USE OF STORAGE TO MITIGATE FREQUENCY VARIATIONS IN A LOAD FREQUENCY CONTROL MODEL

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The increase of renewable and intermittent energy sources replacing more stable and conventional sources such as gas-fired or coal plants in the power grid could lead to large frequency variations, sometimes exceeding that of grid limits (±1 Hertz [Hz] of 60 Hz). These limits are to ensure proper operation of induction generators and also to limit losses in power system components like transformers.

Using a load-frequency control model [1] with the assumption that load-frequency and reactive-voltage stability parts are decoupled [2], it can be shown that the use of specific storage devices (with individual time constants and duration of storage) reduces excessive frequency variations due to renewable energy.

We look at a simple system with four different sources of power: (a) a gas-fired plant servicing as the frequency leader, (b) a wind-powered system, (c) a short-term storage unit to smooth wind variation (battery type), and (d) a long-term storage unit as a reserve plant (constant-speed hydro plant). The short-term storage plant responds to the variations of wind within a few 60-Hz cycles (designated as the storage response time); however, the long-term storage plant is assumed to have a lead time of about 5 to 10 minutes.

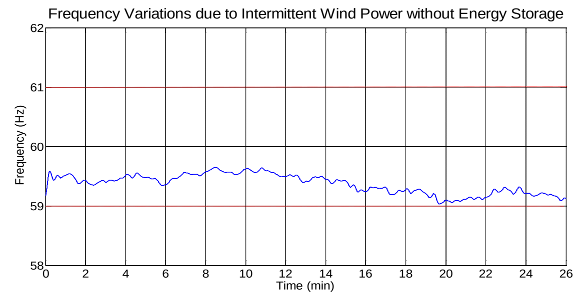
Table 1. Storage description.

Type of Generation	Rated Power (MW)	Duration of Discharge
Gas-Fired Plant	300	Months
Wind System	250 (max)	Intermittent
Short-Term Storage	90	3-4 minutes
Long-Term Storage	120	3 hours to days

The simulated wind system is assumed to have a maximum rated power of 250 megawatts (MW). Simulations done are for wind energy (megawatt hour [MWh]) penetration levels ranging from 10% to 40% of the overall load energy of ~90 MWh.

A sodium sulfur (NaS) battery connected to a wind farm in Minnesota has been used effectively for wind leveling and smoothing operations. Using a model of this NaS battery as short-term storage, frequency variations due to variability of renewable energy have been observed to decrease due to a wind-smoothing operation.

Figure 1(a) shows frequency variations of a system without any energy storage devices. Figure 1(b) shows corresponding frequency variations of a power system with the NaS battery model for a wind-smoothing operation.



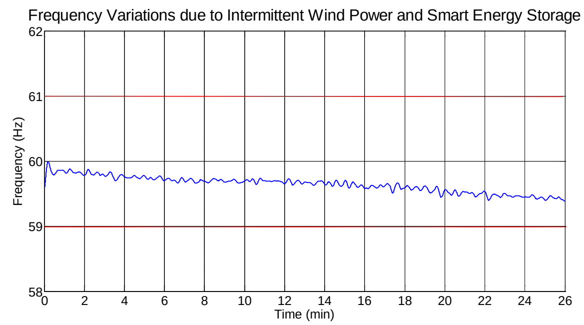


Fig. 1a (right) and 1b (left). Frequency variations.

This study found that:

(1) Different response times of various storage devices could lead to an increase (or decrease) of frequency variations with other parameters held constant. It is observed that the transients due to the switching in/out of storage devices could resonate with other components of the grid, thus leading to sharp increases in frequency deviations.
(2) Without any storage devices, the frequency changes are almost proportionate to the size and power profile of the intermittent power penetration. This result is shown assuming that there are no load changes in the system. The main reason for this assumption is to show that with just variability in renewable energy, large frequency deviations could be observed in the power grid.
(3) Differing time constants of the various interacting power sources (i.e., wind, gas-fired plant, and energy storage) could lead to an unstable system.
(4) The selection of a proper speed-droop characteristic plays an important role. At very small speed-droop values, undamped oscillating frequency deviations with increasing magnitude are observed [3, 4].
(5) Peak-power tracking must not induce power oscillations due to a searching algorithm for finding the maximum power point.
(6) Sufficient power capability of a transmission line plays an important role and is assumed in this model to be true.

REFERENCES

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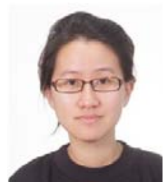
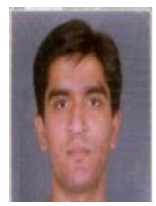
BIOGRAPHICAL NOTES



Conference presenter: Michelle Lim received a B.S. degree in aerospace engineering and an M.S. in electrical engineering from Wichita State University in 2006 and 2009, respectively. She has worked on the economic feasibility of integrating wind energy in the state of Kansas with a Department of Energy grant in 2009. She has also worked at the National Institute for Aviation Research and Bombardier-Learjet Inc. in Wichita, Kansas. Currently, she is an electrical engineering Ph.D. candidate at the University of Colorado at Boulder.



Mohit Chhabra received a B.S. degree in electrical engineering from Western Michigan University, Kalamazoo, and an M.S. in electrical engineering from the University of Virginia, Charlottesville. As part of his graduate thesis, he simulated and implemented PID and LQR control algorithms on a magnetic bearing based test machine. Previously, he worked as a controls engineer with SPX Corporation in Riverside, Michigan, working on the control and safety aspects of large-scale heat treat machines. He is working towards his Ph.D., and currently holds the position of Research Associate in the Renewable Energy for the Grid research group at the University of Colorado at Boulder.

Frank Barnes received his B.S. from Princeton University in electrical engineering in 1954 and his M.S. Engineer and Ph.D. from Stanford University in 1955, 1956, and 1958. He joined the University of Colorado in 1959. He was appointed a Distinguished Professor in 1997. He was elected to the National Academy of Engineering in 2001 and received the Gordon Prize 2004 for innovations in Engineering Education from the National Academy. He is a fellow of IEEE, AAAS, and ICA and served as Vice President of IEEE for publication and as Chairman of the Electron Device Society. In the last four years he has been working on energy storage and the integration of wind and solar energy into the grid and the effects of electric and magnetic fields on biological systems.