A Review of Strategy to Capture Niche Marketing of HTS Power Distribution Cable

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Abstract- It becomes difficult and high in cost to construct new ducts and/or tunnels for power cables in domestic areas. This paper presents possible strategy of an HTS distribution cables for distributing electric power in local areas as niche marketing. Reflected were its important distinction such as system configuration, rationale, establishment of strategy and considerably high economical efficiency compared with present underground cables.

In this paper, applicable important items by using HTS distribution cables in water pumping powerhouse and distribution substation as example objective regions were reviewed. Based on this, the following items on distribution HTS system are examined.

(1) A review of constructing a model system to introduce high temperature superconducting distribution cables to objective areas is presented.

(2) The strategy to capture HTS distribution cable in water pumping powerhouse and distribution substation as niche marketing regions were reviewed.

(3) In concrete, system configuration, rationale, establishment of strategy and considerably high economical efficiency are reviewed between existing cable and HTS one.

Keywords - superconducting distribution cable, niche marketing, system configuration, rationale, establishment of strategy

1. Introduction

In recent years, large cities have become more information and intelligence oriented and power demand is expected to rise as a result. Power supply to urban areas is mostly done through underground power transmission lines because of difficulty in securing space and for aesthetic purposes. Therefore, it is necessary to construct underground power transmission lines for reliable power supply. However, as underground space in urban areas is already overcrowded with subways, communication and water supply facilities, and buildings, it is difficult to construct conduits and tunnels for underground transmission lines. In addition, engineering works such as construction of tunnels account for most of the construction cost of new underground cables.

As the cost of engineering works is expected to rise in the future, transmission cost will increase.

To reduce the transmission cost, it is necessary to replace existing conduits with small size large capacity transmission cables. A lot of efforts have been put into the development of superconducting cables in industrialized countries including the U.S., Japan, and Korea. And various researches on following areas are underway: expected effects of superconducting cables, optimal system configuration and proper voltage class to supply to urban areas, and proper cable capacity[1][2][3][4][5]. In the case of Korea, the most pressing issue is the assessment of the market for the high temperature superconducting(HTS) cable under development. The biggest market share will go to over 154kV class transmission cable as it has excellent application effects and economical efficiency against investment. Application of the HTS cable to the next generation power transmission system is a real possibility in the U.S., Japan, Korea, and other countries. And active researches on the development of superconducting cable systems to increase cable transmission capacity and to reduce the cost of underground construction are underway. However, in the case of distribution level HTS cable, the market size is smaller and the interest in its development is not as high. But it is possible to increase profitability by specializing in the distribution level or transmission level HTS cable targeting small specialized markets. This paper examines the feasibility of applying the 22kV class HTS cable to a niche market in Korea by examining the rationale and strategy for some cases and comparing its economy with the conventional cable.

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2. Main Discourse

2.1 Application target

This paper examines the market to apply the 22kV class HTS cable, which is under development in Korea along with the transmission level HTS cable. And the target equipment and application targets are selected for examination as follows.

(1) Target equipment

The voltage class and line capacity of distribution level superconducting cable to be applied to a niche market in Korea is as follows.

- Distribution level HTS cable
- Voltage class : 18 ~ 23 kV
- Line capacity : 50 ~ 500MVA

(2) Application targets

Possible areas to apply the target equipment presented above (1) in a niche market in Korea are examined. 5 possible areas are examined and the results can be summarized as follows.

2.1.1 Power plant generator outgoing line

- As the outgoing voltage of a power plant generator is 18~23kV, large capacity outgoing is possible by replacing the line with the distribution level superconducting cable
- Application targets include thermal power plants, nuclear power plants, and storage hydroelectric power plants

2.1.2 Storage hydroelectric power plant/pumping up line

- It is possible to withdraw large capacity by replacing the outgoing line that connects the set up transformer of storage hydroelectric power plant to the above the ground 154/345kV GIS substation with the transmission level superconducting cable.
- Application targets : Storage hydroelectric power plants(Sancheong, Samrangjin, and Muju)

2.1.3 Distribution line in new residential complexes

- Establish a method to withdraw using the distribution level superconducting cable in new residential complexes
- Estimate the construction cost using the superconducting/ conventional cable according to the withdrawal plan
- Find ways to reduce capital investment following the application of superconducting cable

2.1.4 New installation in high load and density areas(Kangnam area)/Distribution withdrawal lines for new substations

- Establish a method to withdraw from a new substation using the distribution level superconducting cable.
- Determine the size of line, tunnel and conduit using the superconducting/ conventional cable
- Find ways to reduce capital investment following the application of superconducting cable

2.1.5 Distribution outgoing line for a new consumer from an existing substation

- Establish a method to withdraw using the distribution level superconducting cable from an existing substation due to new high voltage demand.
- Determine the size of line, tunnel and conduit using the superconducting/ conventional cable.
- Establish a method to apply the superconducting cable

2.2 Case study of applying the superconducting cable to storage hydroelectric power plants

Of the HTS cable application targets in the Korean market presented in 2.1, this paper examines the cases of storage hydroelectric power plants as it is easier to establish a strategy for them. To examine the cases where the transmission level and distribution level superconducting cables are applied to storage hydroelectric power plants, the overview, configuration, rationale, strategy, and economy of the system are examined and the results are presented here.

(1) Overview

- To examine the feasibility of applying the HTS cable to a storage hydroelectric power plant, Muju and Sancheong storage hydroelectric power plants are examined.
- Muju and Sancheong storage hydroelectric power plants generate electricity from the upper dams during the day and pump up the water from the lower dams to upper dams at night using motors.
- The configuration and topography of a storage hyroelectric power plant are presented in Fig. 1.

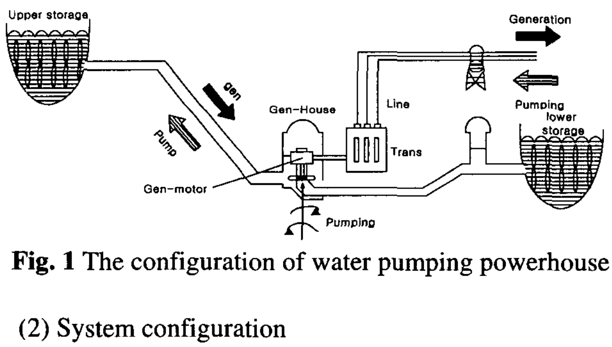

Fig. 1 The configuration of water pumping powerhouse

(2) System configuration

- The configuration of power generation system at a storage hydroelctric power plant(Muju) is shown in Fig. 2.
- 2 units of generator/motor located underground are connected to the step up transformer through the Isolated Phase Bus(IPB), and 2 circuits of OF cables connect the

set up transformer and the 345kV GIS on the ground.

• Power is transmitted from the GIS Switch Yard to Muju Yangsu T/L and Seodaegu 2T/L through overhead lines.

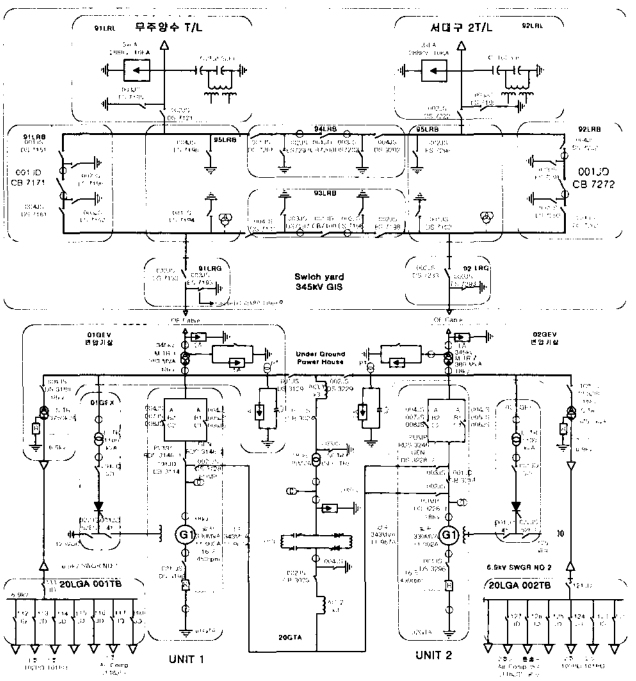

Fig. 2 The power system of water pumping powerhouse(Muju)

(3) Specifications

• Generator/motor rating
  - Capacity : 330MVA x 2 units
• Step up transformer
  - Voltage : 18/345kV
  - Capacity : 380MVA x 2 units
• Isolated Phase Bus(IPB)
  - Rated voltage : 18kV
  - Rated current : 13,000A
  - Length : 90m
• OF Cable
  - Rated voltage : 345kV
  - Maximum voltage : 362kV
  - Number of cable lines : 2 circuits
  - Length of cable : 810m
  - Cable construction type : conduit(4.5m)

(4) Rationale

• In the case of underground generator outgoing line, the IPB, a metal enclosed bus, is used to transmit high capacity current from the rated generator output voltage of 18kV to the 345kV step up transformer. But the cost is very high at between 2 - 3 billion won. It is estimated that using the HTS cable that can transmit high capacity current will bring a big benefit.

• To replace the IPB used at the power plant with the HTS cable, the features of IPB are examined. The IPB is a motion duct that transmits high capacity current from the main generator to the main transformer at hydroelectric, nuclear, and storage hydroelectric power plants. It is possible to design one with the rated current of up to 50,000A. The cooling type can be self cooled or forced air cooled. The insulator supports the high capacity conductor in the IPB and its features are as follows. Fig. 3 shows the internal view of IPB and Fig. 4 shows the IPB installed at Muju storage hydroelectric power plant.

- Conductor

Designed according to the rated current, it is octagonal or circular shape and made of highly conductive aluminum plate with the purity of 99.5%.

- Enclosure

Highly conductive aluminum plate with the purity of 99.5% is rolled and welded to make the circular enclosure surrounding the conductor.

- Coating

To prevent the heat diffusion of self cooled IPB, the enclosure is coated with matte dark color.

- Support insulator

The support insulator made of porcelain or epoxy supports the conductor symmetrically with the conductor as the axis and has sufficient leak creepage distance.

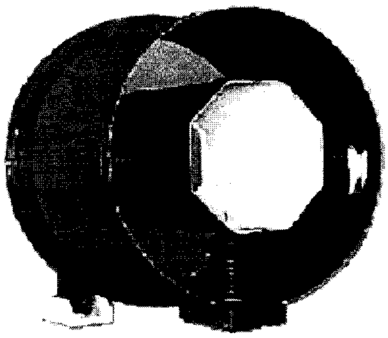

Fig. 3 The internal view of IPB

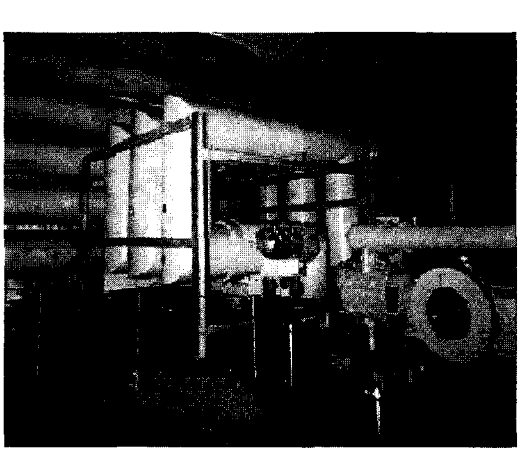

Fig. 4 The figure of IPB which is installed in buried powerhouse(Muju)

(5) Establishment of strategy

• The market strategy for the HTS cable to be developed for storage hydroelectric power plants is as follows.

• First of all, the IPB line with the outgoing voltage of 18kV from the generator/motor located underground to the step up transformer can be replaced with the HTS cable of 500MVA. In this case, high cost IPB can be eliminated and the effect of HTS cable application is estimated to be very big.

• Also, OF cables consisting of 2 circuits of 345kV installed in the tunnel from the step up transformer to the outdoor 345kV GIS Switch Yard can be replaced by the HTS cable.

• At this time, if 6 phases of conventional 2 circuits OF cables is replaced by 2circuits 3 phases general type HTS cable, the size of the tunnel can be reduced from 4.5m to 3.5m.

• Fig. 5 shows the system configuration of generator motor, step up transformer, outdoor 345kV GIS Switch Yard, transmission tower, and 345kV substation of an existing storage hydroelectric power plant.

• Fig. 6 shows the system configuration when the superconducting cable is applied.

(6) Examination of economy

• The items examined to compare the economy of conventional cable and superconducting cable are as follows.

- Cost of outgoing line from the generator motor to the set up transformer
- Cost of step up transformer
- Cost of tunnel construction
- Cost of power cable installed in the tunnel

• The unit prices used for the evaluation of economy are as follows.

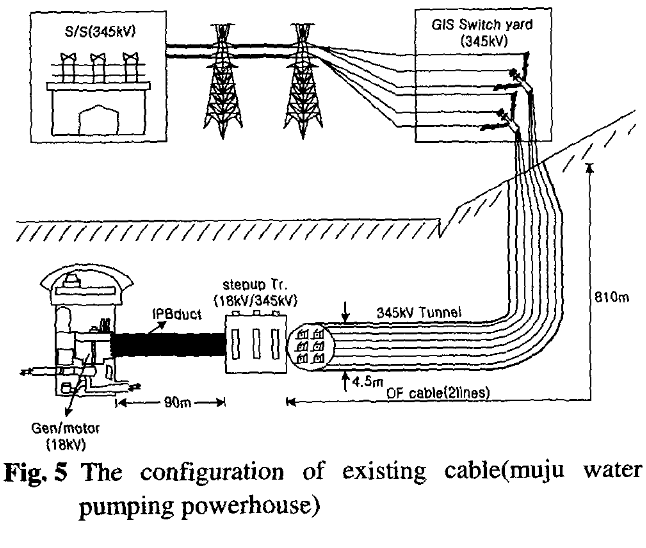

Fig. 5 The configuration of existing cable(muju water pumping powerhouse)

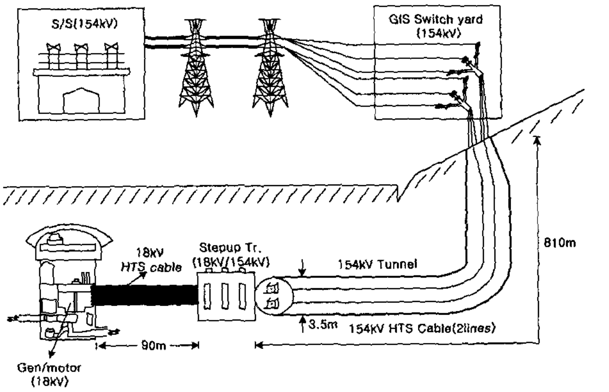

Fig. 6 The configuration of HTS cable(muju water pumping powerhouse)

- KEPCO's distribution area construction cost estimate
- Construction costs of Muju, Sancheong, and Samrangjin storage hydroelectric power plants
- KEPCO's investment financing standard construction cost

• Table 1 shows the construction cost of a storage hydroelectric power plant when the conventional cable system is applied. And Table 2 shows the construction cost of a storage hydroelectric power plant when the superconducting cable is applied.

2.3 Examination of the application of HTS to a new high voltage consumer from a distribution substation

As mentioned in "2.2", in addition to storage hydroelectric power plants, this paper also examined a case where the superconducting cable can be applied for new high voltage consumers as a feasible market. The overview, configuration, rationale, strategy, and economy of the system for the distribution level HTS cable for a new high voltage consumer are examined and the results are as follows.

Table 1 The evaluation of construction cost estimate by item(existing cable)

Item	Classification	Unit cost	Length (or unit)	Number of lines	Cost (million won)
Generator	Generator outgoing line(IPB)	10 million won/line · m	90m	2	1,860
Step up transformer	Oil filled transformer (18 kV/345kV)	1.8 billion won/unit	2 units	-	3,600
Tunnel	Shield construction (4.5m)	12 million won/m	810m	-	9,720
	Cable(OF) construction cost	1.883 billion won/ line · km	810m	2	3,050
Total construction cost estimate					18,230

Table 2 The evaluation of construction cost estimate by item(HTS cable)

Item	Classification	Unit cost	Length (or unit)	Number of lines	Cost (million won)
Generator	Generator outgoing line(superconducting cable)	2 million won/line · m	90m	2	360
Step up transformer	Oil filled transformer (18 kV/154kV)	1.5 billion won/unit	2 units	-	3,000
Tunnel	Shield construction (3.5m)	9 million won/m	810m	-	7,290
	Construction cost of superconducting cable	1.678 billion won/ line · km	810m	2	2,718
Total construction cost estimate					13,368

(1) Overview

• To examine the feasibility of applying the HTS cable for new and expanded demands to an existing substation, the project to accommodate power demands to Sacheon Substation due to the expansion of Korea Water Resources Corporation's water purification station and a new high voltage consumer is examined.

• Sacheon Substation is a 154kV substation which is run with 2 Banks. To supply power to the water purification station, the number of banks is to be increased to 3. This paper examines a distribution project where 10,000kW is supplied to the expanded water purification station and new demand each through normal line and spare line.

• Therefore, the distribution project requires 4 circuits in total including 2 main circuits for the expanded water purification station and new high voltage demand and 2 spare circuits.

• Sacheon Substation's existing tunnels and transmission conduits can be used to lay distribution lines for 4 circuits. However, as for the tunnels, the location and direction are not compatible with new supply and the transmission conduits can not be used as the conduits necessary for transmission networking between substations in the future, new distribution conduits need to be constructed.

(2) System configuration

• Fig. 7 shows the configuration of conventional cable for the expanded water purification station and new high voltage demand at Sacheon Substation.

• 12 phases 4 circuits are taken out from the underground GIS substation bank through 9 holes 175mm corrugated tubes and connected to M/H outside the substation and power is supplied to the consumer through the riser and underground cable.

• As an overhead line can not be used between Sacheon Substation and the water purification station, the system consists of alternate underground and overhead riser and takes the form of a line per circuit, and it is shown in Fig. 8.

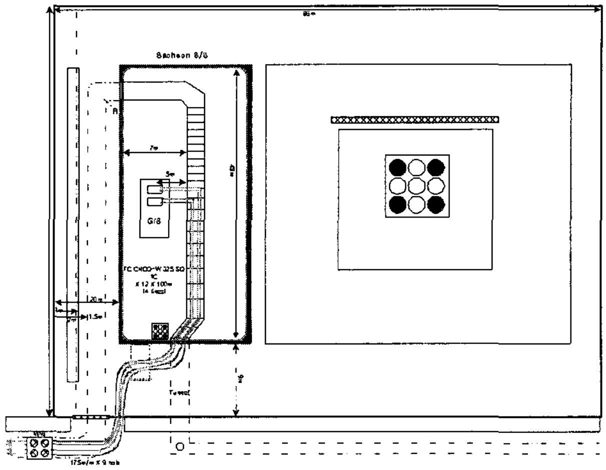

Fig. 7 The configuration for lay of exiting cable(Sacheon substation)

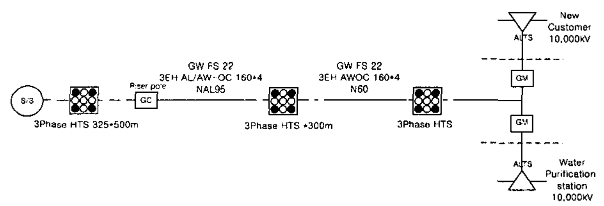

Fig. 8 The configuration for lay of exiting cable/overhead by line(Sacheon substation)

(3) Equipment specifications

• Substation rating

- Voltage : 154/22.9kV
- Capacity : 60MVA x 3Bank

• Size of conduit/tunnel

- Tunnel : width(2.39m) x height(2.1m)
- Conduit : 9holes, 6holes

• CNCV cable

- Rated voltage : 22.9kV
- Number of cable lines : 4 lines, 12 phases
- Length of cables : 3,509m
- Cable laying type : Conduits(9holes)

• Overhead line

- Rated voltage : 22.9kV
- Number of lines : 4 lines, 12 phases
- Length of overhead lines : 21,000m
- Connected with the cable by riser pole

(4) Rationale

• To transmit power from the substation GIS bank to a new consumer requiring 22.9kV and the expanded water purification station requiring20MVA without interruption, the system needs the ALTS method, which requires 4 lines since a line is reserved for each of the new and expanded demands. If the HTS cable that can transmit high capacity current is used, the number of lines can be reduced to 2 circuits Therefore, the application effect will be very big.

• As the number of lines is reduced, the number of holes of the conduits needed for outgoing line from the substation GIS bank to the 22.9kV new consumer and expanded water purification station can be reduced also.

• Taking into account the matters presented above, Fig. 9 shows the single line diagram of the configuration of superconducting cable from Sacheon Substation to the water purification station and new consumer.

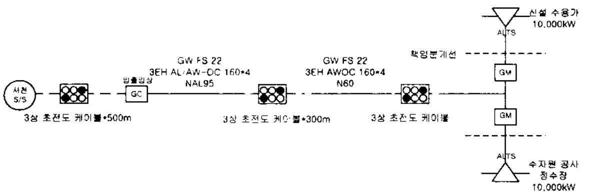

Fig. 9 The configuration for lay of HTS cable by line (Sacheon substation)

(5) Establishment of strategy

• The market strategy for the HTS cable that can be applied to the line connecting Sacheon Substation to the new and expanded high voltage demands is as follows.

• First of all, the 4 circuit outgoing lines from the substation GIS bank to the new high voltage consumer and Korea Water Resources Corporation's expanded water purification station can be replaced with 2 lines of 50MVA distribution level HTS cables. In this case, the effect of applying HTS cable instead of expanding conventional CV cable will be big.

• Also, replacing the conventional CV cable with the HTS cable can reduce the planned 9 holes conduit to 6 holes conduit.

• Fig. 10 shows the system configuration when the current plan for Sacheon Substation is replaced by the superconducting cable.

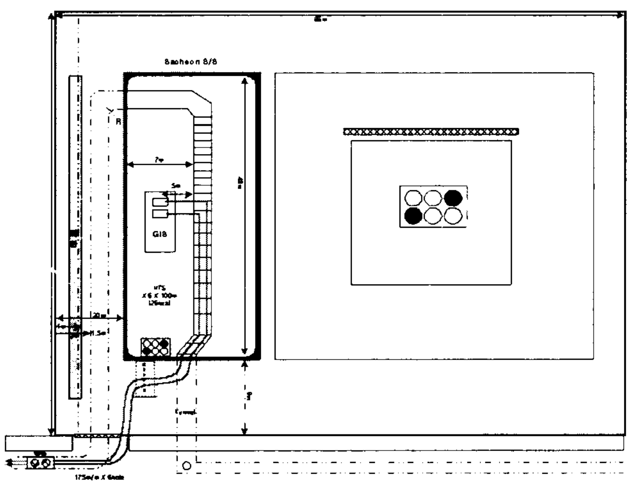

Fig. 10 The configuration for lay of HTS cable(Sacheon substation)

(6) Examination of economy

• The items need to be compared for the evaluation of the economy of applying the conventional cable and the superconducting cable to Sacheon Substation are as follows.

- Cost of line from the underground GIS transformer bank to the conduit manhole
- Construction cost according to the number of holes of conduit
- Construction cost of cable from the conduit manhole to the new consumer and the water purification station

• The unit costs used for the evaluation of economy are as follows.

- KEPCO's distribution area construction cost estimate
- KEPCO's investment financing standard construction cost

• Table 3 shows the construction cost when the conventional cable system is applied to Sacheon Substation and Table 4 shows the construction cost when the HTS cable system is applied.

Table 3 The evaluation of construction cost estimate by item(existing cable)

Item	Classification	Unit cost	Length (km)	Number of lines	Cost (million won)
Underground line	Cable construction cost(FR CNCO-W 325SQ	98.296 million won/ line · km	3.509	4	1,380
Overhead line	Overhead line construction cost (AWOC 160×3 N AL 95	52.182 million won/ line · km	2.1	4	438
Conduit	AS(9 holes) Corrugated tube φ 175mm	358.964 million won/ km	3.509	-	1,260
Total construction cost estimate					3,078

Table 4 The evaluation of construction cost estimate by item(HTS cable)

Item	Classification	Unit cost	Length (km)	Number of lines	Cost (million won)
Underground line	Superconducting cable construction cost(3phase general type)	196.592 million won/ line · km	3.509	2	1,380
Overhead line	Overhead line construction cost (AWOC 160×3 N AL 95	52.182 million won/ line · km	2.1	4	438
Conduit	AS(6 holes) Corrugated tube φ 175mm	276.961 million won/ km	3.509	-	972
Total construction cost estimate					2,790

3. Conclusions

Compared to the 154kV HTS cable, the market and economical efficiency of 22kV HTS cable is thought to be limited. This study examined the application of 22kV HTS cable to a niche market in Korea. The rationale, strategy, and economy of the application of 22kV HTS is compared with the conventional cable through case analysis and its feasibility is confirmed. The results and features of this paper are as follows.

(1) The application targets and feasibility of distribution level HTS cable to be developed are examined.

(2) The voltage class and line capacity of distribution level HTS cable that can be applied to a niche market in Korea are presented.

(3) Of the application targets for distribution level and transmission level HTS cables, the case of a storage hydroelectric power plant and new high voltage demand to a distribution substation is examined because the effect of strategy establishment and application is big.

(4) The system overview and configuration for the application of distribution level HTS cable for each case is examined.

(5) For each case, the strategy to apply the HTS cable is established and its economy is compared with that of conventional cable and the feasibility of distribution level HTS cable in a niche market is confirmed.

(6) The examples of distribution level HTS cable design based on the strategy and system configuration are presented.

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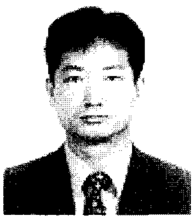

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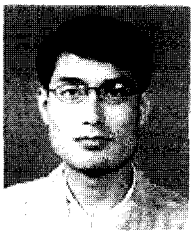

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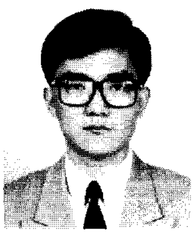

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