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Time-Averaging Period for Regulation Service

Because electricity is a real-time product, system operators must adjust generation to match load on a moment-to-moment basis, providing the ancillary service called regulation. But what do we mean by moment-to-moment?

This article addresses that question by providing background information on the regulation ancillary service and by analyzing short-interval changes in system-level generation and load for four electrical systems. Three systems are large, with peak demands between 10,000 and 20,000 MW, while the fourth system has a peak demand of under 5,000 MW. One of the large systems relies primarily on hydro units for regulation, while the other three systems use fossil units. For each system, we obtained 30-second data for 1 or more days on total generation and load. We analyzed these data to see how quickly and with how much lag generation follows load.

Regulation Ancillary Service

To the system operator, *regulation* is a reliability service it delivers to the interconnection. That service includes management of the actual interchange flows with other control areas to match closely the scheduled interchange flows and support of interconnection frequency at its reference value (usually 60 Hz). Both functions require the system operator to maintain a moment-to-moment balance between generation and load within its control area. Regulation is the primary mechanism that the operator uses during normal operations to ensure compliance with the North American Electric Reliability Council's (NERC) Control Performance Standards (CPS) 1 and 2 [1].

From the perspective of regulation suppliers, the service requires generating units that are online and producing energy, equipped with automatic generation control (AGC) equipment, and that can change output quickly. Such units must be producing energy below their maximum output and above their minimum output (to provide headroom and footroom, respectively, for the regulation service).

As the U.S. electricity industry continues to restructure, competitive generation is being unbundled from the regulated monopoly function of system control. The Federal Energy Regulatory Commission (FERC) recently issued Order 2000, which encourages utilities to form regional transmission organizations that are independent of generation [2]. As a consequence, system operators will increasingly purchase reliability services from generators in competitive markets. Competitive markets can work well only if it is possible to measure unambiguously delivery of the service in question.

Although the energy-management systems at most control centers automatically send raise or lower signals to certain generators as often as once every 2-6 seconds, generators neither need to nor can follow signals that rapidly. NERC's CPS 1 is an annual average of 1-minute values [3]. CPS 2 is a 10-minute average.

Different control areas use AGC systems with different deadbands and filters on area control error. In particular, some systems still control to the old NERC requirements (A1 and A2), which were more strict than the current CPS 1 and 2 requirements. These differences affect the amount and movement of generators providing the regulation service.

This article addresses the question: What is the appropriate time-averaging period to measure regulation consumption and delivery? We address this issue from an empirical perspective rather than a theoretical one. The four systems from which we obtained data all meet the relevant NERC requirements and are pleased with their regulation performance. Therefore, we made no effort to identify how fast generators *should* respond to AGC requests; rather we focus on how fast they *do* respond.

Addressing this issue is important for both generation and load. For generation, to be able to sell regulation to a system operator, an unambiguous method must be available to measure real-time delivery of the service. Otherwise, the system operator may pay for a service it does not fully receive, or the generator may provide services for which it is not fully compensated. NERC's proposed Policy 10 defines a supplier control error as the difference, at time *t*, between the actual output of a resource providing an ancillary service and the system-operator's expectation for output at that time [4]. Whether *t* is based on 30-second or 2-minute averages could substantially affect the measured performance of resources.

Loads differ dramatically in their use of the regulation service. These differences might be unfairly magnified if the time interval is too short or inappropriately diminished if the interval is too long.

We obtained data on 30-second generation and load for one or more days from four control areas. Three are large with loads in the 10,000-20,000 MW range, while the fourth is small, with a load less than 5,000 MW. Two of the large systems and the small system use fossil units to provide regulation, and the third large system uses hydro units for regulation.

We used a 30-minute rolling average of generation or load to identify the regulation component [5]. For example, the rolling average calculated with 30-second data is:

$$Q_{\text{average-t}} = \text{Mean}\,(Q_{t\text{-}30} + Q_{t\text{-}29} + ... + Q_t + Q_{t+1} + ... + Q_{t+30}),$$

where Q is either system-level generation or load, and t is a 30-second interval.

Regulation is then the difference between the actual and average values at time t:

$$\text{Regulation}_t = Q_t \;!\; Q_{\text{average-}t}.$$

We aggregated the resultant 30-second measures of generation and load regulation to 60-, 120-, and 240-second averages. We examined the data visually, creating graphs of generation and load regulation versus time using the four temporal aggregations. We then calculated the correlation coefficients between generation and load. Finally, we developed regression models of generation regulation as a function of current and past values of load regulation.

Large System 1

This control area provided data on system generation and load for a day in December during which the peak load reached almost 14,000 MW. Figure 1 shows the relationship between the regulation components of generation and load for the 8 to 9 a.m. hour. The top graph (30-second averages) shows that load has more frequent fluctuations, especially more reversals of direction. In going from 30- to 60- to 120- to 240-second averages, the generation patterns change only slightly, but the load patterns become much less ragged and much smoother. As the time-averaging period becomes longer, the generation and load patterns converge. However, in all cases, generation lags load by about 2 minutes.

These visual observations are confirmed by statistical analysis. We calculated correlation coefficients between generation and load for each of the four time-averaging datasets. We then repeated these analyses by lagging generation 1, 2, 3, or 4 minutes from load (Figure 2). The correlation between generation and load increases with the time-averaging period, from 0.47 for 30-second averages to 0.59 for 4-minute averages. With a lag of 2 minutes, the correlation coefficients are 0.63 for 30-second averages and 0.66 for 2-minute averages.

Finally, we ran regression models of the form:

$$\text{Generation}_t = a + b\times\text{Load}_t + c\times\text{Load}_{t\text{-}1} + d\times\text{Load}_{t\text{-}2} + \ldots,$$

where t is time and a, b, c, d, and so on are coefficients determined by the regression model.

Although we estimated models for all four time-averaging periods, we focus here on the model with 1-minute averages. (Results are similar across models.) This model, which explains 44% of the variations in generation regulation, shows that generation is not a function of current load. However, generation strongly and positively depends on loads one, two, and three minutes ago.

Large System 2

This control area provided data for several days in February when peak loads ranged between 13,000 and 17,000 MW. We analyzed this data the same way we did for the first large system. The results were remarkably similar.

Graphs of the regulation components of generation and load at the 30-, 60-, 120-, and 240-second levels of aggregation show the same patterns. Generation follows load with a lag of about 2 minutes. For the shorter time-averaging periods, load is more volatile than generation, but, for the longer periods, the patterns are quite similar.

The regression model of generation as a function of current and past levels of load had an R^2 of 0.48. The model coefficients showed that generation is a weak function of current load and a strong function of loads 1, 2, 3, and 4 minutes ago. Table 1 summarizes the model parameters. According to this model, generation is three times more responsive to load 1 minute ago than to present load and almost five times more responsive to load 2 minutes ago.

Large System 3

This control area provided data for a day in March. Unlike the two other large systems, this one relies primarily on hydro units for its regulation. Because these hydro units are flexible and fast, generation accurately follows load at the 30-second level (Figure 3). The correlation coefficient between generation and load is 0.8. Neither longer time-averaging periods nor lags between generation and load improve the correlation. Although generation and load are highly correlated, the generator movements are only about 60% of the load movements.

The regression model of generation regulation as a function of current and past values of load regulation has a much higher R^2 value than for the other large control areas (almost 0.9 versus 0.4-0.5). In addition, current load is four times more important in explaining generation movements than are past values of load.

Small System

The fourth system from which we obtained data differed substantially from the first two systems (large systems 1 and 2) in two respects. First, this system is much smaller with a peak load of less than 5,000 MW. Second, this system includes several electric steel mills, which have very volatile loads. This system differs from the third large system (large system 3) in that it relies primarily on fossil units for regulation.

Because of these differences, our visual examination of generation and load data showed a much greater lag between generation and load, on the order of 4 minutes instead of the 2 minutes observed for the two large fossil-based systems. The regulation component of load for this small system crosses zero 16 times during 1 hour. By comparison, the regulation component of load for large system 1 crosses zero only six times and that for large system 2 only eight times. On the other hand, the regulation component of generation crosses zero about the same number of times for these three systems (five to seven times).

The correlation coefficients between generation and load also show a different pattern for this small system. The correlation between generation and load increases in going from 30-second averages to 4-minute averages, as occurred for the other two systems. However, the correlation between lagged generation and load is highest for a lag of three or four minutes, compared with two minutes for the two large systems.

The regression model of generation as a function of load (based on 1-minute averages) has an R^2 of 0.70, substantially higher than for the two other systems. Once again, generation is largely independent of current load. For this small system, generation is a function of loads during the prior 9 minutes. In other words, generation follows load with a much longer lag for this system than for the two large systems.

Tentative Conclusions

Not surprisingly, results differ between the three large and one small system. Generation follows load in the small system with a longer time-averaging period (two to four minutes rather than one to two minutes) and with a longer lag (four minutes rather than zero to two minutes). We offer two tentative conclusions based on our analyses of these four systems:

- Although control centers signal generators on AGC to move up or down as often as once every few seconds, the appropriate time-averaging period for the regulation service is likely 1 to 2 minutes
- The time-averaging period for regulation differs among control areas as a function of system size, the mix of generators on AGC, composition of the load, and AGC control logic.

References

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[4] "Policy 10, interconnected operations services (draft 3.0, 1999b), Princeton, NJ: North American Electric Reliability Council, December 1999.

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As a consequence of FERC Order 2000, system operators will increasingly purchase reliability services from generators, and it must be possible to measure delivery of service unambiguously

Figure 1. Relationship between the regulation components of generation (solid line) and load (dashed line) for large system 1 with 30-second averages (top) and 120-second averages (bottom)

Figure 2. Correlation coefficient between generation and load regulation for large system 1 as a function of the time-averaging period and the lag time between load and generation

Table 1. Regression model of generation as a function of current and past loads

Variable Name	Coefficient	*t* Statistic*
Intercept	-0.045	-0.03
Load	0.069	1.75
Load-1	0.203	3.69
Load-2	0.325	5.80
Load-3	0.227	4.05
Load-4	0.118	2.11
Load-5	0.065	1.15

* A *t* statistic greater than 2 means that the coefficient is statistically significant at the 5% level or better.

Figure 3. Relationship between the regulation components of generation (solid line) and load (dashed line) for large system 3