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Conceptual application methodology of 22.9kV HTS cable in metropolitan city of Republic of Korea

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Abstract-- **As the power demand has increased and power industry deregulation has progressed, the transmission and distribution system will have more complicated problems by the influence of investment reduction and NIMBY phenomena for overall power system. It is expected that the route length per MW demand will reduce gradually from 0.6[C-km/MW] to 0.53[C-km/MW] in 2010. This comes up to a real serious problem of system planning and operational viewpoints. HTS technologies related to power system have properties to solve these complex transmission and distribution constraints, especially for metropolitan area, in the future. As the HTS technology has developed, the HTS cable technology can be the most effective alternative to solve the future expected power network constraints. This paper describes the application methodology of developing 22.9kV HTS cable by CAST for practical distribution system. 22.9kV HTS cable under development with step-by-step application methodology can substitute the existing and planning conventional 154kV cable. If this scheme is applied, part of downtown 154kV substation of metropolitan city such as Seoul can be changed into 22.9kV switching station. It can give great economic, environmental and additional benefits to all of the concerned authorities.**

1. INTRODUCTION

Now that the power demand in Korea has increased 4~5% on the average by every year, the peak demand in 2010 will be over 60 thousand MW. Particularly, it is expected that load density within the metropolitan area to increase more rapidly than the other areas. To satisfy the power demand growth and maintain the high supply reliability, it is imperative to construct the well-designed transmission and transmission network as well as the generation facilities. Under this circumstance, as an alternative to overcome the shortage of future power network facilities and environmental problems, the application possibility of HTS cable is gathering strength.

This paper describes the basic plan to apply developing 22kV HTS cable by CAST in practical distribution system such as downtown in metropolitan area. It is basically investigated the application of 22kV HTC as the alternative plan to substitute the existing or planning 154kV/22.9kV conventional cable. As a first stage to study the application methodology of 22.9kV HTS cable, this paper induces the application countermeasures to practical power network by qualitative analysis. The technological background and future application trends by each countermeasure is described

2. NECESSITY OF HTS CABLE

2.1. Prospects of Korean power network

As the investment reduction caused by power industry deregulation and NIMBY movement, it is expected that route length per unit demand will reduce from 0.6 C-km/MW at present to 0.53 C-km/MW in 2010. It shows that capacity of power network is not enough as compared with increasing demand in the future and the distribution and transmission capacity per route should be increased. This means that the bulk transmission and distribution line over existing power network is necessary. Fig.1 describes the expected route length per unit demand in the future.

Table I describes the route length and procession rate of 154kV underground cable in Korea. The general rating

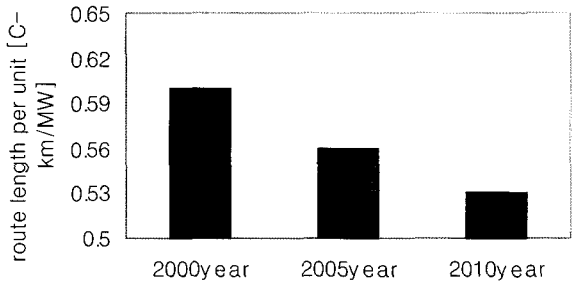

Fig. 1. Expected route length per unit demand.

TABLE I.
ROUTE LENGTH AND PROCESSION RATE OF 154KV UNDERGROUND CABLE [CIRCUIT-KM]

Year	2000	2005	2010
Total 154kV Route length	16,747	20,475	22,453
154kV underground cable route length	1,143	2,207	2,599
Procession rate	6.8	10.8	11.6

of 22.9kV distribution system in Korea is CNCV 325[mm^2] and has 10MW capacity. It has presently 197,660[C-km] length in 2002 and 8.7% procession rate compared to the total distribution line. The rate of 154kV underground transmission line is expected to increase from on the 6.8% level in 2000 to about 11.6% in 2010 and 13.4% until coming 2020.

According to continued load density increase within the metropolitan area, the necessity of 154kV substation and underground cable construction in the downtown area is higher and higher. This causes the more investment and resistance to environmental protection. To solve these problems, the distribution and transmission capacity per unit route should be increased. This is the basic reason of HTS cable application in downtown area of metropolitan city.

2.2. Necessity of HTS cable

In the case of metropolitan city like Seoul, it is inevitable to make bulk capacity underground cable as the power load density is raising due to highly developed city functions. However, there is a limit to increase the transmission capacity per distribution line. The multi-circuit burying has difficult problems to secure the site in overcrowded city and deal with heavy burden of public construction cost. Along with underground cable expansion, it is needed to construct the new substation in downtown area. It affects negatively environment and burying site problem as well as expense increase of power supply in general.

HTS cable can transmit the power as the type of low voltage/bulk capacity and reduce the investment and power loss. Therefore, HTS cable comes to the front as an alternative plan to enlarge the distribution and transmission capacity and reduce the substation facility in metropolitan city. If the HTS cable applies to metropolitan area, it can be omitted the fairly much part of 154kV substation which should be built in the downtown area. In addition, construction cost of underground route can be cut sharply because the size of HTS underground cable becomes small and the bulk capacity is possible. There are general benefits in terms of overall power system when the HTS cable is applied in downtown area.

- ○ Reduction of power loss
  (Increase of transmission/distribution efficiency)
- ○ Possibility of low voltage, bulk capacity transmission
- ○ Reduction of cable site and burying cost
- ○ Omission of 154kV substation and altering to switching station
- ○ Benefits in terms of investment and environment

3. BASIC CHARACTERISTIC OF HTS CABLE

For HTS cable application, firstly the basic characteristics of HTS cable in terms of system operation should be analyzed. At present, it is difficult to have the exact technical parameter as the state of undergoing development of HTS cable in Korea.

Table II compares the electrical characteristics of existing conventional cable with the HTS cable supposing that transmission capacity of HTS cable is several times over than that of conventional cable in same voltage level. Although characteristic impedance of HTS cable is slightly smaller than conventional cable, the voltage drop of HTS cable is higher because capacity of HTS cable is several times larger than that of conventional cable. Furthermore, it is expected to cause a problem of flow redistribution among transmission lines in case of HTS cable application. But the problem of voltage drop and flow redistribution in case of HTS cable application can be covered by technical countermeasures and proper selection of application site.

TABLE Ⅱ.
BASIC TECHNICAL PARAMETERS (ASSUMING SAME VOLTAGE LEVEL AND SEVERAL TIMES LARGER CAPACITY THAN CONVENTIONAL CABLE)

Items		HTS Cable	Conventional Cable	NOTE
System constants	R	≒ 0(Superconducting) ≒ R_Q (Quenching)	100%	
	L	75% or so	100%	
	C	50% or so	100%	
	$Z = \sqrt{\frac{L}{C}}$	82% or so	100%	
	$SIL = \frac{V^2}{Z}$	122% or so	100%	
Power loss		nearly zero	2-3% or so	
Voltage drop		negative	positive	opposite result if same capacity
Voltage variation		light load : Negative heavy load : Positive	light load : Negative heavy load : Positive	conclusion refer to SIL value
Fault current		positive	negative	Opposite result in case of Substituting 22kV HTSC for existing 154 kV
Stability		positive	negative	no big difference
Power flow redistribution		Necessary to detailed study for specific application cases		

4. POSSIBILITY OF 22KV HTS CABLE APPLICATION

4.1. Summary of application methodology

Although 22kV HTS cable application can have various types, this study divides largely into Utility and Customer system application in the light of application subject and methodology. Firstly, application methodology for Customer system is to find the specific application site by each case considering the condition of individual

Customer, which bears a character of Niche Marketing. Therefore, it is difficult to mention concretely about each case as it depends on the specific condition by each pertinent Customer. Table III describes the application methodology of 22.9kV cable for customer system.

TABLE III.
APPLICATION METHODOLOGY OF 22KV CABLE FOR CUSTOMER SYSTEM

Methodology	Application reason	Note
Special place	Being inevitable reason For HTS cable	Specific case
Over 10MW, 22.9kV Customer	No necessary to substitute by 154kV cable in case of 22.9kV HTS cable application	Specific case

Application for Utility system, which differs from Customer system, is to find the general methodology coincided with specific condition. Table IV describes the several application methodologies for 22.9kV HTS cable. Among several methodologies in Table IV, the application methodology to change the existing and planning 154kV cable into new 22.9kV HTS cable is described in detail.

TABLE IV.
APPLICATION METHODOLOGY OF 22.9KV HTS CABLE FOR UTILITY SYSTEM

Methodology	Application reason	Note
Newly-established power plant IPB	low voltage, bulk capacity	specific place
Distributed generation plant on the seashore	low voltage, bulk capacity	specific place
Composite thermal plant nearby Seoul	low voltage, bulk capacity	specific place
Substitution 22.9kV HTS cable for existing and planning 22.9kV cable	- change of retired existing cable - increasing capacity of new planning cable	possible type for application
Substitution 22.9kV HTS cable for existing and planning 154kV cable	- change of retired cable - omission of 154kV S/S in downtown area	possible type for application

4.2. Summary of application methodology

This is the application methodology to substitute 154kV existing or planning conventional cable into 22.9kV HTS cable. It just makes existing 154kV S/S in the heart of the city to do function as a switching station and supply the power through the long distance 22.9kV HTS cable from the 154kV S/S in remote place. This application methodology has distinctly following advantages and it results in changing the paradigm of distribution and transmission type in metropolitan city. This gives the benefits of avoiding NIMBY movement and reduction of a substation site and construction costs

○ Omission of 154kV substation in downtown area and changing to 22.9kV switching station

○ Reduction of underground cable burying site

Since it is practically impossible to change the entire 154kV substation in downtown area into 22.9kV switching station at once, step by step driving strategy is necessary. The following flow step is the application strategy by each step for 22.9kV HTS cable application.

(STEP-1) Substitute only one 154kV conventional cable between 154kV S/S into 22.9kV HTS cable

○ Just leave the existing 154kV S/S as it is and only substitute 154kV conventional cable which connects two substations into 22.9kV HTS cable by connecting the two substation's 22.9kV bus. This concept is one-to-one change such as substituting 154kV single cable into 22kV HTS single cable with same capacity.

○ It is reasonable to have the capacity of HTS cable around 200MVA, which is nearly similar to the one of existing 154kV. Also, it is needed to select separately the best-suited capacity of HTS cable in terms of effective utilization of existing cable route.

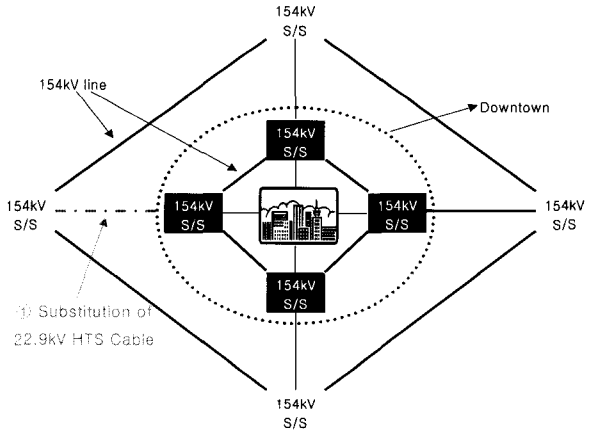

Fig. 2. STEP-1 : Application methodology of 22.9kV HTS cable application.

(STRP-2) Change conventional 154kV S/S into 22.9kV switching station

○ 154kV S/S in downtown area which is connected to HTS cable from remote another 154kV S/S (refer to 1st step) is changed to 22.9kV switching station. Also, all of the 154kV cable lines in this switching station should be changed to 22.9kV HTS cable lines. In this case, it is able to have benefits from great reduction of site and equipment cost as possible to compact 154kV substation in a hub of city.

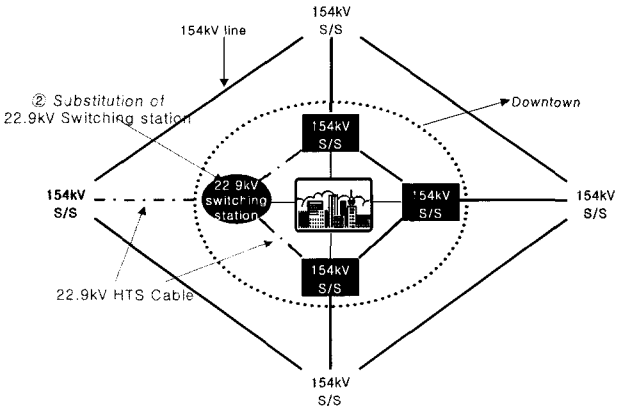

Fig. 3. STEP-2 : Application methodology of 22.9kV HTS cable application.

(STEP-3) Change 154kV S/S in the vicinity of 22.9kV switching station into 22.kV switching station

○ Nearby 154kV S/S which is connected to 22.9kV HTS cable from local 22.9kV switching station is changed to 22.9kV switching station. Along with this, the 154kV cable line, which is connected to another 154kV S/S from this changing 22.9kV-switching substation, should be changed to 22.9kV HTS cable. In this case, like the former case it can gives benefits due to the sharp decrease of site and cost of substation facility.

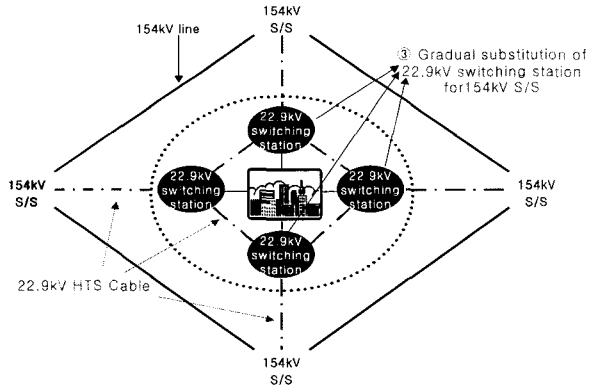

Fig. 4. STEP-3: Application methodology of 22.9kV HTS cable application.

(STEP-4) Change 22.9kV conventional existing or planning cable line into 22.9kV HTS cable in downtown area

○ Basically, to change 22.9kV conventional cable in downtown area into 22.9kV HTS cable is a different subject from the above step. The conventional existing and new burying 22.9kV underground cables are change to gradually and sequentially.

○ In this case, the 22.9kV HTS cable can transmit much bigger power than conventional 22.9kV cable at same size, which means it does not need to do construction for additional cable route and can gives benefits in economic viewpoints.

○ It is reasonable to select the capacity of HTS cable around 50MVA provisionally. When assuming that

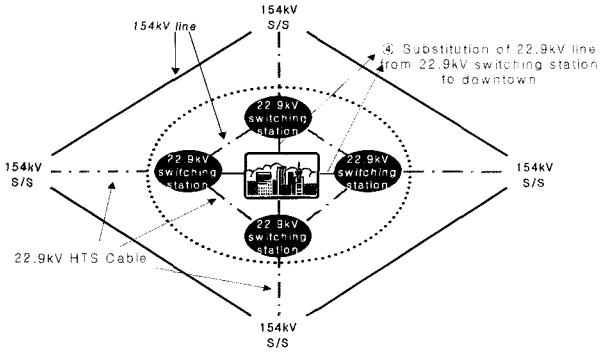

Fig.5. STEP-4: Application methodology of 22.9kV HTS cable application .

2~2.5 times more increase of load density in downtown around 2020 and 2 times wider area where a single distribution feeder supply power than present, it is estimated that the capacity is required five times more than 10MVA existing conventional cable.

5. CONCLUSTION

The general conclusion of this paper and proposal for future power system application are as follows.

○ HTS cable, which can transmit bulk capacity power with low voltage and lower power loss, is as an epochal alternative plan to solve the problem of future power system in metropolitan area.

○ The application methodology of 22.9kV HTS cable is divided by customer and utility system application. Among these applications, this paper describes the application strategy to substitute the 154kV conventional existing or planning cable into 22.9kV HTS cable step-by-step in detail.

○ 22.9kV HTS cable application in downtown area rather than 154kV conventional cable has epochal benefits by the reduction of 154kV substation and cable construction cost.

○ Related to the future R&D directions of 22.9kV HTS cable, it is necessary to develop by dividing 200MW, 22.9kV HTS cable for 154kV cable substitution and 50MW 22.9kV HTS cable for 22.9kV distribution cable substitution.

○ If HTS 22.9kV cable is applied to substitute 154kV conventional cable, there are several technical problems such as excessive voltage drop and unbalanced flow redistribution. These problems can be covered by other technical countermeasures. But,

the detailed investigation should be done to find the technical countermeasure according to practical application site.

ACKNOWLEDGMENT

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EXAMPLE REFERENCES

[1] Ladie Pierluigi, Mansoldo Andrea "HTS Cable application studies and technical/economical comparisons with conventional technologies", PES-WM 2002

[2] Richard Silberglitt, Emile Ettedgui, Anders Hove "Strengthening the Grid : Effect of High Temperature Superconducting Power Technologies on Reliability, Power Transfer Capacity and Energy" RAND, 2002

[3] YOON "Basic planning for HTS 22.9kV cable" KERI 2003

[4] KEPCO, "Long-term prospets for transmission system" 2002