## ABSTRACT

The present research aims to focus on addressing the issues emerging due to the large penetration of Renewable Energy (RE) into the Indian grid. The study deals with integrating the optimally designed RE Hybrid systems with the Indian grid and proposed to be participating in the electricity markets and environment which will be subjected to free competition. The hybrid plants are those which are designed to reduce the variability by combining mainly two major resources e.g. solar and wind and further improving the controllability of the system through charging and discharging capability from Battery Energy Storage System.

In this study, optimal sizing of a grid-connected solar-wind hybrid plant of 3.37 MW size is designed and installed with an objective to maximize the yield from a given piece of land based on local observation data and electrical connections at NTPC Kudgi, in Karnataka. The variability or ramp-rate of power generated from the RE plant is a major concern that affects adversely on the power quality of the grid. Globally the ramp-rate of 10%/min is being imposed as a regulation for renewable integration. Recently in India also, a ramp-rate of 10%/min is introduced as a technical standard for connectivity to the grid and soon this will become a part of system design for the upcoming installations.

The ramp-rate of solar, wind and hybrid system were evaluated by collecting real-time data of 5-sec interval from this plant. MATLAB simulation code was developed to size the single battery system or hybrid battery energy system. The hybrid battery system was sized by decomposing the power signal through a method called Variational Mode Decomposition (VMD) into two separate low and high-frequency components and thereby providing a combination of high energy and high-power batteries respectively.

Further to sensitized on the high cost of the battery, a concept of Levelized Cost of Storage (LCOS) is proposed and technological details of the various batteries was analyzed, which takes care of not only the capital cost but also the degradation, life cycle, and efficiency cost into consideration. The LCOS has been calculated for various technologies and application and sensitivity analysis were performed.

Lastly, a techno-economic study has been performed to make this a business case generating positive revenue for the primary frequency response market. Different control logics were proposed and the simulation code was developed to evaluate the same.

The proposed study is not only providing insight about the various design and technical aspects but also pave way for policy advocacy in bringing the technical and economic regulation for flexible renewable generation and grid operation in India with large RE penetration.