Impact of Large Amounts of Wind Power on Primary Frequency Control: a Technical and Economic Study

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Renewable energy sources help reaching the environmental, social and economic goals of producing electrical energy in a clean and sustainable matter. Among the various renewable resources, wind power is assumed to have the most favorable technical and economic prospects and offers significant potential for reducing greenhouse gas (GHG) emissions. As wind power installations are more and more common in power systems, additional research is needed in order to guarantee the quality and the stability of the power system operation.

Maintaining the frequency as close as possible to its rated level is one of the most important tasks for grid operators in order to maintain a stable electricity grid. However, the significant penetration of wind generation in power grids has raised new challenges in the operational and planning decisions of power systems. Wind turbine units almost always include power converters decoupling the frequency dynamics of the wind power generators from those of the grid. This decoupling causes a reduction in the total system inertia, affecting the system's ability to overcome frequency disturbances.

To study the impact of wind power on the system inertia, first the Nordic 32-A System, representing a scaled version of the Swedish grid, is implemented in PSS/E. A system identification of model parameters with actual data follows. This ad-hoc identification method determines the dynamic parameters of the governors and prime movers in the model. The two metrics of primary frequency control; the instantaneous minimum frequency and the rate of change of frequency (ROCOF) are simulated using the identified power system, and via an extrapolation, the maximum wind power penetration in Sweden is found, considering that the system has to comply with the instantaneous minimum frequency requirements and also that the tripping of the generators' ROCOF relays is prevented.

The second part of the work focuses on an economic study of the cost to guarantee an adequate frequency response, particularly the Primary Reserve (PR). The Primary Reserves is the capacity of the generators that is reserved for the governors to use for Primary Frequency Control (PFC). Primary Reserves also include the ramping capability requirement of power plants for regulating power imbalances caused by contingencies.

Recent studies have shown that having more renewable resources, such as wind with no PFC capability as well as an electricity market design with no incentive for PFC, are important drivers for a decline in the frequency response in the system. One solution is the careful design of a PFC ancillary service market by introducing suitable constraints to ensure the adequacy of Primary Frequency Control. However, applying these constraints will increase the generation cost especially when more and more wind power is integrated. This work proposes the use of an adequacy constraint to evaluate the economic impact of wind integration with respect to its influence on guaranteeing an adequate PFC. To analyze the cost increment for maintaining an adequate frequency response in the presence of wind power, an optimal power flow (OPF) problem is designed with an objective function of the generation cost minimization and considering a PFC adequacy constraint. The results show that the inclusion of the new constraints in the optimal dispatch OPF leads to a higher dispatch cost.

Keywords: Inertial response, primary frequency control, power system simulation, system identification, wind power integration, optimal power flow