Flexibility Chart

Evaluation on Diversity of Flexibility in Various Areas

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***Abstract*— This paper evaluates various aspects of flexibility in power systems worldwide within the multi-country study framework of IEA Wind Task 25, including grid components and actions which have been favoured for enhancing flexibility in different areas/countries/regions, and how TSOs/ISOs/ utilities intend to manage variable generation in their operating strategies. One methodology to evaluate the diversity of flexibility sources is a "flexibility chart", which can illustrate several flexibility parameters (*e.g.* hydro, CCGT, CHP, interconnection) in a polygonal radar (spider) chart.**

Keywords- wind; variable generation, wind energy, solar energy, system flexibility; interconnection; Combined Cycle Gas Turbine (CCGT); Combined Heat and Power (CHP)

I. Introduction

Accessing sources of system flexibility is one of the most critical steps in achieving high penetration of variable generation, including wind and solar, at every power system scale; *e.g.* Transmission System Operator (TSO) / Independent System Operator (ISO) / utility operating areas, countries, and synchronous areas. Some countries have developed significant interconnection capacities to manage the variability and forecasting errors for wind and solar production, while others focus on national solutions such as increasing the share of combined cycle gas turbines (CCGTs) with very fast responses, or the share of dispatchable combined heat and power (CHP) plants, or the conversion of old hydro power stations to operate in the flexible pumped hydro storage mode (PHS). There is no 'silver bullet' or 'royal road' to ensure the flexibility in each system. Instead, flexibility options and solutions vary greatly, with different strategies being appropriate for different systems.

So far, several trials have been proposed to measure the flexibility of power systems; *e.g.* the International Energy Agency's (IEA's) GIVAR (Grid Integration of Variable Renewables) Project proposed the *Flexibility Assessment (FAST) Method* in their report in 2011 [1]. In [2], the simplified index *Maximum Share* of wind power was evaluated as an indication of how challenging it is to integrate a larger share of wind power in a certain system. Also, a scorecard to measure flexibility was designed [3]. These methods will be useful for quantitative estimation of flexibility in a targeted country/area.

A proposed "*Flexibility Chart*" [4] is employed to visualize the dominant factors and compare the variety of solutions in different countries/areas. The chart was designed as an "at-a-glance" graph that clearly shows the difference of flexibility strategies and provides an easy-to-understand tool, even for non-technical experts including journalists and policy makers.

According to the FAST method proposed by the IEA GIVAR [1], flexible resources are categorised into four types; dispatchable plant, storage, interconnection capacity and demand side response. In the present Flexibility Chart, five parameters are selected; penetration ratio in capacity (% of peak load) for CCGT, CHP, pumped hydro, hydro and interconnector capacity. As there are no reasonable measures to estimate the capacity of demand side management at the present time, the demand side flexibility is neglected in this analysis.

Note that CHP and CCGT plants cannot always operate as dispatchable generation with quick response. Some types of CCGT with a high operation temperature, especially many plants in Japan, are designed as base-load generation for very high efficiency operation. Therefore, it is necessary to distinguish flexible from inflexible CCGT plant to refine the analysis. Also, CHP plant cannot act as a flexible resource without communication links, which are required