Recent status and progress on the HTS application of AC and DC power transmission in Korea

Minwon Park, Seok Ju Lee, In-Keun Yu; Changwon National University
Youngin Won, Yangho Kwak, Hyungsuk Yang; KEPCO
Jin Bae Na, Cheol Hyui Lyu, Seung Ki Park; LS cable
What was changed during last 50 years in Korea?

- Development of Korean power network

**Power system in 1965**

**Power system in 1975**

**Power system in 2016**

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Ref. 1) www.kepco.co.kr
2) 제7차 전력수급기본계획

- Generator
  - 765 kV 변전소
  - 345 kV 변전소
  - 765 kV 가공선로
  - 345 kV 가공선로
  - 345 kV 지중선로

- Generator
  - 154 kV 변전소
  - 154 kV 가공선로

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20th Sep. 2017 EUCAS, GENEVA, Minwon Park, Changwon National University
History of the technology development of electricity

\[ P = V \times I \]

Power loss
\[ = r(Cu \& Al) \times I^2 \]

\[ P = \frac{V_r \times V_s}{X_1} \sin\delta \]

Utility has concentrated on the increasing of voltage level.
Just using **HTS**, 5 times more current without any resistivity in use.

Dramatically, voltage can be decreased at the same power capacity.
Implications of Korean power network
- Current status and the direction for the future

In technological and scholarly characteristics of power system
“Image of traditional disciplines”
→ “Trends of conservative approach”

In power application
“Consistent direction (Voltage)”
→ “Emphasis on efficiency of power”

Paradigm shift by utility

From “Forthright consumption”
→ To “Energy storage”

From “Copper & aluminum”
→ To “Ceramic (HTS wire)”

From “AC system”
→ To “DC system”
HTS power application R&D in Korea last 15 years (2001~2016)

- **JEJU Project (2011.07~2016.10)**, 10M$/yr, 5yrs
  - HTS DC Power cable; 80kV, 60MVA, 500m
  - HTS AC Power cable; 154kV, 500m
  - cable all grid connection to deliver wind farm power
  - SFCL is also considered to connected to grid
  - KEPCO (funded and grid opened)

- **ICHEON (2009.01~2013.12)**, 5M$/yr
  - HTS Power cable; 22.9kV, 50MVA, 500m (KEPRI, LS, KERI, etc.)
  - HTS Power cable; 22.9kV, 150MVA 100m
    - cable all grid connection
  - SFCL; 22.9kV, 630A class (KEPRI, LS, etc.)
  - SFCL; 22.9kV, 3kA class
    - all grid connection
  - KEPCO (funded and grid opened), Korea has only one utility company.

- **DAPAS (2001.06~2011.03)**, 10M$/yr
  - HTS Power cable; 22.9kV and 154kV class (KERI, LS, KEPRI, etc.)
  - HTS Xsfe; 154kV class core technology (KPU, etc.)
  - SFCL; 22.9kV, 600A and 3kA class, 154kV core tech. (KEPRI, LS, etc.)
  - HTS Motor; 5MVA class (DHI, KERI, etc.)
  - 2G wire; 1km, 500A/cm_width (KERI, SuNam, etc.)
  - CAST (Project Management)
What was changed last 15 years

- **3 HTS power cables** (AC 22.9kV, AC 154kV, DC 80kV) were installed in real test grid.
- 1 HTS power cable (AC 22.9kV) is ready to be commercially available.
- **2 SFCL** (AC 22.9kV, 154kV) were connected to the real test grid.

- World class 2G HTS wire company (SuNAM) was established.
HTS Power Cable
Worldwide HTS power cable projects

- **AC HTS cable**
- **DC HTS cable**

<table>
<thead>
<tr>
<th>Project Details</th>
<th>Length</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 m, 138 kV, 574 MVA</td>
<td>6 km, 50 kV, 250 MVA</td>
<td>1 km, 10 kV, 40 MVA</td>
<td>2.5 km, 20 kV, 50 MW</td>
<td></td>
</tr>
<tr>
<td>1 km, 22.9 kV</td>
<td>100 m, 154 kV, 3.75 kA</td>
<td>100 m 22.9 kV, 3 kA</td>
<td>1 km, 20 kV, 2.5 kA</td>
<td></td>
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<td>1 km, 20 kV, 2.5 kA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 km, 50 kV, 250 MVA</td>
<td>360 m, 1.3 kV, 10 kA</td>
<td>100 m, 22.9 kV, 1.25 kA</td>
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<td></td>
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<td>1 km, 22.9 kV</td>
<td>100 m, 22.9 kV, 3 kA</td>
<td>100 m 22.9 kV, 3 kA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>170 m, 13.8 kV, 4 kA</td>
<td>20 m, 20 kA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 km, 12 kV</td>
<td>240 m, 66 kV, 1.8 kA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 m, 154 kV, 3.75 kA</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
World 1st fully commercialized HTS power cable installation

R&D in advance ➤ Pilot demonstration ➤ Commercialization

First commercialization

- Shingal project: 100% funded by KEPCO
  - Project period: Sep., 2016 ~
  - System configuration: AC23kV 50MVA, 1km-cct + 7.5kW @69K Turbo Brayton Cooling system
  - Project cost: USD10M
  - Type test in progress

System configuration

Installation Site
HTS power cable graph (Length x Voltage)

Wall is not length. Wall is **commercially available** or not.
Concept of 23kV HTS power cable application for commercialization

- In order to achieve the economic advantage of HTS power cable,
- a new concept of 23kV HTS power cable was proposed.
- And, more detail economic benefit from analysis was done.

Conventional power network

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>345/154 kV s/s</td>
<td>154/22.9 kV s/s</td>
</tr>
</tbody>
</table>

HTS power network

(3 s/s → 2 hub s/s)

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>154/22.9 kV Hub s/s</td>
<td>22.9 kV hub</td>
</tr>
</tbody>
</table>

Avoid from downtown

- In order to achieve the economic advantage of HTS power cable,
- a new concept of 23kV HTS power cable was proposed.
- And, more detail economic benefit from analysis was done.
City information
(residential, business, industrial area)
Name of city; Changwon
Area of city: 126.1 km²
Population of city: 488,135 people
Installed 154kV S/S: 6 stations
(23 Bank)
Installed capacity: 1,380 MVA
Peak load: 886.6 MVA(winter season)

→ When a new city is constructed as mentioned above, similar level of substation is needed to supply power to the city. (Scheduled substation is also considered.)
→ Several substations can be replaced by switching stations only with HTS power cable.
Direct receiving industrial load area

<table>
<thead>
<tr>
<th>S/S</th>
<th>Installed capacity</th>
<th>Peak load</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>240 MVA</td>
<td>189.1 MVA</td>
</tr>
<tr>
<td>B</td>
<td>180 MVA</td>
<td>86.5 MVA</td>
</tr>
<tr>
<td>C</td>
<td>240 MVA</td>
<td>171.2 MVA</td>
</tr>
<tr>
<td>D</td>
<td>240 MVA</td>
<td>143.9 MVA</td>
</tr>
<tr>
<td>E</td>
<td>240 MVA</td>
<td>147.8 MVA</td>
</tr>
<tr>
<td>F</td>
<td>240 MVA</td>
<td>148.1 MVA</td>
</tr>
<tr>
<td>Total</td>
<td>1,380 MVA</td>
<td>886.6 MVA</td>
</tr>
</tbody>
</table>

Ref. 1) Changwon electric power transmission center of KEPCO
5 km is very enough length to cover the distance of S/S to S/S. This is one of the next targets of HTS power cable.

The city receives electric power based on two hub-stations with tri-axial HTS power cables.
2km class tri-axial HTS power cable project

- Period: 2017~2021 (5 years)
- Budget: 30M USD/5yrs (fully funded by KEPCO)
- Participants: KEPCO, KEPRI, LS cable (cable supplier), and Changwon National University (core design)

- Scope
  - 23kV, 50MVA, Co-axial HTS power cable development
  - 3km class cooling system development for power cable
  - 23kV HTS power network protection algorithm development
  - 100m HTS power cable test
  - ~2km HTS power cable installation in real power network
New project roadmap of HTS power cable was established.

Now, here

**2km project (2017.01~2021.12)**, 30M$ 
- 23kV Co-axial HTS Power cable
- 3km cooling system for power cable
- 2km 23kV HTS power cable installation
- KEPCO (fully funded)

**Shingal Project (2016.09~2017.10)**, 10M$ 
- 1km 23kV HTS power cable
- Real grid connection
- KEPCO (fully funded)

**JEJU Project (2011.07~2016.10)**, 10M$/yr, 5yrs 
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- SFCL; 22.9kV, 600A and 3kA class, 154kV core tech. (KEPRI, LS, etc.)
- HTS Motor; 5MVA class (DHI, KERI, etc.)
- 2G Wire; 1km, 500A/cm_width (KERI, SuNam, etc.)
- CAST (Project Management)
Why utility company is interested in HTS power cable in Korea
Public nuisance along with voltage

Milyang city 765kV strong resistivity
2 people suicided
7 years construction stopped
(2007-2014)
Now power line in downtown
Future in downtown
Move substation back behind mountain and avoid downtown.

- 2~3km is enough to get the economical benefit.
- No power tunnel (154kV), using power duct (23kV), and very cheap substation land.
Newly required substation; one HTS cable and one OH

More power from superconductivity platform

Conventional network; needs one more substation

Using one HTS power cable platform

5 km between downtown and substation
Planning of HTS power cable in Korea
AC HTS power cable roadmap

- **3phase/1cryo**: 23kV 50MVA 100m
  - Completed

- **3phase/3cryo**: 154kV 1GVA 100m
  - Completed

- **HTS AC Power cable**: 23kV 50MVA 100m
  - Completed

- **DAPAS**: 154kV 600MVA 1km
  - Completed

- **Icheon**
  - 23kV 50MVA 500m
  - On going

- **Shingal**
  - 23kV 50MVA 1km, 1km/unit
  - On going

- **Case 1**: 23kV 150MVA PACAKGE
  - Korean market: 50km, 5km/unit
  - Abroad market too

- **Case 2(1phase)**
  - 23kV 60MVA 2km

- **Case 3(2phase)**
  - 23kV 60MVA 5km, 5km/unit

- **Case 4(3phase)**
  - 23kV 150MVA PACAKGE
  - Korean market: 50km, 5km/unit
  - Abroad market too

- **Case 5**
  - 154kV FCL 100m
  - On going

- **Case 6(FCF)**
  - 50kV, ~1 GVA PACAKGE
  - FCL Cable
  - Korean market: 50km, 5km/unit
  - Abroad market too

- **km/unit**: unit length between 2 SJBs (= coverage of 1 cooling system)
- **50MVA/30kV = 1,800Apeak**
- **1GVA/154kV = 5,300Apeak**
DC HTS power cable roadmap

- **2010**
  - HTS DC Power cable
  - Jeju 80 kV 500MW 500m
  - Completed

- **2020**
  - KERI 250kV, 2.5 GW
    - Key components
    - Completed
  - 250 kV, 1GW (1km, 500m /unit)
    - Termination, Joint box
    - Field test
    - Reliability
  - 250 kV, 1~2.5GW (20km, 5km/unit)
    - Demo project
    - Cu HVDC connection
  - 250 kV, 1~2.5GW (100km, 10km/unit)
    - HVDC HTS DC Package
    - National grid connection
    - Nuk plants → Seoul
    - Worldwide co-work

- **Case DC (LVDC type)**
  - 30kV, 1GW (5km, 5km /unit)
    - Low voltage
    - Big capacity
  - 30kV, 1GW (20km, 10km/unit)
    - Field test
    - Reliability
  - 30kV, 1GW (100km, 10km/unit)
    - Demo project
    - Cu HVDC connection

- **30kV, 1GW**
  - LVDC HTS DC PACKAGE
    - Worldwide co-work

- **Key technologies**
  - 30kV, 1GW (100km, 10km/unit)
    - Field test
    - Reliability

- **Key components**
  - 30kV, 1GW
    - Completed
  - 250kV, 2.5 GW
    - Completed

- **Commercialization**
  - 2010
  - 2012
  - 2014
  - 2016
  - 2018
  - 2020
  - 2022
  - 2024
  - 2026
  - 2028
  - 2030
  - 2032
  - 2034
  - 2036
  - 2038
  - 2040

- **km/unit**: unit length between 2 SJBs (= coverage of 1 cooling system)
- 1GW/250kV = 4,000A
- 2.5GW/250kV = 10,000A
- 1GW/30kV = 33,000A
**New 5yr project by KEPCO**

**Started with 30M USD (100% KEPCO)**

- **1st 2yr**
  - 23kV, 50MVA, 500m
  - Conventional 23kV Replacement

- **2nd 3yr**
  - 23kV, 50MVA, >~2km
  - Superconductivity platform
  - Demo project

**Started with 1.5M USD (funded by Government) as feasibility by KERI**

- **1st 2yr**
  - 154kV, 500MVA (FCL function)
  - Key technology development

- **2nd 3yr**
  - 154kV, 500MVA (FCL function), 1km
  - Conventional 154kV Replacement

**Expected results**

- **Economic cable**
  - No more substation
  - World market

- **Fault current limiting**
  - High energy density area
  - World market

- **No pylon transmission**
  - Korean type DC transmission
  - Future market

**Korean HTS Power cable**

- **23kV Tri-axial**
  - 23kV, 50MVA, 500m
  - Conventional 23kV Replacement

- **154kV FCL type cable**
  - 154kV, 500MVA (FCL function)
  - Key technology development

- **30kV DC 1GW**
  - 30kV, 1GW, 100m class
  - Key technology development
  - DC circuit breaker and so on.

<table>
<thead>
<tr>
<th>Year</th>
<th>HTS wire price (example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>20,000KRW/m 200A/4mm</td>
</tr>
<tr>
<td>2018</td>
<td>15,000KRW/m 250A/4mm</td>
</tr>
<tr>
<td>2019</td>
<td>10,000KRW/m 300A/4mm</td>
</tr>
<tr>
<td>2020</td>
<td>7,000KRW/m 350A/4mm</td>
</tr>
<tr>
<td>2021</td>
<td>6,000KRW/m 380A/4mm</td>
</tr>
<tr>
<td>2022</td>
<td>5,000KRW/m 400A/4mm</td>
</tr>
</tbody>
</table>
HTS Fault Current Limiter
HTS FCL trend in Korea (23kV class)

- HTS SFCL in 22.9 kV grid at Icheon substation
  - SFCL operation (commercial operation)
    1. Dec. 2010 – SFCL installation
    2. 23 Aug. 2011 - energized
    3. Currently under commercial operation
       (To protect a 22.9 kV feeder)
    4. Fault (Feb. 2012) – SFCL properly worked

- SFCL
  1. 22.9 kV, 630 A, hybrid SFCL
  2. SFCL interruption under fault current
     1. < 1.2 kArms : No action
     2. > 1.4 kArms : Instantaneous action
  3. Limiter impedance : 400 mΩ
154kV SFCL installed in real grid for testing

- 154 kV/2,000 A class HTS SFCL (Withstand voltage tests)

Gochang Power Test Center

It is waiting for real fault current even now.
154kV HTS FCL current status

- A resistive type combined with normal-conducting components
- Components of the SFCL
  - HTS element: detects and limits fault current
  - Cooling system: cools the HTS element
  - Switch: protects the HTS
  - Reactor: limits the fault current

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage (rms)</td>
<td>170kV</td>
</tr>
<tr>
<td>Rated current (rms)</td>
<td>2,000 A</td>
</tr>
<tr>
<td>Rated power frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Rated AC withstand voltage (rms)</td>
<td>325 kV</td>
</tr>
<tr>
<td>Rated impulse withstand voltage</td>
<td>750 kV, BIL</td>
</tr>
<tr>
<td>Rated short circuit current (rms)</td>
<td>50 kA</td>
</tr>
<tr>
<td>Operation temperature (K)</td>
<td>71 K</td>
</tr>
</tbody>
</table>

- Now, more than several months very stable operation.
- Single phase 154kV SFCL, design, fabrication, installation, and operation.
- Three phase system will be developed soon.
- Real grid demonstration might be around 2019.
HTS DC reactor
Concept of the HTS DC reactor

- **Shape of the conventional reactor**
- **Conductor of the reactor magnet**
  - Conventional reactor
  - HTS DC reactor

- **Characteristics of the HTS DC reactor**
  - Operation condition: DC
  - Conductor type: HTS wire
  - Magnet type: Air dry core & toroid-type
  - Operation temperature: < 77 K
  - No electrical loss (Zero electric resistance)
  - No Flux leakage (toroid-type)
  - Reduce the reactor’s size, weight and space
Advantage of the HTS DC reactor

- Size advantage of HTS DC reactor (Same scale, without insulator)

Ref: SIEMENS

HTS DC reactor is **one of the solution** for **support load problem** of large scale DC reactor
Advantage of the HTS DC reactor

- Install space of the reactor considered magnetic clearances (ref: ALSTOM)
  - A: Reactor outer surface, Ds: Reactor outer diameter
  - Keep metallic parts not forming closed loops outside B
  - Keep metallic parts forming closed loops or large metallic parts outside C

- Magnetic field distribution of the HTS DC reactor (toroid-type)
  - The toroid-type HTS DC reactor magnet has a much lower leakage flux
  - Most magnetic flux line patterns are formed by the shape of the toroid magnet
- Design results of the 400 mH, 1,500 A class HTS DC reactor using coated conductor
- 400 mH, 1,500 A HTS DC reactor will be operated **within a few weeks**.
HTS DC reactor (400mH, 1,500A)

400mH, 400A class successfully completed with good test results

400mH, 1,500A will be tested soon

20th Sep. 2017 EUCAS, GENEVA, Minwon Park, Changwon National University
Thank you for your attention

On going HTS project or business of AC and DC transmission in Korea

- AC 23kV HTS power cable
- AC 23kV tri-axial HTS power cable
- AC 154kV SFCL
- AC 154kV FCL function HTS power cable
- DC reactor
- DC 250kV power cable

Brief specification

- 1km, 23kV, commercial installation
- 100m, ~2km, 23kV, demo project
- Real grid installation within 2019
- Feasibility R&D
- 400mH, 1,500A fabrication
- Terminal design and test

by
- KEPCO (plan, power network)
- KEPRI (R&D)
- LS cable (supplier)
- Changwon National University (core design)
- KERI, and so on

Done
- 23kV (3Φ) AC cable 100m
- 23kV (3Φ) AC cable 500m
- 154kV (3Φ) AC cable 1km
- 80kV DC cable 500m
- 23kV (3Φ) SFCL
- 154kV (1Φ) SFCL
- 400mH, 400A DC reactor
• Back data
<table>
<thead>
<tr>
<th>구분</th>
<th>발생비용</th>
<th>기존전력공급 계통</th>
<th>Biz1</th>
<th>신규변전소 외곽위치</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>값 (억)</td>
<td>비율 (%)</td>
<td>값 (억)</td>
<td>비율 (%)</td>
</tr>
<tr>
<td>154kV 변전소/120MVA</td>
<td>100.1</td>
<td>38%</td>
<td>100.1</td>
<td>38%</td>
</tr>
<tr>
<td>154kV 변전소/180MVA</td>
<td>118.1</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
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<tr>
<td>154kV 변전소/240MVA</td>
<td>136.2</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
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<tr>
<td>154kV 변전소/300MVA</td>
<td>154.3</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
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<tr>
<td>154kV 변전소 대지구입(택지개발지구 기준)</td>
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<td>0%</td>
<td>1</td>
<td>5%</td>
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<td>33.0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
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<tr>
<td>소합계(억원)</td>
<td>207.1</td>
<td>78%</td>
<td>113</td>
<td>43%</td>
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<tr>
<td>지중송전 전력구 154kV 인입 거리</td>
<td>0.1 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154kV 지중송전 전력구</td>
<td>63.5억/km</td>
<td>12%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>154kV 지중송전 전력 케이블/4Bank</td>
<td>51.4억/km</td>
<td>10%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td>57.5</td>
<td>22%</td>
<td>113</td>
<td>43%</td>
</tr>
<tr>
<td>154kV 변전소간 연계 거리</td>
<td>5.0 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154kV 가공선로 케이블/4Bank</td>
<td>23.0억/km</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>154kV 지중송전 관로/4Bank</td>
<td>77.8억/km</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>154kV 지중송전 전력구/4Bank</td>
<td>114.9억/km</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td>-</td>
<td>0%</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-0.1km</td>
<td>52.9억</td>
<td></td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-0.5km</td>
<td>60.3억</td>
<td>2</td>
<td>121</td>
<td>45%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-1km</td>
<td>72.0억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-3km</td>
<td>132.0억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-5km</td>
<td>186.5억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/100MVA (22.9kV 지중배전관로)-0.1km</td>
<td>54.3억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/100MVA (22.9kV 지중배전관로)-0.5km</td>
<td>72.5억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/100MVA (22.9kV 지중배전관로)-1km</td>
<td>91.0억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/100MVA (22.9kV 지중배전관로)-3km</td>
<td>185.2억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/100MVA (22.9kV 지중배전관로)-5km</td>
<td>259.3억</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td>121</td>
<td>45%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.9kV 배전개폐소</td>
<td>31.5억/개소</td>
<td>1</td>
<td>32</td>
<td>12%</td>
</tr>
<tr>
<td>총합계(억원)</td>
<td>265</td>
<td></td>
<td>265</td>
<td></td>
</tr>
</tbody>
</table>
분석결과 1 - 154kV 변전소/120MVA 신규설치 대비 22.9kV 3상동축초전도 케이블/50MVA 적용 : 154kV 변전소 루프연결 : 지중송전 - 가공선로 적용에 따른

<table>
<thead>
<tr>
<th>구분</th>
<th>발생비용</th>
<th>기존전력공급 계통</th>
<th>신규변전소 외곽위치</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>값</td>
<td>비용 (억)</td>
</tr>
<tr>
<td>154kV 변전소/120MVA</td>
<td>100.1</td>
<td>1</td>
<td>100.1</td>
</tr>
<tr>
<td>154kV 변전소/180MVA</td>
<td>118.1</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>154kV 변전소/240MVA</td>
<td>136.2</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>154kV 변전소/300MVA</td>
<td>154.3</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(택지개발지구 기준)</td>
<td>13.0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(기존도심지 기준)</td>
<td>33.0</td>
<td>1</td>
<td>107</td>
</tr>
</tbody>
</table>

| 소합계(억원) | 207.1 | 25% | 113 | 30% |

22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로) - 0.1km | 52.9 | 0 | - | 0% | 0 | - | 0% |

| 소합계(억원) | 574.6 | 68% | 115 | 30% |

| 소합계(억원) | 121 | 32% |

| 총합계(억원) | 839 | 380 |
지중송전 전력구 인입거리 0.1 km 일 경우.
154 kV 변전소 도심지 대지구입비용 (변전소 대지구입비용(택지개발지구 기준)대비) 138억 이상 일 것.
즉, 154kV 도심 변전소 대지구입 시, 125억(138억 – 13억 = 125억) 이상 추가비용 발생할 것.

<table>
<thead>
<tr>
<th>구분</th>
<th>발생비용</th>
<th>기존전력공급 계통</th>
<th>Biz1 신규변전소 외곽위치</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>값</td>
<td>비용 (억)</td>
</tr>
<tr>
<td>154kV 변전소/120MVA</td>
<td>100.1억/개소</td>
<td>1</td>
<td>100.1억</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(택지개발지구 기준)</td>
<td>13.0억/개소</td>
<td>1</td>
<td>13억</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(기존도심지 기준)</td>
<td>138억/개소</td>
<td>1</td>
<td>138억</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>지중송전 전력구 154kV 인입 거리</td>
<td>0.1 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>154kV 지중송전 전력구</td>
<td>63.5억/km</td>
<td>1</td>
<td>6.3억</td>
</tr>
<tr>
<td>154kV 지중송전 전력 케이블/4Bank</td>
<td>51.4억/km</td>
<td>1</td>
<td>5.1억</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로)-0.1km</td>
<td>52.9억</td>
<td>2</td>
<td>106억</td>
</tr>
<tr>
<td>22.9kV 배전개폐소</td>
<td>31.5억/개소</td>
<td>1</td>
<td>32억</td>
</tr>
<tr>
<td>총합계(억원)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
지중송전 전력구 인입거리 0.5 km 일 경우,
154 kV 변전소 도심지 대지구입비용 (변전소 대지구입비용(택지개발지구 기준)대비) 107억 이상 입 것.
즉, 154kV 도심 변전소 대지구입 시, 94억(107억 – 13억 = 94억) 이상 추가비용 발생할 것.

<table>
<thead>
<tr>
<th>구분</th>
<th>발생비용</th>
<th>기존전력공급 계통</th>
<th>Biz1 실효변전소 외곽위치</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>값(억)</td>
<td>비용(억) 비율(%)</td>
<td>값(억) 비용(억) 비율(%)</td>
</tr>
<tr>
<td>154kV 변전소/120MVA</td>
<td>100.1</td>
<td>100.1 38%</td>
<td>1 100 38%</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(택지개발지구 기준)</td>
<td>13.0</td>
<td>13 5%</td>
<td></td>
</tr>
<tr>
<td>154kV 변전소 대지구입(기존도심지 기준)</td>
<td>138</td>
<td>138 40%</td>
<td></td>
</tr>
<tr>
<td>소합계(억원)</td>
<td></td>
<td>207.1 78%</td>
<td>113 43%</td>
</tr>
<tr>
<td>지중송전 전력구 154kV 인입거리</td>
<td>0.5 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>154kV 지중송전 전력구</td>
<td>63.5</td>
<td>1 31.7 12%</td>
<td></td>
</tr>
<tr>
<td>154kV 지중송전 전력 케이블/4Bank</td>
<td>51.4</td>
<td>1 25.7 10%</td>
<td></td>
</tr>
<tr>
<td>지중송전 전력구 건설비용 소합계(억원)</td>
<td></td>
<td>57.5 22%</td>
<td></td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로) 0.5km</td>
<td>60.3</td>
<td>2 121 45%</td>
<td></td>
</tr>
<tr>
<td>22.9kV 배전개폐소</td>
<td>31.5</td>
<td>1 32 13%</td>
<td></td>
</tr>
<tr>
<td>총합계(억원)</td>
<td></td>
<td>265</td>
<td>265</td>
</tr>
</tbody>
</table>
지중송전 전력구 인입거리 1 km 일 경우.
154 kV 변전소 도심지 대지구입비용 (변전소 대지구입비용(택지개발지구 기준)대비) 74억 이상 일 것.

즉, 154kV 도심 변전소 대지구입 시, 61억(74억 – 13억 = 61억) 이상 추가비용 발생할 것.

<table>
<thead>
<tr>
<th>구분</th>
<th>발생비용</th>
<th>기존전력공급 계통</th>
<th>Biz1 신규변전소 외곽위치</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>값</td>
<td>비용 (억)</td>
<td>비율 (%)</td>
</tr>
<tr>
<td>154kV 변전소/120MVA</td>
<td>100.1</td>
<td>100.1</td>
<td>35%</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(택지개발지구 기준)</td>
<td>13.0</td>
<td>13</td>
<td>5%</td>
</tr>
<tr>
<td>154kV 변전소 대지구입(기존도심지 기준)</td>
<td>138</td>
<td>74</td>
<td>26%</td>
</tr>
<tr>
<td>소합계(억원)</td>
<td>174.1</td>
<td>174</td>
<td>60%</td>
</tr>
<tr>
<td>지중송전 전력구 154kV 인입 거리</td>
<td>0.5</td>
<td>km</td>
<td></td>
</tr>
<tr>
<td>154kV 지중송전 전력구</td>
<td>63.5</td>
<td>63.5</td>
<td>22%</td>
</tr>
<tr>
<td>154kV 지중송전 전력 케이블/4Bank</td>
<td>51.4</td>
<td>51.4</td>
<td>18%</td>
</tr>
<tr>
<td>지중송전 전력구 건설비용 소합계(억원)</td>
<td>114.9</td>
<td>114</td>
<td>40%</td>
</tr>
<tr>
<td>22.9kV 3상동축초전도 케이블/50MVA (22.9kV 지중배전관로) 1.0km</td>
<td>72.0</td>
<td>144</td>
<td>50%</td>
</tr>
<tr>
<td>22.9kV 배전개폐소</td>
<td>31.5</td>
<td>32</td>
<td>13%</td>
</tr>
<tr>
<td>총합계(억원)</td>
<td>289</td>
<td>289</td>
<td></td>
</tr>
</tbody>
</table>