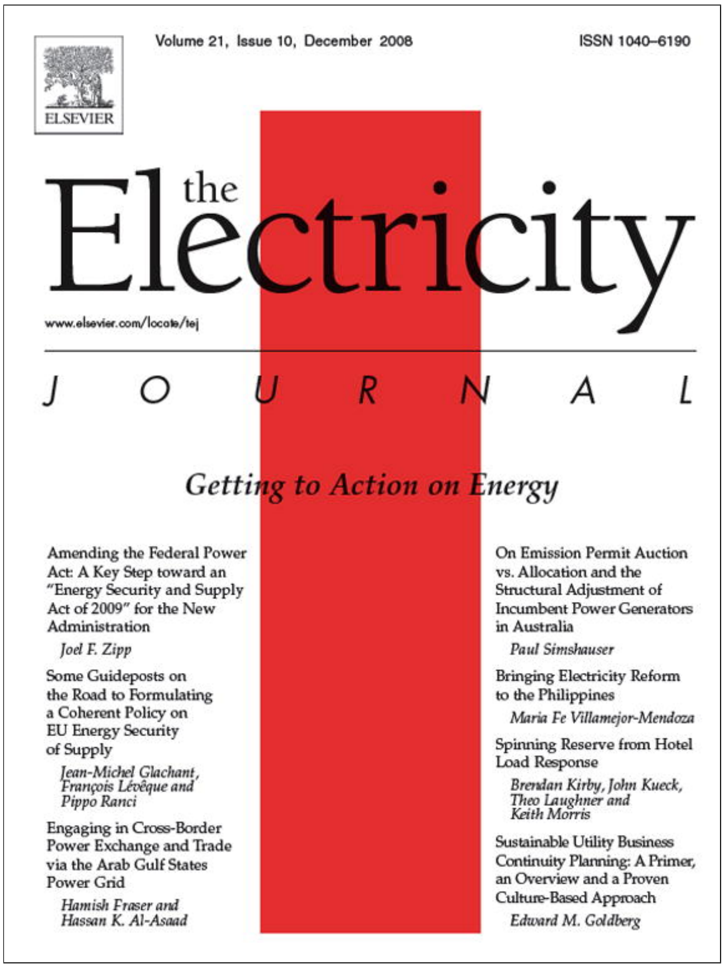

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# Spinning Reserve from Hotel Load Response

*Even though preliminary tests were not conducted during times of highest system or hotel loading during the summer, they showed that hotel load can be curtailed by 22 to 37 percent depending on the outdoor temperature and time of day. Full response occurred in 12 to 60 seconds from when the system operator's command to shed load was issued and the load drop was very rapid.*

*Brendan Kirby, John Kueck, Theo Laughner and Keith Morris*

## I. Introduction and Background

This project was motivated by the fundamental match between hotel space conditioning load response capability and power system contingency response needs. As power system costs rise and capacity is strained, demand response can provide a significant system reliability benefit at a potentially attractive cost.[1]

At Oak Ridge National Laboratory's (ORNL) suggestion, Digital Solutions Inc. (DSI) adapted its hotel air-conditioning/heating control technology to supply power system spinning reserve.

This energy-saving technology is primarily designed to provide the hotel operator with the ability to control individual room temperature set-points based upon occupancy (25 percent to 50 percent energy savings based on an earlier study [Kirby and Ally, 2002]). DSI added instantaneous local load-shedding capability in response to power system frequency and centrally dispatched load-shedding capability in response to power system operator command.

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The 162-room Music Road Hotel in Pigeon Forge, Tenn., agreed to host the spinning reserve test. The Tennessee Valley Authority (TVA) supplied real-time metering equipment in the form of an Internet-connected Dranetz-BMI power quality meter and monitoring expertise to record total hotel load during both normal operations and testing. The Sevier County Electric System installed the metering.

Preliminary testing showed that hotel load can be curtailed by 22 percent to 37 percent depending on the outdoor temperature and the time of day. These results are prior to implementing control over the common area air-conditioning loads, which will increase the curtailment. Testing was also not at times of highest system or hotel loading (September, rather than July and August). Full response occurred in 12 to 60 seconds from when the system operator's command to shed load was issued. The load drop was very rapid, essentially as fast as the two-second metering could detect. Load restoration was ramped back in over several minutes. The restoration ramp can be adjusted to the power system needs.

Frequency response testing was not completed. Initial testing showed that the units respond essentially instantaneously. Problems with local power quality generated false low frequency signals which required testing to be stopped. This should not be a problem in actual operation since the frequency trip points will be staggered to generate a droop curve that mimics generator governor response and the actual trip frequencies will be low enough to avoid power quality interference.

Overall, the preliminary testing was extremely successful. The hotel response capability matches the power system reliability need, being faster than generation response and inherently available when the power system is under the most stress (times of high system and hotel load).

## II. Hotel Response Capability and Power System Reliability Needs

The power system must be continually ready to respond to the sudden failure of a major generator or transmission line. Extra generating capacity is kept available to provide a series of reserves that can restore the generation/load balance as shown in Figure 1. The reserves are sequenced with spinning reserve responding immediately followed by non-spinning reserve and replacement reserves.[2] Finally, the energy market responds and conditions return to normal. When responsive loads provide contingency reserves it frees up generation to supply load rather than having generation idling, ready to supply reserves.

It is desirable to restore the contingency reserves as quickly as possible so that they are available to respond to another generation failure. North American Electric Reliability Corporation (NERC) rules require reserves in the east to be restored within 105 minutes. Western Electric Coordinating Council (WECC) rules require reserves to be restored within 75 minutes in the west. In actual practice reserves are typically restored much faster, as shown in Figure 2 for New York (NYISO), New England (ISO-NE), and California (CAISO). Both California and

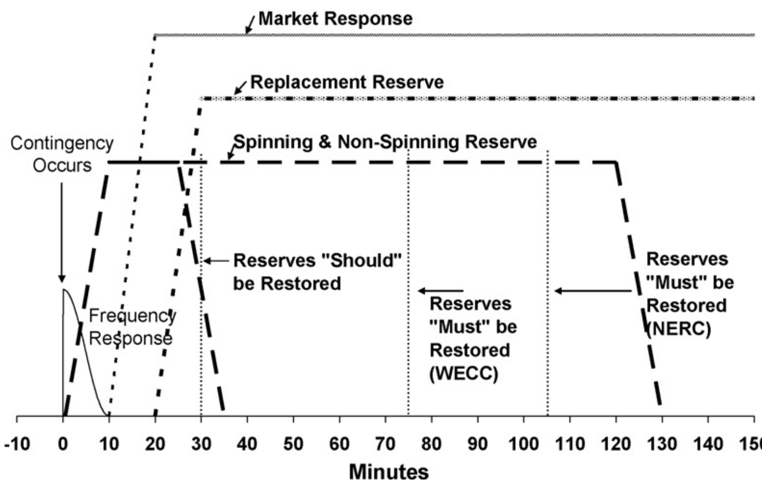


**Figure 1:** A series of contingency reserves is kept available to maintain power system reliability in case a major generator suddenly fails

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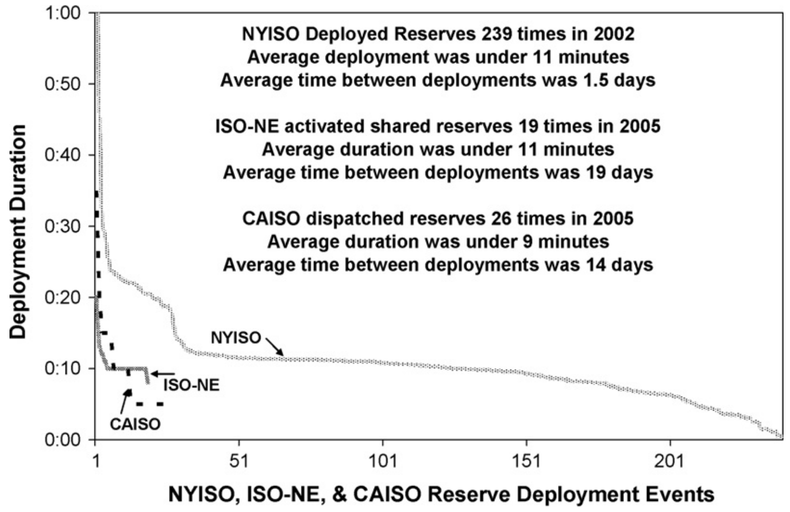


**Figure 2:** ISOs differ in the frequency of their use of contingency reserves but reserve deployments average about 11 minutes

New England deploy contingency reserves about twice per month. New York uses contingency reserves about 10 times more frequently. Figure 2 also shows that in all three balancing areas the contingency reserve deployment is typically short, averaging around 11 minutes, but is occasionally longer.

The power system need for rapid response that typically lasts 10 to 30 minutes but which can occasionally last longer, shown in Figures 1 and 2, matches the response capability of some space conditioning loads quite well. These loads are typically capable of numerous short curtailments and infrequent sustained curtailments (Kirby, 2003). They can be rapidly restarted and are ready to immediately respond again should another contingency arise. They do not have ramping time, minimum on time, or minimum off time limits that constrain many generators. The only time delay is for the control signal to get from the system operator to the load; much faster than the 10 minutes allowed for generation to fully respond. When responding to system frequency deviations, the curtailment can be essentially instantaneous. Communications delays are not encountered because frequency is monitored at the load itself.

Supplying contingency reserves is technically more attractive to some loads than providing peak reduction because the response duration and response frequency are greatly reduced. Peak reduction requires actually responding, typically for multiple hours per day, often for multiple days in a row. Providing contingency reserves requires that the load be *poised* to respond immediately if a power system emergency occurs but to operate normally otherwise. This imposes a technical communications and control requirement on the load but does not otherwise interfere with the load's normal function.

Supplying faster, shorter, ancillary services is typically more attractive economically as well because spinning reserve is typically worth two to eight times as much as non-spinning reserve and two to 20 times as much as replacement reserves on an annual average basis.[3] Ancillary service prices value response speed rather than response duration (Kirby, 2006).

## III. Co-Optimization: Excellent for Generation, Bad For Load Response

Co-optimization (also called joint optimization, simultaneous optimization, or rational buying) minimizes the total cost of energy, regulation, and contingency reserves by allowing the substitution of ''higher-value'' services for ''lower-value'' services. If a generator offers spinning reserve at $8/MW-hr, for example, and other generators are offering non-spinning reserve at $12/MW-hr the co-optimizer will use the spinning reserve resource for non-spinning reserves (instead of the non-spinning reserves offered) and pay it the spinning reserve clearing price. Co-optimization has many benefits. It encourages generators to bid in with their actual costs for energy and each of the ancillary services. When they do so, the co-optimizer is able to simultaneously minimize overall system costs and maximize individual generator profits.

Market rules and system dispatch software in some regions (not TVA) force all resources (generators and loads) that offer to provide ancillary services to be co-optimized across all ancillary services and energy. Unfortunately, co-optimization can effectively bar responsive loads as well as emissions-limited generators and water-limited hydro generators from offering to provide ancillary services. As indicated by the preliminary testing described in this article, a hotel can be an excellent provider of spinning reserve. The hotel can be instantaneously frequency-responsive. It can respond to system operator commands much faster than conventional generation. It may have nearly zero response cost (other than the initial capital cost for the communications and control equipment). It might be able to easily sustain response for 15 to 30 minutes on a regular basis and for 60 minutes or longer occasionally. In short, it may be a nearly ideal supplier of spinning reserve. But the hotel would be completely unable to provide an 8-, 12-, or 24-hour response if co-optimized to provide an *energy* response. If there was a risk that the attractive offer to provide spinning reserve could be exercised as an energy source, the hotel would simply not enter the spinning reserve market. The power system would be denied the benefit of this excellent reliability resource.

Many responsive loads differ from most generators in that the cost of response rises with response duration. An air-conditioning load, for example, incurs almost no cost when it provides a 10-minute interruption but incurs unacceptable costs when it provides a six-hour interruption. Conversely, a generator typically incurs startup and shutdown costs even for short responses, but only has ongoing fuel costs associated with its response duration. In fact, many generators have minimum run times and minimum shutdown times. This low-cost-for-short-duration-response (coupled with fast response speed) makes hotel space conditioning (and some other loads) ideal for providing spinning reserve but less well suited for providing energy response or peak reduction.

*A hotel can be an excellent provider of spinning reserve. It can be instantaneously frequency-responsive.*

Unfortunately, current market rules in New York and New England let the ISOs dispatch capacity assigned to reserves for economic reasons as well as reliability purposes. As long as the ISO has enough spinning and non-spinning reserve capacity to cover contingencies, it will dispatch any remaining resources economically regardless of whether that capacity is labeled as contingency reserve or not. Ancillary service and energy suppliers are automatically co-optimized. This policy works well for most generators but causes severe problems for loads that need to limit the duration or frequency of their response to occasional contingency conditions.[4] Loads can submit very high energy bids in an attempt to be the last resource called but this is still no guarantee that they will not be used as a multi-hour energy resource. Submitting a high-cost energy bid also means that the load will be used less frequently for contingency response than is economically optimal. Price caps on energy bids further limit the ability of the loads to control how long they are deployed for.

Fortunately, there is a simple solution. California had this problem with its rational buyer but changed its market rules and now allows resources to flag themselves as available for contingency response only. PJM allows resources to establish different prices for each service and energy providing a partial solution. The Electric Reliability Council of Texas (ERCOT) does not currently have the problem because most energy is supplied through bilateral arrangements that the ISO is not part of. Energy and ancillary service markets are separate. Possibly as a consequence, half of ERCOT's contingency response comes from

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responsive load (the maximum currently allowed) while no loads offer to supply balancing energy.

## IV. Preliminary Testing Results

The Music Road Hotel in Pigeon Forge, Tenn., agreed to host the spinning reserve tests. DSI controllers were installed in 162 rooms and on 12 hallway air conditioners. The primary function of the DSI controllers is energy savings. The DSI controllers have a temperature sensor and accept commands from the hotel front desk. When the hotel room is unoccupied (not rented) the controllers override the air conditioner's and heater's local thermostat setting and allow the room temperature to move to an energy saving hotel-selected value.

The DSI controller also monitors the power supply voltage and turns the unit off if voltage is inadequate. This feature is designed to protect air-conditioning and heat pump compressors from low- or high-voltage burnout. It also helps the power system avoid voltage collapse.

Spinning reserve capability was added by providing the ability for the power system operator to remotely issue a curtailment command to as many or as few devices as desired. For the loss of a major generator, the power system operator will likely curtail all of the loads simultaneously. A local problem can be addressed by curtailing all of the loads within a region or zone. Device groupings can be predefined for the system operator convenience. Frequency response capability was also added.

### A. Hotel load profile

Air-conditioning and heating loads are, of course, driven by outside temperature. Unfortunately, testing of spinning reserve response could not be started until September, after the peak of the cooling season. The hotel exhibits a daily load pattern that is similar to that of the power system itself. The evening hotel load drop is at about 10 pm (**Figure 3**) so the hotel should be able to supply spinning reserve well into the evening hours.

### B. Testing spinning reserve response

The first four spinning reserve tests were performed on two days in September 2008. Data from the Sept. 3 tests was recorded at a 1-minute interval. Data from the Sept. 5 tests was recorded at a 2-second interval. Results from both tests are shown in **Figure 4** with both the actual data and trend lines plotted. The size of the load reduction differed in each case, ranging from a 22 percent drop at 9 am on Sept. 5 to a 37 percent drop at 2 pm on Sept. 3. Interestingly, the uncontrolled baseload was reasonably consistent (180–195 kW). The load drop was very fast in all four cases: as fast as the metering rate.

Each test curtailed air-conditioning load for 15 minutes. Individual loads are returned to service in five blocks with 90 seconds between each block restoration. Longer interruptions are controlled by repeating the curtailment command. Precise timing data showing the lag between signal initiation and load curtailment was not collected but informal observation showed time delays of 12 to less than 60 seconds.

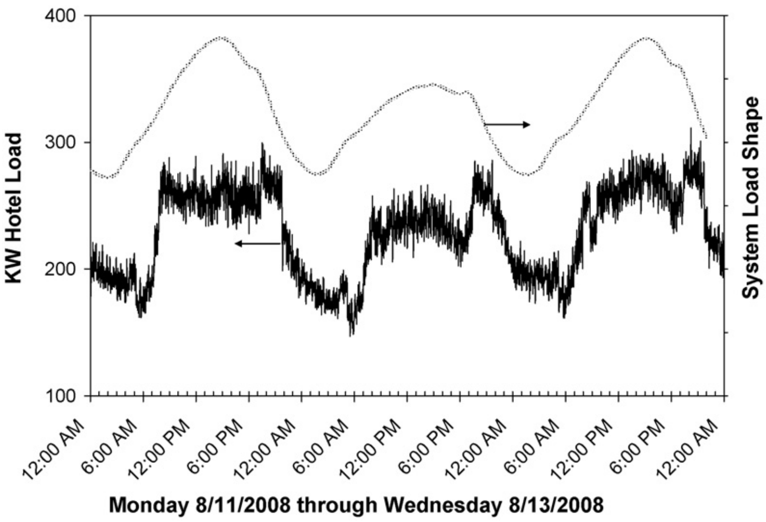


**Figure 3:** The hotel shows a typical daily load pattern that is similar to that exhibited by the power system itself, with the evening drop occurring around 10 pm

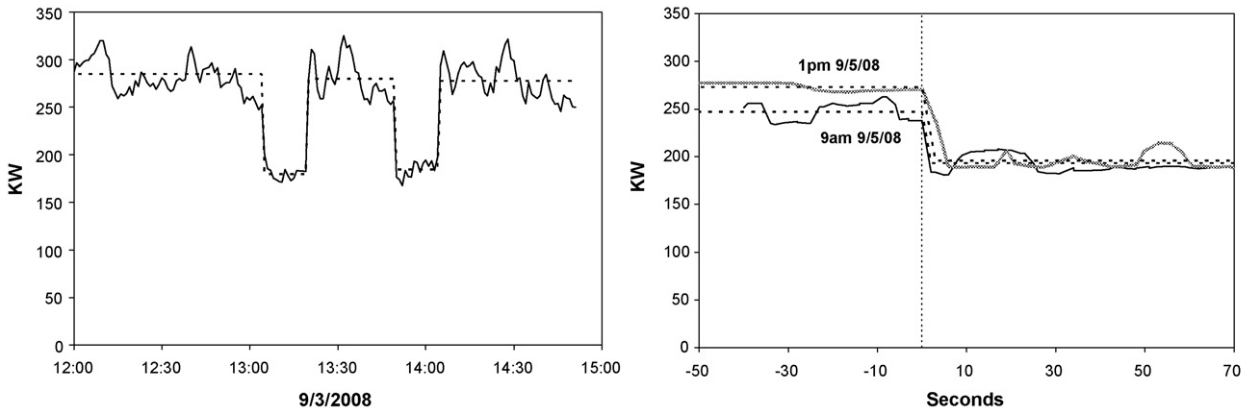


**Figure 4:** Four spinning reserve tests were conducted on two days

### C. Room temperature and humidity rise

Temperature and humidity were monitored in 12 of the 162 rooms during the first two spinning reserve tests. Rooms were selected on the sunny side of the hotel on the fifth and seventh (top) floors to deliberately bias the results towards a greater temperature rise. On average the temperature rose 1.7 °F and humidity rose 2 percent during the 15-minute test. Temperature recovered 1.5 °F and humidity recovered 0.1 percent on average during the 15 minutes after the test. Outdoor temperature was 90 °F during the temperature rise tests.

Temperature rise testing was not perfect. Some room doors were left open to facilitate equipment checking and this allowed relatively hot, humid hallway air to enter the rooms. Still, the test indicated that short curtailments normally associated with spinning reserve events should not be a significant concern. A longer test of temperature rise is scheduled to determine the impact on temperature and humidity of a one-hour curtailment.

## V. Frequency Response

Autonomous frequency response is an important characteristic of spinning reserve. When a large enough contingency occurs (the sudden failure of one or more large generators, for example) to shift the interconnection frequency, generator governors respond automatically to help restore the generation/load balance and return frequency to 60 Hz. They do not wait for the system operator to command the response; they sense the frequency shift and respond immediately. This fast response, though relatively rarely called upon, is critical for maintaining power system reliability.

For responsive loads to supply spinning reserve they too must respond to power system frequency deviations. The DSI load control units monitor power system frequency and provide rapid autonomous response when frequency declines. Both the underfrequency trip point and the underfrequency duration can be configured to meet the utility reliability requirements. Frequency trip points can be staggered among individual units or among individual hotels to provide smooth frequency response and to create a ''droop'' curve, as shown in Figure 5.

''Droop'' refers to the proportional increase in response provided by generator governors as the frequency deviation increases. It would not be desirable to have all of the online generators provide their maximum output for a small frequency deviation. Too much generation might be added and the power system would be out of balance in the other direction. To avoid this, the governors provide increasing output as the power system frequency declines further and further from 60 Hz. Under normal conditions power system frequency is held close to 60 Hz as shown in Figure 6. Generator governors typically have an intentional 0.035 Hz deadband where they ignore system

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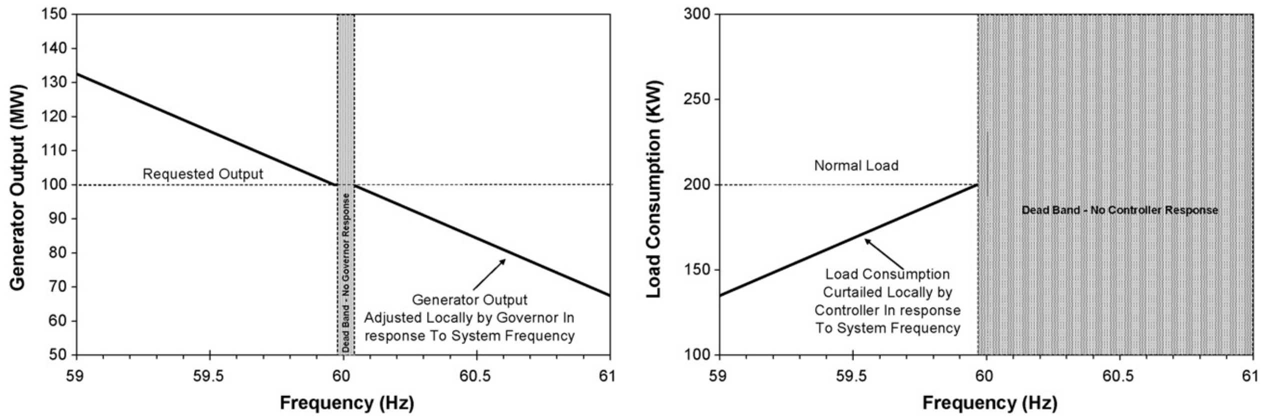


**Figure 5:** Generator (left) and load (right) autonomous frequence response are equivilent reliability resources for underfrequency response

frequency deviations. This lets the generators ignore small system frequency fluctuations that result from normal generation/load imbalances.

When responsive loads provide spinning reserve they must provide response that is equivalent to that offered by generators. Most importantly, loads providing spinning reserve must respond to frequency deviations in the governor response range shown in Figure 6. This is well above the frequency at which involuntary load shedding occurs.

It is also important for load frequency response to provide, in aggregate, a droop characteristic that is similar to that provided by generation. An individual load may not be able to provide a linear droop response but a collection of loads can. By setting a slightly different frequency trip point for each individual load the aggregate load frequency response characteristic can be tailored to any desired response. Note that the Figure 5 load response differs from the generator governor response in that the load does not provide

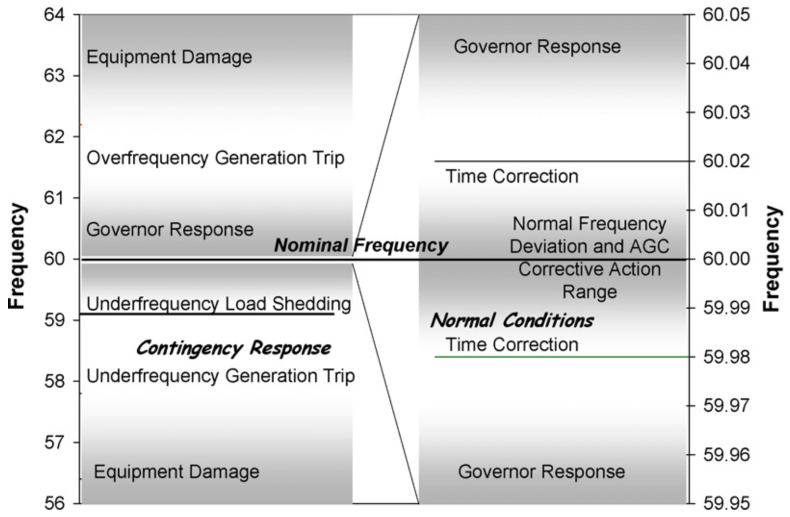


**Figure 6:** Power system frequency is tightly controlled under normal conditions

response for high frequencies. While this is a difference it is not generally a power system reliability problem for two reasons. First, high-frequency events are less common than low-frequency events because large generator trips are more common than large load trips. Perhaps more importantly, the power system is inherently better equipped to deal with overgeneration conditions than undergeneration conditions. Most (not all) generators can reduce output in an emergency and there is almost always an abundance of generation that can be backed down in an emergency while there may not be excess generation that can immediately increase.

**A. Testing frequency response.** Testing generator or responsive load frequency response in actual operation is difficult, especially in the eastern interconnection. Large frequency events are fortunately rare. It is necessary to move the frequency response points closer to 60 Hz so that there will be a reasonable number of frequency events to respond to in a reasonable amount of time. Unfortunately, initial testing resulted in numerous trips per hour rather than the expected two trips per day. Further investigation showed that local power quality events were resulting in momentary frequency deviations that the load controllers were responding to as system frequency events. While fast response was demonstrated further frequency response testing was suspended until the power quality problem can be remedied. Response during actual operations would not be impacted by poor power quality since the actual response frequency would be farther from 60 Hz.

## VI. Conclusions and Future Work

Digital Solutions Inc. adapted its energy-saving hotel air-conditioning control technology to supply power system spinning reserve. DSI added instantaneous local load-shedding capability in response to power system frequency and centrally dispatched load-shedding capability in response to power system operator command.

Preliminary testing showed that load can be curtailed by 22 percent to 37 percent, depending on the outdoor temperature and the time of day. These results were prior to implementing control over the common area air-conditioning loads and were for testing in September rather than the peak load months of July and August. Full response occurred in 12 to 60 seconds, much faster than generation-based response. Load restoration was ramped back in over several minutes. The restoration ramp can be adjusted to the power system needs.

Frequency response testing was not completed. Initial testing showed that the units respond very quickly. Problems with local power quality generated false low frequency signals that required testing to be stopped. This should not be a problem in actual operation since trip frequencies will be set low enough to avoid responding to power quality events.

Overall, the preliminary testing was extremely successful. The hotel response capability matches the power system reliability need, being faster than generation response and inherently available when the power system is under the most stress (times of high system and hotel load).

DSI has developed a hot water heater controller based on the same communications and control technology. The system is designed for use in peak reduction and for the provision of spinning reserve. Controllers respond to system operator commands but they also respond to power system frequency and system voltages, just as the hotel controllers do. Testing of the hot water heater response is expected as soon as a suitable host utility is identified.■

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### Endnotes:

**1.** Other loads are also potentially excellent suppliers of spinning reserve for essentially the same reasons discussed here. Residential air conditioning, hot water heaters, pool pumps, agricultural water pumping, many industrial processes, commercial freezers, and numerous other loads are potentially in this category.

**2.** A frequency responsive reserve is being discussed which will replace the frequency responsive component of spinning reserve.

**3.** Based on analysis of hourly ancillary price data covering 2002 through 2007 for CAISO, ERCOT, and NYISO.

**4.** Co-optimization often does not work for energy- or emissions-limited generators either.

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