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Impact of short-term storage on frequency response under increasing wind penetration

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HIGHLIGHTS

- Assessing impact of short-term fast responding storage on system frequency response.
- Battery storage integrated into single-area AGC model of IEEE 24 bus RTS system.
- Improves CPS1 scores, procures lesser regulation and reduces generation cycling.
- Incentivizing short-term storage's regulation performance improves its economics.

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ABSTRACT

In this paper, the effort is to study the impact of short-term storage technology in stabilizing the frequency response under increasing wind penetration. The frequency response is studied using Automatic Generation Control (AGC) module, and is quantified in terms of Control Performance Standards (CPS). The single area IEEE Reliability Test System (RTS) was chosen, and battery storage was integrated within the AGC. The battery proved to reduce the frequency deviations and provide good CPS scores with higher penetrations of wind. The results also discuss the ability of the short term storage to benefit the system by reducing the hourly regulation deployment and the cycling undergone by conventional units, by dint of their fast response; and sheds light on the economic implications of their benefits.

1. Introduction

One of the significant impacts of renewable integration into the traditional and inflexible power system is upon the frequency response of the system [1]. Since these renewables, especially wind, are variable and unpredictable, the system is facing frequent and large ramps [2]. It has led to a significant rise in regulation reserves (to compensate the minute-to-minute mismatch between generation and load) and contingency reserves (10-min spinning and non-spinning).

The reserves from conventional generation units to tackle this issue related to renewable integration are proving to be insufficient [3]. Infact, using the slow moving conventional units for reserves proves counterproductive as at times they add to the net ACE and therefore the impose higher regulation requirements [4]. In addition to that whatever ramps they provide causes further fatigue and reduction of life cycle due to the heavy cycling [5] they are subjected to, which eventually contributes to increase in contingency reserves, operational & maintenance costs and overall production costs [6]. Overall, the need is not only for higher ramping capability requirements, but also for higher quality reserves, i.e., fast response (almost instantaneous) and precise control in providing regulation.

Fast ramp providers such as gas turbines, demand side resources and storage are touted as some of the technologies capable of supplying the required amount of regulation at the precisely scheduled moment [7]. Among these, the researchers, system planners and investors are specifically looking into storage to help out this new grid scenario [8,9]. Such technologies are capable of quickly responding to system regulation needs and increase the reliability of the system both in terms of decreasing outage quantities and cycling, and improving the frequency response by complying with NERC CPS [10].

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Nomenclature

$ACE_{1\text{-min}}$	1-min averages of the ACE over a year
B	frequency bias in terms of MW per 0.1 Hz
Δf	frequency deviations
$\Delta f_{1\text{-min}}$	1-min averages of the frequency deviations over a year
H	inertia
K_0	battery converter gain constant
L_{RT}	real-time load
Reg(t)	regulation requirement at hour t
T_A	actual tie-line flow
T_S	scheduled tie-line flow
T_d	battery converter time constant
V_{conv}	voltage across the battery converter
W_{RT}	real-time wind
ϵ	maximum acceptable steady-state frequency deviation
$\delta_{CPS}(t)$	additional regulation allocations at hour t to improve CPS standards

Abbreviation definitions

ACE	area control error
AGC	automatic generation control
ALFC	automatic load frequency control
AVR	automatic voltage regulator
CAES	compressed air energy storage
CPS	control performance standards
C–S	capacity–service ratio
DA	day-ahead
ED	economic dispatch
ISO	independent system operator
MCP	market clearing price
NERC	North American Electric Reliability Corporation
NL	net load
PHS	pumped hydro storage
RTED	real-time economic dispatch
RTS	reliability test system
SCED	security constrained economic dispatch
SCUC	security constrained unit commitment
SMES	superconducting magnetic energy storage
SoC	state of charge
UC	unit commitment

Storage technologies range from long-term (in terms of energy capability) bulk storage such as PHS and CAES to fast-responsive short term storage such as batteries, flywheel, SMES and super capacitors. Storage technologies though have been around for many decades, due to the high capital investments there are some impediments in their wide-spread usage in the grid. At this juncture, it is important to perform studies that evaluate their wide range of benefits and monetize them in order to increase their value for providing grid services [11].

In this paper, the effort is to study the impact of short-term storage technology in stabilizing the frequency response under increasing wind penetration. The frequency response is studied using AGC module, and is quantified in terms of CPS measures. The single area IEEE RTS system was chosen, which includes seven coal generators, two oil generators, three natural gas generators that participate in AGC. To this portfolio, fast responding battery storage module is added, and the improvement in frequency response and the various other benefits that storage brings are studied.

The organization of this paper is as follows. Section 1 gives an introduction of AGC and CPS measure. Section 2 presents the single-area AGC model and the storage model that will be integrated within AGC, and also discusses the manner in which the study accounts for the impact of increasing wind penetration on AGC. Section 3 discusses the results of simulation case studies for IEEE 24 bus RTS system. Finally, Section 4 presents the conclusions.

2. Automatic generation control and frequency performance

2.1. Automatic generation control

In the power system the load and generation are constantly changing and hence there is a need to balance out these fluctuations. When the load and generation are balanced the power system is said to be in equilibrium. The reactive power balance is carried out by the AVR that maintains the terminal voltage of each generator in the system to a constant value using its excitation system. The real power balance is achieved using two levels of control. The primary control loop is called the Automatic Load Frequency Control (ALFC) or the speed governor that adjusts the turbine output to match the change in the load. All the generators in the system contribute to change in generation to balance the load change. Apart from the power change, the load fluctuation causes a steady state frequency deviation which is balanced using the integral controller. This is called the secondary or supplementary control loop. Both the ALFC and the integral controller loop are together called as the Automatic Generation Control (AGC).

The AGC is like a remote control to the generator as it replaces some of the manual controls to change its generation level based on the input signal received at the system control center, i.e., raise, lower or no pulse indicating increase, decrease or maintain the current generation levels respectively. If frequency deviation is positive, the area generation has to be decreased and vice-versa. The main objectives of the AGC are:

i) Maintain the steady frequency
ii) Maintain the scheduled tie-line flows
iii) To distribute the required change in generation among the online generators economically

In a multi-area system, the AGC therefore corrects the frequency deviations and the tie-line deviations in a way that each control area compensates for its own load change. All the generators within a single area are typically replaced by an equivalent generator for that area ALFC. The measurement of the steady-state frequency deviation and the net tie-line deviation (actual-scheduled) is combined into a signal called Area Control Error (ACE). Using the ACE signal, the AGC for each area corrects its own load deviations.

$$ACE = -10B\Delta f + (T_A - T_S) \quad (1)$$

where B is frequency bias in terms of MW per 0.1 Hz, usually a function of natural frequency response of the area. In the single area system the AGC has the function of regulating the system frequency in an economic fashion using the available generators. In this case, the ACE signal comprises of only steady-state frequency deviations. The dynamics of a system with different types of generations such as thermal, hydro, gas, oil, etc. depends on the contributions from various generations towards offsetting the ACE.