Electricity Transmission and Distribution

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** In general, transmission systems are used for transporting large blocks of electricity over long distance (higher voltage) from power plants to local substations closer to the final customers, while distribution systems are used for delivering electricity over shorter distances (lower voltage) from these substations to final consumers [1,2, 5]. High voltage (HV) electricity can be transmitted as alternating current (AC) or direct current (DC). There are several advantages of using HVDC systems over HVAC for transporting large volumes of electricity over long distances [4, 7]: lower losses, lower investment costs, less land space, easier to control the active power in the link, etc. In 2012, HVDC transmission lines globally reach 195 GW of capacity with another 133 GW of capacity planned in about 65 projects [6]. These projects range from 100 MW of capacity to 7000 MW. The configuration of electric transmission and distribution (T&D) systems vary across regions. In the US, three grids represent about 275,000 km of high-voltage (> 200 kV) transmission lines (3,800 km of 765 kV AC lines and more than 4,800 km of 500 kV DC lines) and 9.7 million km of low-voltage distribution lines [10]. In the European Union, there are four interconnected HV transmission systems, 4 million distribution transformers, 10 million km of distribution power lines (97% of all power lines in Europe) that are linked to the transmission network by 10,700 interconnection points [5].

■ **PERFORMANCE AND COSTS –** Energy losses are measured as the fraction of the transported energy that is lost mainly due to line heating. Losses are lower in HVDC than in HVAC over long distances: for a ±800 kV line voltage, losses are about 3% per 1,000 km for an HVDC while they are about 7% per 1,000 km for an HVAC line [4]. For HVDC sea cables, losses are about the same but can reach 60% per 100 km for a 750 kV HVAC sea cable. Most of the total T&D losses occur in the distribution systems. It has been falling significantly in the US from 16% in 1926 to 7% today [10] and in other developed countries (5.1% to 7.7% in 2010). In developing countries, losses vary between 11.6% and 20.7% for 2010 [8]. Emission factors associated to T&D losses are derived as a percentage of the total electricity generated in a region or a country [11]: it varies between 5% in OECD countries and up to 20% in developing countries. The cost of HVDC transmission systems vary widely with its design as well as the economic, geographical and environmental conditions. For a bipolar HVDC line, a cost of 190 k€/km is estimated and converter stations are estimated to 190 M€. For a double AC line, a cost of 190 k€/km (each) is estimated and AC substations (above 600 km) are estimated to 60 M€ [7]. The relation between cost and capacity (MW) is not linear. Another source [13] gives cost data per MW-km: 746$ -3318$ for long distance and 1491-6636 for lower voltage transmission lines. Substation costs vary between 10,700–24,000 $/MW. Investment in transmission systems are higher in scenarios with higher renewable shares. Advanced metering infrastructure (AMI) brings significant operational benefits in distribution systems, although they do not cover the full investment costs: 150$ to 400$ per meter [7].

■ **POTENTIAL AND BARRIERS –** In many countries, the existing infrastructure for electricity transmission and distribution is aging and becoming obsolete or overstressed with the increasing penetration of intermittent renewables-based electricity sources. Projected investments in the electricity sector over the 2012-2035 period for the global generating capacity reaches about $9.7 trillion dollars, with an additional $7.2 trillion for T&D grids (40% to replace existing infrastructure and 60% to build new infrastructure) [1]. Depending on the region, the cost for transmission infrastructure varies between 4%-15% of the total cost and between 27%-34% for the distribution infrastructure. Potential savings resulting from grid modernization are significant with a benefit-to-cost ratio of between 4:1 and 6:1 ratios [9]. Many challenges will affect the electricity grids of many countries on the long term [10]. In particular, investment in improving flexibility within the system will become increasingly important with the penetration of intermittent forms of energy. This will involve modifications in the designs and operations of systems as well as reforms in the processes for transmission planning and system expansion. The penetration of electric vehicles and increasing changes in demand variability will accelerate the decline in capacity utilization and consequently increase electricity costs. The penetration of distributed generation (subsidies provided by net metering) will involve modifications in the design and operation of distribution systems. In relation with the future challenge, the industry faces a near-term shortage of skilled workers, such as engineers. New technologies and policies for reliability and efficiency will need to be developed and deployed to enhance observation and control in T&D systems as well as to make demand more responsive to real-time costs.

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