Abstract—With the increase of power demand and the progress of power industry deregulation, the transmission and distribution systems will have more complicated problems by the influence of curtailing investment and the NIMBY phenomena in overall power systems. [1-2] It is expected that the route length per MW demand of South Korea will decrease gradually from 0.6[C-km/MW] to 0.53[C-km/MW] in 2010.[3] This comes up to a real serious problem from system planning and operation 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 to practical distribution system in downtown metropolitan area. It is basically investigated the application of 22kV HTS Cable as the alternative plan to substitute the existing or planning 154kV/22.9kV conventional cable. In the first stage to study the application methodology of 22.9kV HTS cable, this paper induces the application countermeasures for practical power network by qualitative analysis. Also, this paper describes the technical background of reasons for applying 22.9 kV HTS cable in future.

II. NECESSITY OF HTS CABLE

A. Prospects of Korean power network

As the investment is curtailed because of power industry deregulation and NIMBY movement, it is expected that route length per unit demand will decrease from 0.6 C-km/MW at present to 0.53 C-km/MW in 2010. It indicates that capacity of power network is not enough compared with increasing demand in the future. So, the distribution and transmission capacity per route should increase. This implies that the bulk transmission and distribution line over existing power network is necessary. Fig.1 shows the expected route length per unit demand in the future. The general rating of 22.9kV underground distribution system in ROK is CNCV 325 [mm²] and has 10MW capacity. It has presently 197,660[C-km] in length in 2002 and 8.7% procession rate compared to the total distribution line. Table.1 describes the route length and procession rate of 154kV underground cable in ROK. 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. Owing to constant increase of load density within the metropolitan area, the demand of 154kV substation and underground cable construction in downtown area becomes higher and higher, which result in excessive investment and adverse impact on the environment. To solve those problems, the distribution and transmission capacity per unit route should be increased. This is why we should apply HTS cable to downtown area in metropolitan city.
Table 1. Route length and procession rate of 154kV underground cable (Circuit-km)

| (year) | Total 154kV Route length | 154kV underground cable route length | Procession rate |
|--------|--------------------------|------------------------------------|----------------|
| 2005   | 20,475                   | 2,207                              | 10.8           |
| 2010   | 22,453                   | 2,599                              | 11.6           |

B. Necessity of HTS cable

In case of metropolitan city like Seoul, it is inevitable to make bulk capacity underground cable dealing with the increase of power load density due to highly developed city functions. However, there is a limitation on the increase of transmission capacity per distribution line. The multi-circuit burying has difficult problems, which are securing the site in overcrowded city and managing the heavy burden of public construction costs. Along with underground cable expansion, it demands to construct the new substation in downtown area. Also, it has adverse affects on environment and burying site as well as it causes the expenditure increase of power supply in general.

HTS cable can transmit the power 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 is applied to metropolitan area, we can avoid several construction works of 154kV substation which should be built in downtown area. In addition, construction costs of underground route can be sharply curtailed because the size of HTS underground cable becomes smaller, of course the bulk capacity is still possible. Here are general benefits of when the HTS cable is applied to downtown area in overall power system.

- Reduction of power loss
  (Increase of transmission /distribution efficiency)

Table 2 compares electrical characteristics of existing conventional cable with those of HTS cable supposing that the transmission capacity of HTS cable is several times larger than that of conventional cable on same voltage level. Although characteristic impedance of HTS cable is slightly smaller than that of 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 if HTS cable is applied. But problems like voltage drop and flow redistribution, which can occur when HTS cable is applied, can be covered by technical countermeasures and proper selection of application site.
IV. POSSIBILITY OF 22kV HTS CABLE APPLICATION

A. Summary of application methodology

Although application of 22kV HTS cable can have various types, this study divides largely into Utility and Customer system application in 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 because it depends on the specific condition of each pertinent Customer. Table 3 describes the application methodology of 22.9kV cable for customer system.

| Methodology | Reason for application | Note |
|-------------|------------------------|------|
| Specific place | Being inevitable reason for HTS cable | Specific case |
| Over 10MW, 22.9kV Customer | No necessary to substitute by 154kV cable when 22.9kV HTS cable is applied | Specific case |

Applying to Utility system, which differs from Customer system, is to find the general methodology coincided with specific condition. Table 4 describes the several application methodologies to 22.9kV HTS cable. Among several methodologies in Table 4, it is described in detail to change the existing and planning 154kV cable into new 22.9kV HTS cable.

| Methodology | Reason for application | 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 | Suitable type for applying |
| Substitution 22.9kV HTS cable for existing and planning 154kV cable | - change of retired cable - omission of 154kV S/S in downtown area | Suitable type for applying |

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 downtown of the metropolitan city to do functions as 22.9 kV switching station and supply the power through the long distance 22.9kV HTS cable from the 154kV S/S in remote substation. 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 substation site and construction costs.

- Skipping 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. These following steps are application strategies for 22.9kV HTS cable application.

STEP 1: Substitute only one 154kV conventional cable between 154kV S/S into 22.9kV HTS cable

- Just leaving the existing 154kV S/S as it is, this step only substitute 154kV conventional cable which connects two substations into 22.9kV HTS cable by connecting two substation's 22.9kV bus. This concept is one-to-one change such as substituting 154kV single cable for 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.
STEP III: Change 154kV S/S in the vicinity of 22.9kV switching station

- 154kV S/S in downtown area which is connected to HTS cable from remote 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 gain benefits of huge reduction of site and equipment costs as much as possible to compact 154kV substation in a hub of city.

![Fig. 3 STEP-2: Application methodology of 22.9kV HTS cable application](image)

STEP IV: Change 22.9kV conventional existing or planning cable line into 22.9kV HTS cable in downtown area

- Basically, it is a different subject from above steps to change 22.9kV conventional cable in downtown area into 22.9kV HTS cable. The conventional existing 22.9kV and new burying 22.9kV underground cables are changing 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 give merits from economic viewpoints.

- It is reasonable to select the capacity of HTS cable around 50MVA provisionally. When assuming that the load density in downtown around 2020 is 2~2.5 times more increasing than now and has 2 times wider area where a single distribution feeder supply power than present, we can estimate that the required capacity is five times more than 10MVA existing conventional cable.

![Fig.4 STEP-4: Application methodology of 22.9kV HTS cable application](image)

V. CONCLUSION

General conclusions of this paper and proposals of 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 can be mainly divided into customer and utility system applications. Between these applications, this paper describes the application strategy to substitute the 154kV existing or planning cable into 22.9kV HTS cable step-by-step in detail.
Compared to 154kV conventional cable, 22.9kV HTS cable application in downtown area has epochal benefits by the reduction of 154kV substation and cable construction costs.

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

If HTS 22.9kV cable is applied to substitute 154kV conventional cable, we should solve several technical problems such as excessive voltage drop and flow redistribution. The exhaustive investigation and detailed study should be done firstly to find the technical countermeasure according to practical application site.

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