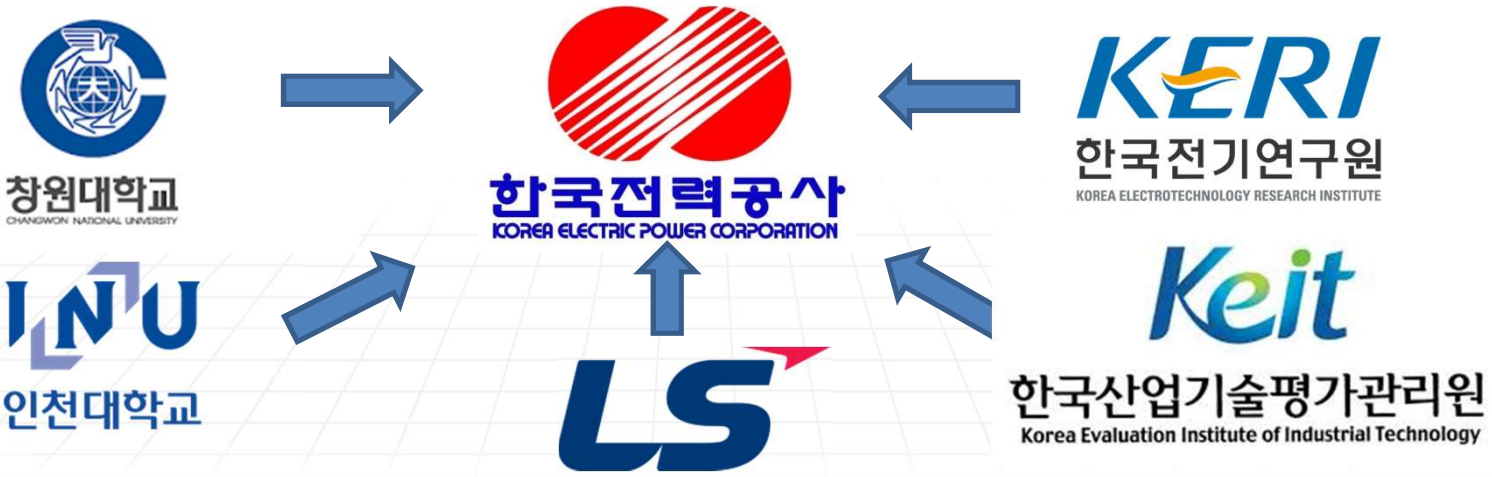


Ref. KEPCO & CNU

Development of Tri-axial HTS Cable

Research Project Overview

- Title : Development of 23kV Tri-axial Cable System and Business Model
- Period : Mar. 2017 ~ Feb. 2022 (5 years)
- Budget : $ 26 M (Funded by KEPCO)
- Target : (Before) 60 MVA 3 km (Present) **120 MVA 3 km**



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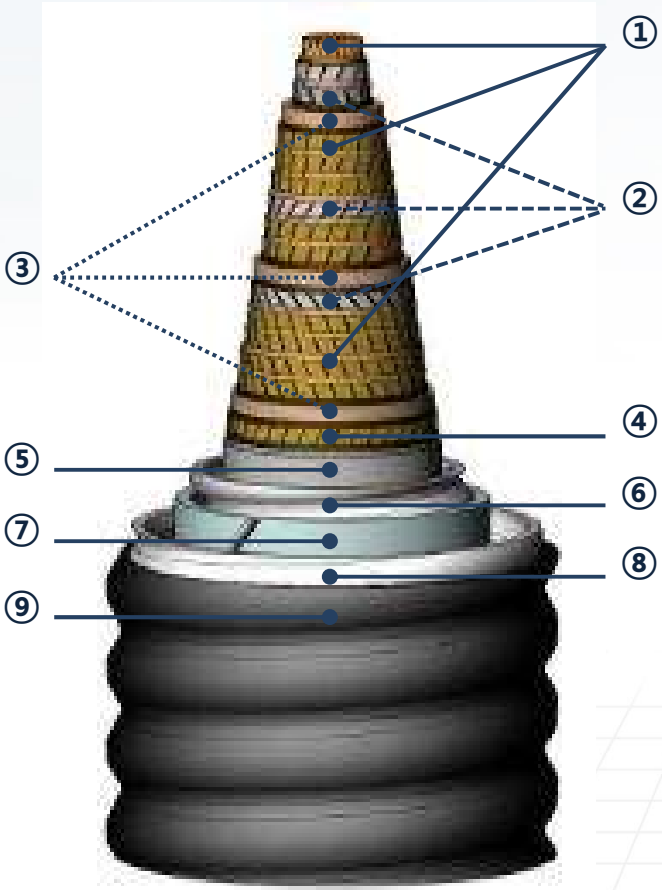
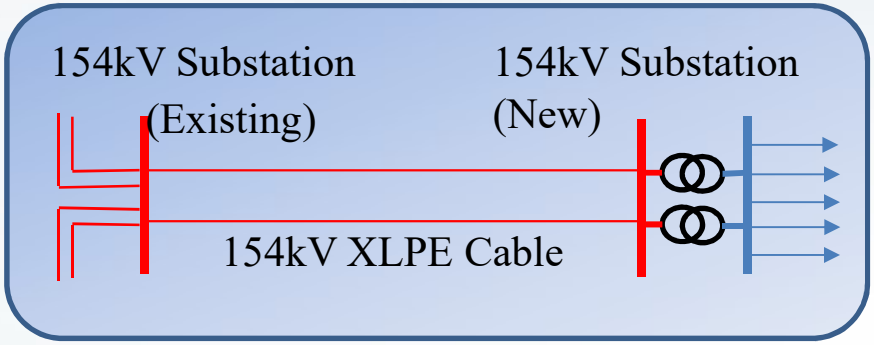
Development of Tri-axial HTS Cable

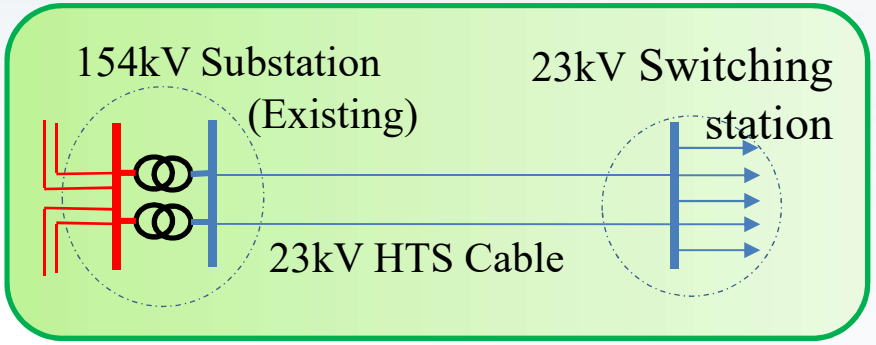
The main feature is that the LN_2 return path is configured separately to increase the length of the HTS cable up to 3 km.

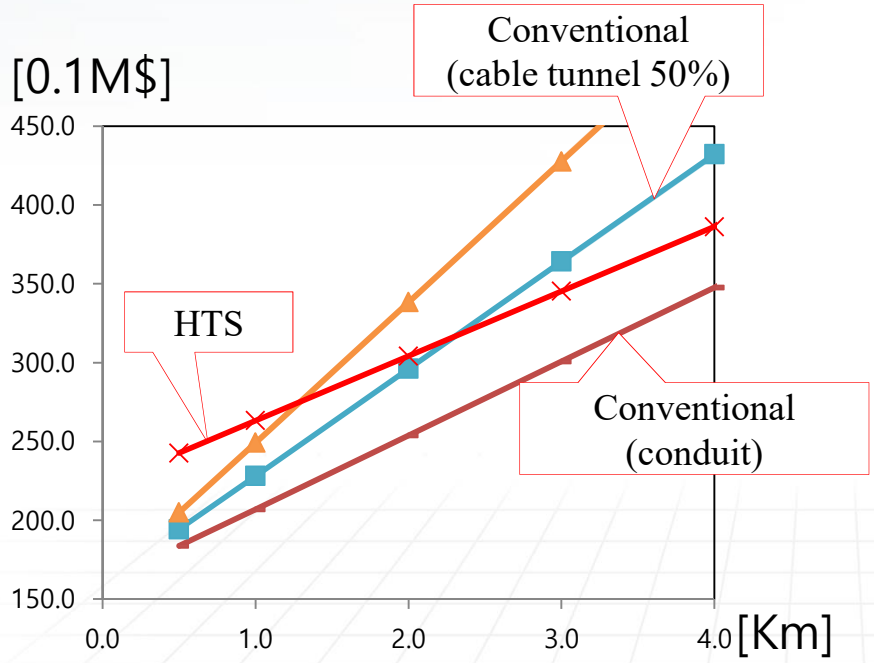


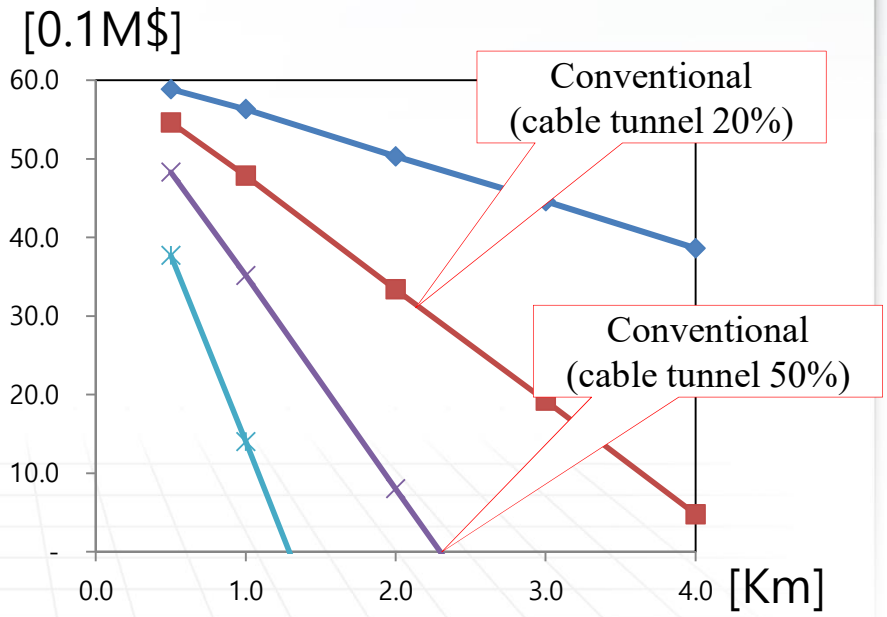
·		
①	Former	- Frame for attaching optimal number of superconducting tapes for each phase - Fault current path for phase
②	Superconducting Conductor	- Rated current path for each phase
③	Electrical insulation	- Electrical insulation between phase-to-phase or phase-to-ground
④	Copper shield	- Shielding interior or exterior emission of electromagnetic field
⑤	Protective binder	- Binding and protecting cable core
⑥	LN_2 vessel	- Vessel for LN_2 flow
⑦	Thermal insulation	- Reducing radiation heat leak
⑧	Vacuum vessel	- Vessel for maintaining high vacuum in thermal insulation layer
⑨	Jacket	- Protecting the cable from external influences

Economics Evaluation of HTS Hybrid System

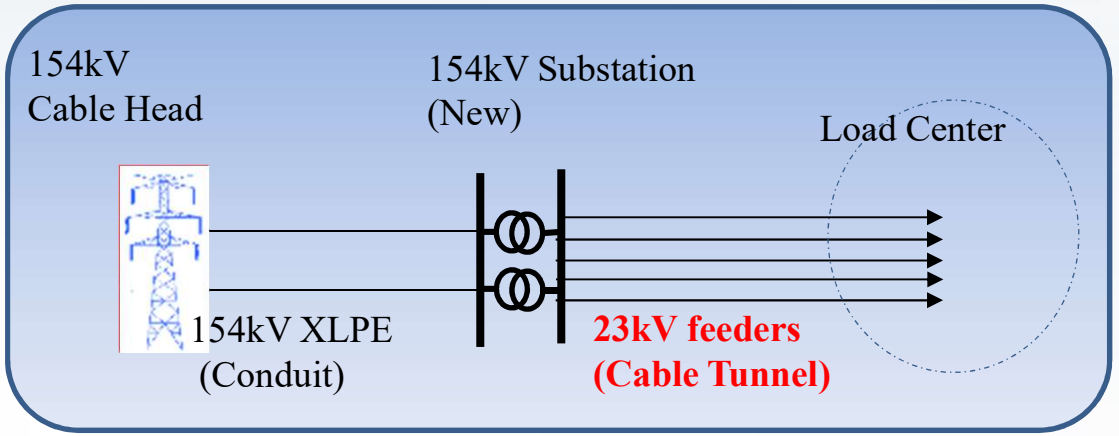


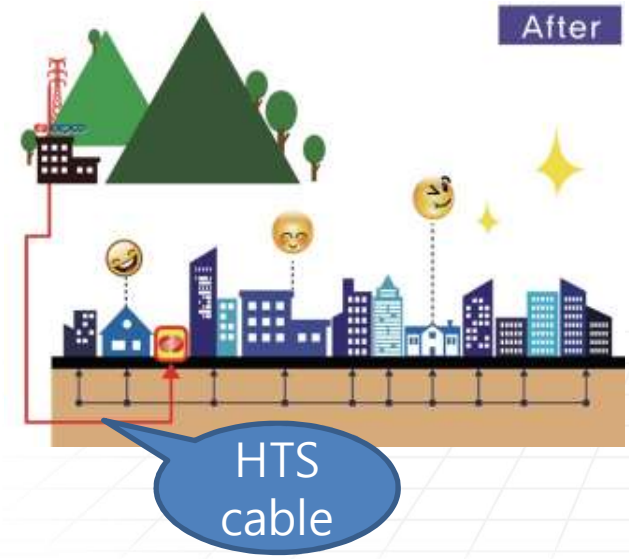


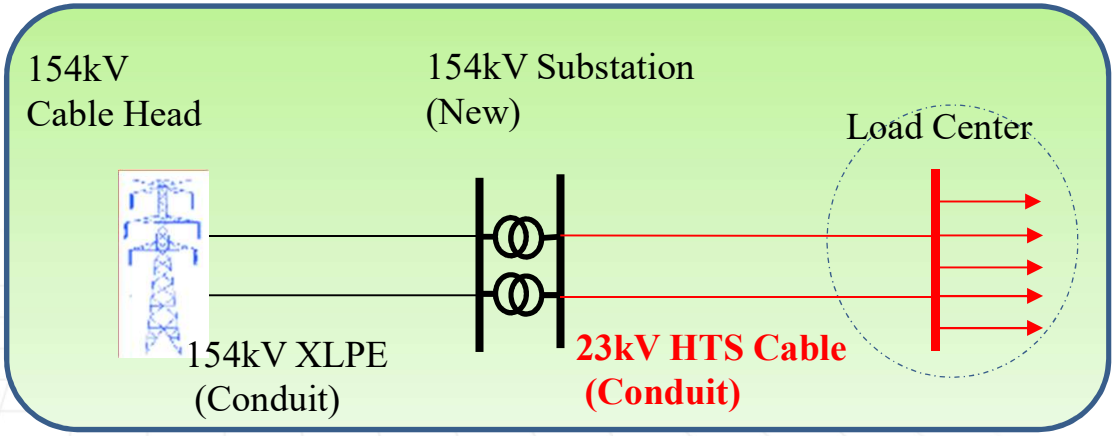




Economics Evaluation of HTS Hybrid System

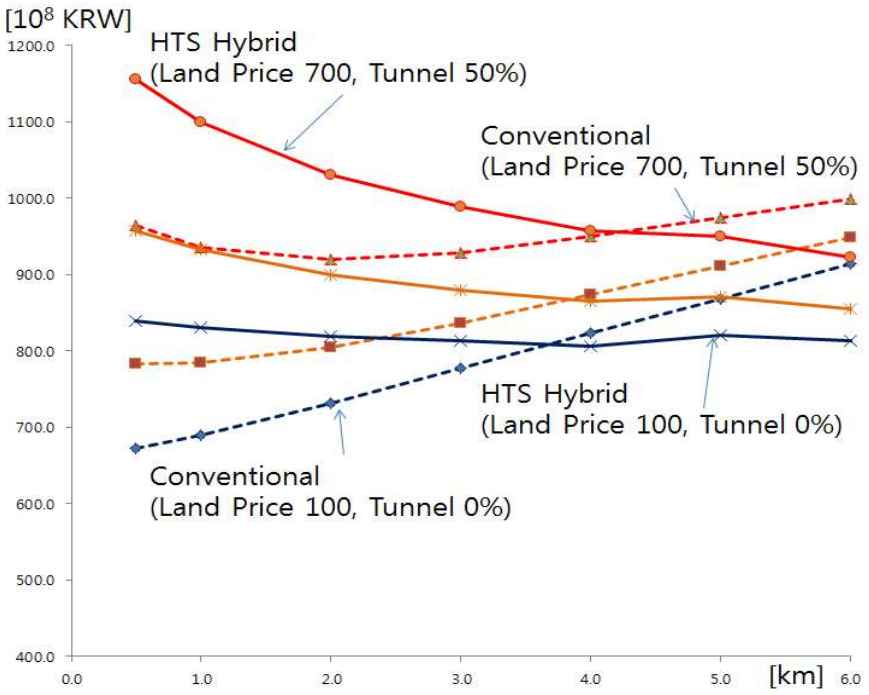


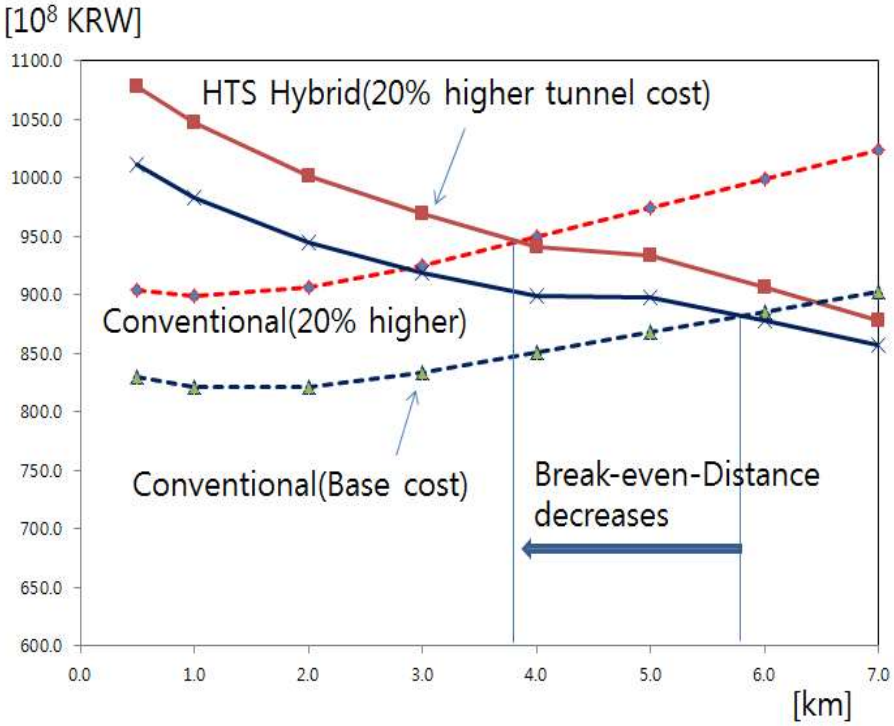




Economics Evaluation of HTS Hybrid System

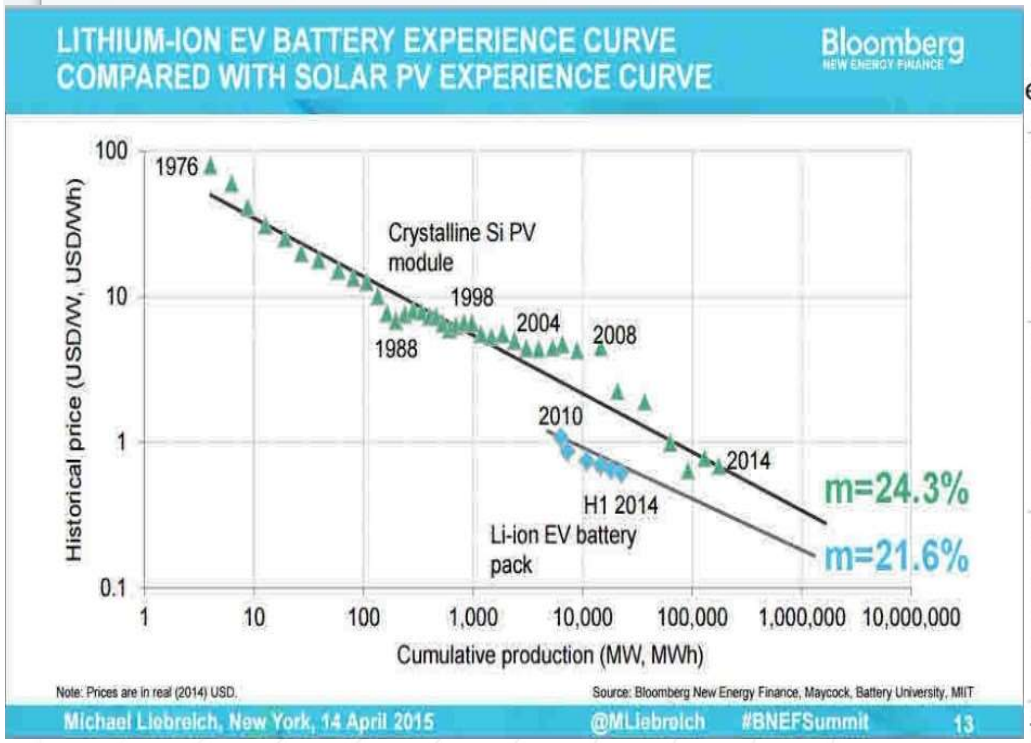
- Most importantly, there is a break-even distance even in this case where the investment costs of both conventional and the HTS hybrid method are the same.
- The high investment cost of HTS cables can be offset by the effects of land acquisition, the cable tunnel construction , and the price reduction of the tri-axial HTS cable.



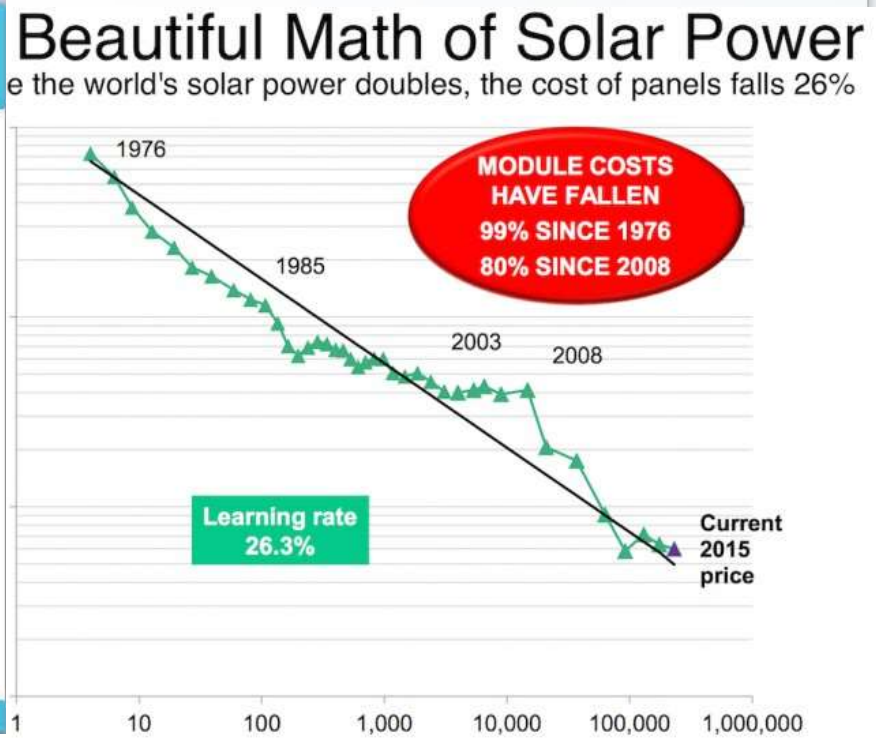


Will Moore's law apply to HTS cables?

- Moore's law is the observation that # of transistors in IC doubles about every 2 years. Similarly, Swanson's law says the cost of solar panels drops 20% for every doubling of cumulative production.
- **Why not to the HTS wires?**



Source : Bloomberg New Energy Finance, Apr. 2015



Source : BNEF via Think Progress, Jul. 2016

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Will Moore's law apply to HTS wires?

Thank You for your Attention

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