

Renewable Integration in Power Grids

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS** – The brief deals with the integration of variable renewable power technologies (primarily wind and solar power) into the power grids. Renewable energy technologies for electricity generation can be grouped into dispatchable renewables, which are basically ready for production on operator's demand (e.g. hydro, geothermal and biomass power), and non-dispatchable (or variable) renewables, which electricity production depends from meteorological conditions and/or daily time (e.g. wind and solar). The typical modular size of variable renewable technologies is well suited to so-called distributed power generation systems where a number of small power plants are connected to the distribution grid and produce electricity close to the demand site. However, the connection of variable renewables to the distribution grids requires several factors to be examined such as the impact on slow voltage variations, the power plants behavior under faulted condition, and their interaction with the protection systems. The integration of a significant amount of variable renewables into power grids requires significant transformations of the existing grids aimed to: **a)** allow electricity to flow not only from centralized power plants to users, but also from small users/producers to the grid; **b)** introduce a significant energy storage capacity to store electricity (energy) from variable renewables when the production exceeds the demand; **c)** establish intelligent grid and demand management in order to reduce peak-loads; and **d)** improve grid interconnection at regional and international level to increase flexibility, stability, and security of supply. All together these transformations lead to the concept of so-called *smart grids* which are intended to provide the power system with the necessary flexibility to balance supply and demand in the presence of a significant share of variable renewable power capacity. The available experience in the integration of a significant share of renewable power into large grids comes from European countries such Denmark, Germany, Italy, Spain, and the United Kingdom, with significant wind and solar power installed capacity. In these countries, the associated issues are being solved in the light of further increase of the renewable electricity share. Experience with the integration of very high (>>50%) renewables share is available from applications for small islands.

■ **PERFORMANCE AND COSTS** – Small and fast (seconds to minutes) variations of variable renewable power output (e.g. wind power) rarely impact the power system. More important are slow (minutes to hour time-scale) variations that result in an increased need for reserve capacity and other interventions to ensure a stable operation of the power system. In general, the level of interventions depends on the share of the renewable electricity and capacity in the power system. For a 10% renewable electricity share the increase of reserve capacity is estimated to range between 1.5% and 4% of the installed variable (e.g. wind) capacity. However, variability issues may also be solved through more interconnection of the grid to other grids to achieve more flexibility in supply-demand balance. The cost incurred in the integration of variable renewables in existing grids can be categorized in grid infrastructure costs and system operation costs. The grid infrastructure costs include grid connection and grid upgrading costs. For most renewable technologies the grid connection cost is estimated to be in the range 0-5% of the project investment cost; for onshore wind projects this cost is estimated at around 8%, for off-shore wind projects the cost ranges between 10% and 25%. Grid upgrading costs depend on grid characteristics and are estimated at between €0.5/MWh and €3.0/MWh for a 20-30% renewable (wind) electricity share. System operation costs refer to the extra cost incurred in the conventional part of the power system. Based on a variety of empirical studies on wind power, system operation costs are in the range of €2-4/MWh for low wind penetration (below 10% of capacity share) and about €5-6/MWh for high wind penetration (above 20% capacity share).

■ **POTENTIAL AND BARRIERS** – All major energy projection studies anticipate a very significant increase of renewable power in the electricity mix in all world regions. Key questions deal with the cost of renewables integration into power grids, policy and regulatory issues, and the availability of suited technologies (e.g. energy storage technologies). For example, it has been estimated that for the European distribution network the total investment need will amount to € 480 billion by 2035. In modern liberalised electricity markets, electricity generation and supply (retail) are market-based activities, governed by market competition rules, while transmission and distribution services are usually regulated. Grid investment would require a proper and stable regulatory and policy environment, with appropriate incentives and long-term horizon. Experts generally agree that no insurmountable technical constraint exists for the achievement of the projected renewable share in 2050, but the economic and regulatory frameworks are critical issues to be dealt with.