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Use of New Technologies to Mitigate Visual Impact and Public Concerns Related to Siting of Transmission Lines

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Introduction

Reliance on the transmission grid to meet load deliverability requirements in population centers continues to grow. New transmission capacity can enable delivery of enough generating capacity from remote resources to meet demands in densely populated urban areas. However, new overhead transmission lines often face fierce opposition from land-owners and communities along a proposed new route.

Evaluation of transmission capacity expansion options need to be thorough and should consider construction costs, permitting and timelines, as well as costs and schedule impacts of public hearing processes, environmental impact studies, easements, access roads, environmental restrictions, restoration and maintenance.

For example, a new overhead transmission line may initially appear to be the preferred option for increasing transmission capacity. However, public and land-owner opposition, environmental impact restrictions, and potential legal action by opponents may make project construction so uncertain – or delay the estimated in-service date so much – that the project may not be a viable option for resolving a looming transmission reliability problem.

Fortunately, continued research and incremental developments over the past several decades have provided reliable and proven equipment and technologies that are well suited to overcome today's transmission challenges. A prime example is installation of environmentally-friendly submarine or underground transmission within existing infrastructure rights-of-way for overhead transmission lines, roadways, railroads, gas lines, etc.

Today's Transmission Congestion Issues

Transmission congestion always has an adverse impact on electricity consumers cost and/or the environment. Transmission congestion occurs when actual or scheduled flows of electricity on a transmission line are restricted to below desired levels – either by the electrical capacity of the line or by operational restrictions created to protect the security and reliability of the grid. When a transmission constraint prevents the delivery of clean renewable electricity from a remotely located area to a load center, system operators must re-arrange the generation dispatch on both sides of the constraint, cut wholesale transactions previously planned, or, as a last resort, reduce electricity deliveries to consumers. When constraints prevent delivery of energy from cleaner or less expensive resources, energy that is deliverable from more expensive and/or higher emission resources must be used instead.

Boosting Transmission Capacity

In many areas where transmission capacity is already constrained by thermal limits of transmission lines or their associated equipment, construction of new transmission circuits may be the only feasible option to alleviate grid constraints and looming reliability problems. However, when faced with fierce public opposition against new overhead transmission lines, partial or complete undergrounding of a planned new transmission circuit may be the only practical solution. Undergrounding balances the construction costs of new transmission facilities with system reliability risks and transmission congestion costs from not completing needed transmission capacity expansion on time.

AC Cables for Short- and Medium-Distance Underground or Submarine Transmission

Polymer insulated cables have become a mature and proven technology for both high voltage ("HV") and extra high voltage ("EHV") electric transmission systems. Because these cables do not contain any insulating fluids, there is no risk of accidental release of oil or other hazardous materials and substances into the environment and the technology is a natural choice for construction of underground transmission line segments in sensitive areas.

Polymer insulated cables for alternating current (AC) transmission systems are commercially available today for conductor sizes up to 5,000 kcmil (approx. 2,500 mm^2). Reliability performance of EHV class cable has been proven in numerous projects around the world since the early 1980's. More recently, high capacity 345 kV and 400 kV cross-linked polyethylene ("XLPE") insulated underground and submarine cables have been installed in large AC transmission projects in Connecticut, New York, Illinois, the United Kingdom, Germany, Denmark and Spain. Furthermore, the performance of 500 kV XLPE cables have been proven in AC transmission projects in China and Japan.

An XLPE insulated underground cable circuit can be directly buried in a 3-4 feet wide and 4-6 feet deep trench at the inside perimeter of an existing overhead transmission line right-of-way, or along the shoulder of a roadway or railroad. An XLPE insulated underground cable circuit can also be installed in a traditional duct bank system inside a roadway. Once installed, XLPE insulated cables are virtually maintenance free.

It should be noted, however, that the capacity rating of an underground or submarine AC transmission circuit diminishes with distance, limiting the practical application of EHV AC cable segments to short and medium distance. The primary reason is that the 60 Hz alternating voltage in the grid causes a flow of 60 Hz alternating current in the cable due to the repeated charging of the cable segment's electrical capacitance. Since the electrical capacitance increases cumulatively with the length of a cable segment, the 60 Hz current also increases cumulatively with the length. That, in turn, results in an upper length limitation beyond which it will no longer be practical to build AC transmission lines underground or underwater since most of the cable's capacity will be utilized by the charging current. For example, simply connecting a twenty-five (25) miles long 345 kV AC transmission cable segment to the grid will result in approximately 600 Amperes of alternating current even if the cable segment is disconnected at the other end and carries no real power.

DC Cables for Long-Distance Underground and Submarine Transmission

In response to industry demands for cost efficient long distance underground and submarine transmission systems, ABB introduced in the late 1990's XLPE insulated cable systems for high voltage direct current ("HVDC") transmission. Unlike AC transmission, there is no length limit for underground and submarine transmission segments using XLPE insulated HVDC cables. After the initial impulse of charging current at the energization of the cable segment, there will be no significant charging current flowing in the cable. Hence, the entire capacity rating of the cable can be utilized for transmission of real power regardless of the length of the underground or submarine segment.

The first commercial underground transmission system using XLPE insulated HVDC cables was commissioned in 1999 at a circuit rating of 160 kV (±80 kV), 50 MW. The HVDC link, which is approximately 43 miles long, connects a large wind farm on the south end of the island of Gotland in the Baltic Sea to the island's principal population center, which is located on the northern end of the island. An HVDC underground circuit requires only two cables whereas an EHV AC underground circuit typically requires three cables plus a continuous ground cable for the sheath bonding at the splice locations.

Since the 1990's, XLPE insulated HVDC cables have been qualified and introduced for commercial use at incrementally higher circuit ratings. Voltage ratings up to ±640 kV and ampacity ratings up to around 2000 amperes are now available. (HVDC cables can be manufactured with conductor sizes up to 6000 kcmil (approx. 3000 mm^2). The incremental development of HVDC cables mirrors the development of XLPE insulated cable for increasingly higher AC voltage ratings since the 1970s and reflects the utility industry's conservative approach and preference for proven designs.

Long XLPE insulated HVDC underground and submarine circuits rated 300 kV (±150 kV) were commissioned in 2002. Since 2015, HVDC underground and submarine cables circuits rated 640 kV (±320 kV) have been in operation in multiple large transmission projects in Europe. Development has continued and HVDC cable ratings of 2000-2500 MW are likely to become a reality in the near future as available cable voltage ratings have increased to ±500 kV and ±640 kV.

Underground transmission lines with a capacity rating in excess of 2000 MW can now be directly buried in a 1½-2 feet wide and 4-6 feet deep trench at the inside perimeter of an existing overhead transmission line right-of-way, or along the shoulder of a roadway or railroad. Like XLPE insulated AC cable circuits, an HVDC underground cable circuit can also be installed in a traditional duct bank system inside a public roadway.

Grid Support and Benefits of Modern HVDC Voltage Source Converter Stations

In parallel with the development and introduction of XLPE cables for HVDC based long distance underground and submarine transmission, ABB developed and introduced a new generation of HVDC stations based on voltage source converter (VSC) technology. Compared to earlier generations of HVDC stations, today's HVDC VSC stations need no harmonic filtering equipment, include few mechanical switching devices, are much more compact, and can easily be sited in densely populated urban areas with stringent requirements regarding audible noise and visual impact.

The characteristics of HVDC VSC stations are ideal for load center areas where local fossil fuel or nuclear based generation is retiring and replaced by renewable generation resources located in remote areas far away from the load. Unless new reactive power resources are added to the grid near load centers when local generators retire, the areas often face voltage stability issues and looming reliability problems if power is imported over long traditional AC transmission lines.

HVDC lines with VSC stations address such reliability issues by utilizing the inherent capability of the VSC technology to supply and absorb reactive power in a way that closely resembles a generator. That is, an HVDC transmission line with an HVDC VSC station at the receiving end can provide essentially the same local reactive and AC voltage support services to the grid near the load center as a local generator, even though the source of the real power may be located at a remote location with favorable wind and/or sun intensity conditions.

HVDC links with VSC stations can also provide critical black-start services to major load centers that were previously supplied by local fossil fuel based generators. By utilizing the inherent self-commutating capability of the VSC technology and power flow control on the HVDC line, the HVDC link can convert power from remotely located generators at the sending end of the link to a powerful 60 Hz power frequency resource at the receiving end that can quickly commence restoration of the electricity supply in a major metropolitan area after a major black-out event. Such black-start functionality is already implemented in several existing VSC based HVDC links and has been verified through elaborate field tests of the black-start mode, including energization of AC transmission lines and transformers from the HVDC station and support of the start-up of other generation facilities.