WHAT IS THE CORRECT TIME-AVERAGING PERIOD FOR THE REGULATION ANCILLARY SERVICE?

Eric Hirst and Brendan Kirby
Consulting in Electric-Industry Restructuring
Oak Ridge, Tennessee 37830

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1. INTRODUCTION

The regulation ancillary service can be viewed from two perspectives, the bulk-power system operator and the suppliers to the operator. To the operator, regulation is a reliability service it delivers to the Interconnection. That service includes (1) management of the actual interchange flows with other control areas to match closely the scheduled interchange flows and (2) 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 the operator uses during normal operations to ensure compliance with the North American Electric Reliability Council's (NERC's) Control Performance Standards (CPS) 1 and 2 (NERC 1999a). Regulation also assists in recovery from disturbances, as measured by compliance with NERC's Disturbance Control Standard.

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 (MW/minute) over an agreed upon range (MW). 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). This service can be provided by any appropriately equipped generating unit that is connected to the grid and electrically close enough to the control area that physical and economic transmission limits (e.g., congestion, transmission outages, losses, and transmission costs) do not prevent the importation of this power.

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 (1999) recently issued Order 2000, which encourages utilities to form regional transmission organizations that are independent of generation. 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 two to six seconds, generators neither need to nor can follow signals that rapidly. NERC's CPS1 is an annual average of one-minute values (Jaleeli and VanSlyck 1997). CPS2 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 stricter than the current CPS 1 and 2 requirements. These differences affect the amount and movement of generators providing the regulation service.

This paper addresses the question: What is the appropriate time-averaging period to measure regulation consumption (by loads, nonregulating generation, regulating generation that poorly follows the AGC requests, and interchange) and delivery (by generators operating under AGC)? 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, as noted above, 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 (1999b) 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. 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.

If regulation is defined as a very short-term service (e.g., 10 seconds), then the amount required to follow time-varying loads will be greater than if regulation is defined over a longer period (e.g., 2 minutes). Similarly, a 10-second definition may inappropriately exclude some generators from participating in regulation markets because those generators are not able to vary their output quickly enough. On the other hand, a 5-minute definition may inappropriately include some generators that have low ramp rates.

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 to 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; 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 (Kirby and Hirst 2000). For example, the rolling average calculated with 30-second data is:

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

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:

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

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 vs 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.

Our overall finding, based on observations from these four systems, is that the appropriate time-averaging period is roughly one to two minutes. Perhaps more important, differences in results among the cases suggest that it is important to conduct such analyses for each control area. Differences among control areas in size, composition of load (in particular, the existence of nonconforming loads, such as steel mills), the mix of generation (in particular, fast-moving hydro units vs slow-moving fossil units), and AGC philosophy can affect the appropriate interval for the regulation service.

2. 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. Figures 1 and 2 show, for the 8 to 9 am hour, the relationship between the regulation components of generation and load. The first 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 two minutes.

These visual observations are confirmed by simple 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 (Fig. 3). 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 two minutes, the

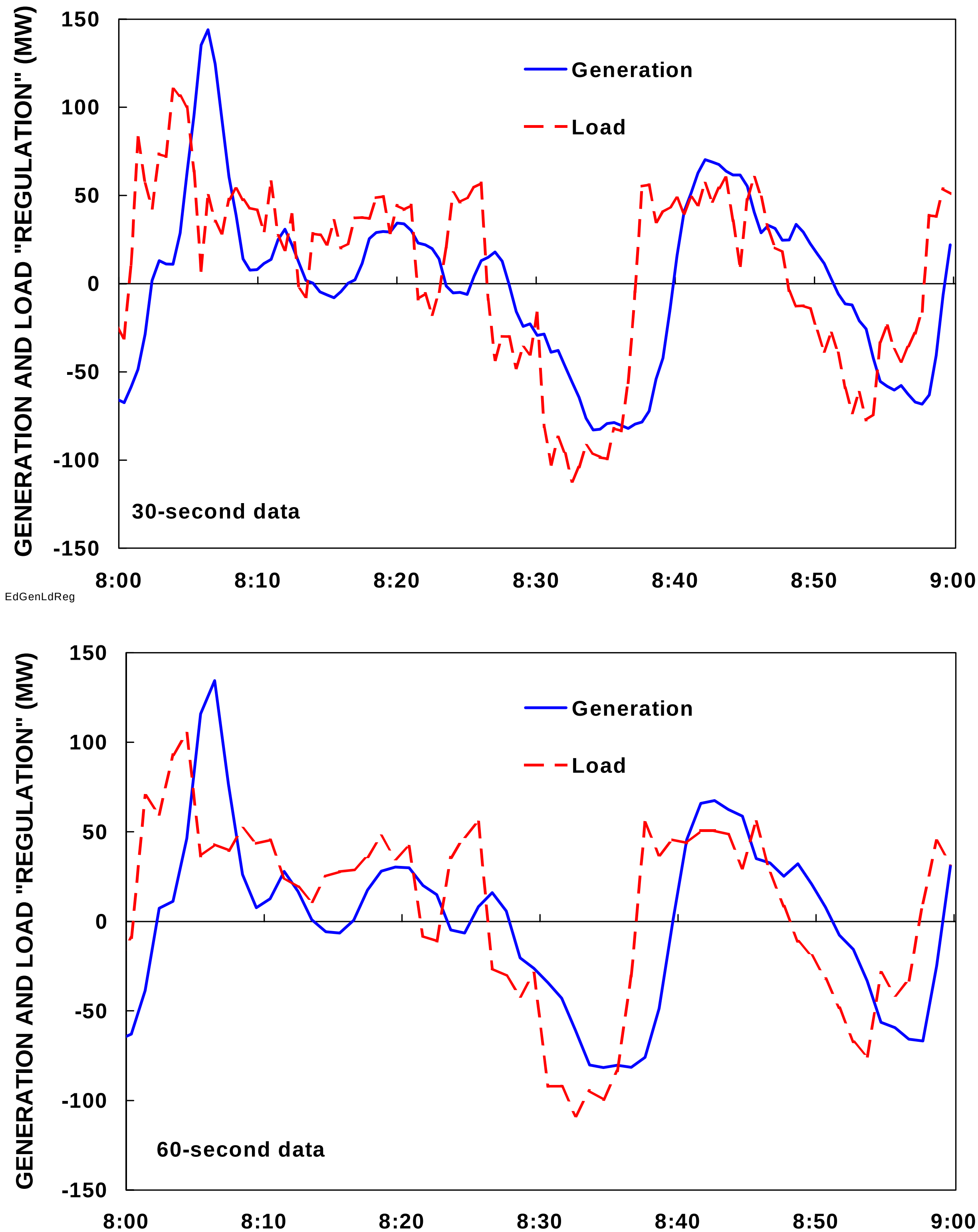

Fig. 1. **Relationship between the regulation components of generation (solid line) and load (dashed line) for large system 1 with 30-second averages (top) and 60-second averages (bottom).**

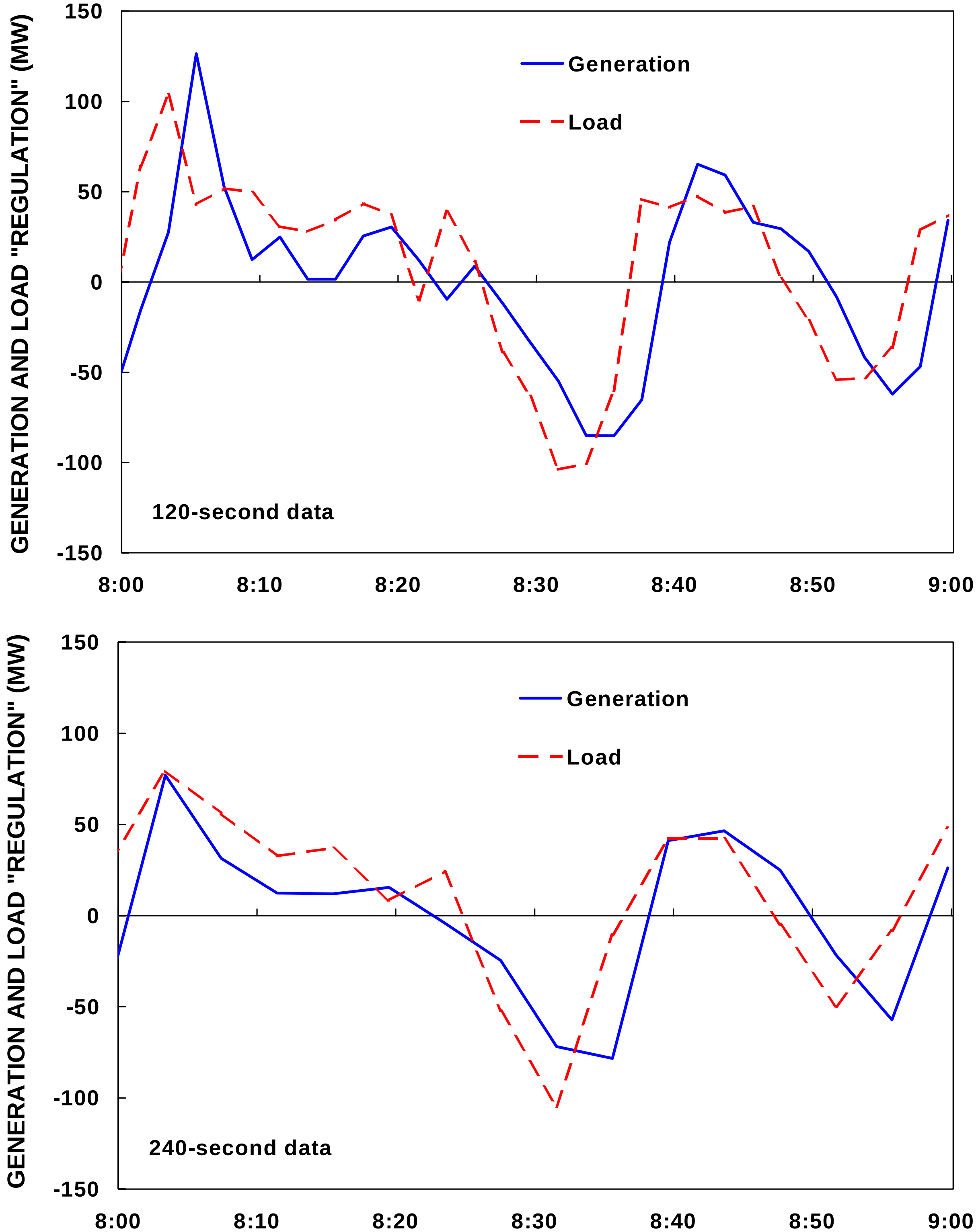

Fig. 2. **Relationship between the regulation components of generation (solid line) and load (dashed line) for large system 1 with 120-second averages (top) and 240-second averages (bottom).**

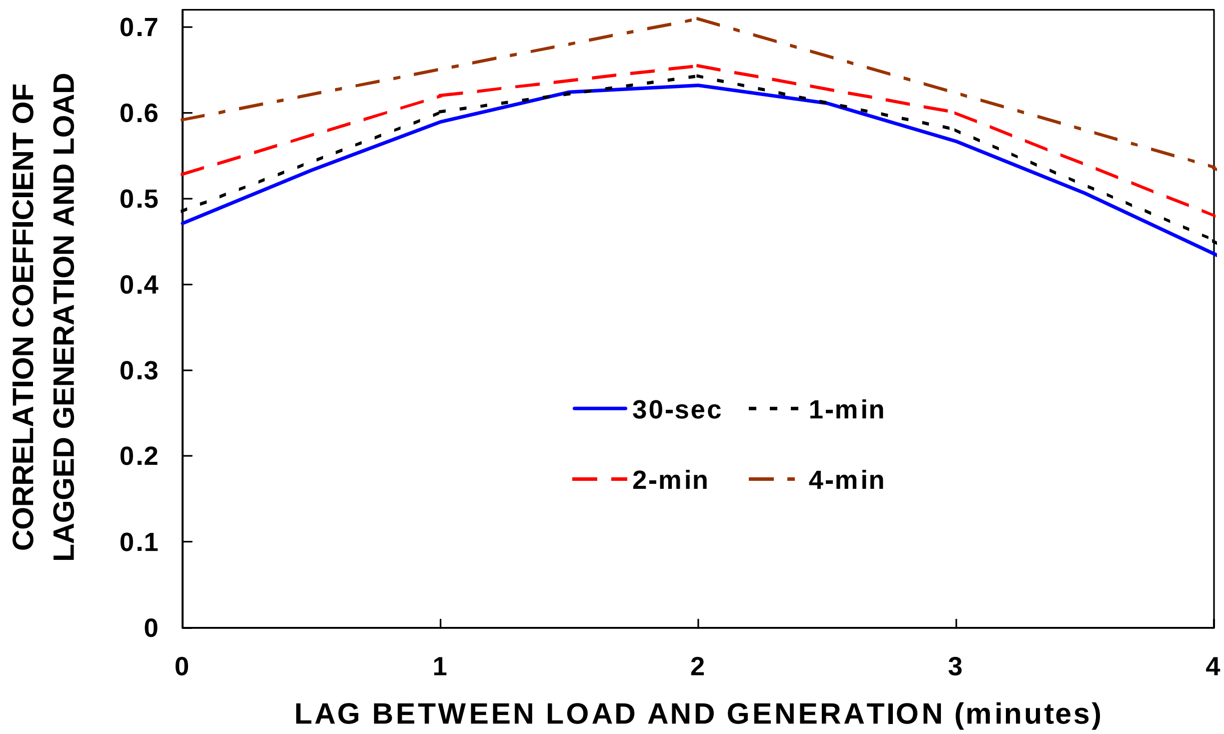

Fig. 3. **Correlation coefficient between generation and load regulation for large system 1 as a function of the time-averaging period and the lag time between load and generation.**

correlation coefficients are 0.63 for 30-second averages and 0.66 for 2-minute averages.* Thus, the observed 2-minute displacement between generation and load seen in Figs. 1 and 2 is confirmed by the correlation coefficients shown in Fig. 3.

Finally, we ran regression models of the form:

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

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, with an R^2 of 0.44, shows that generation is not a function of current load. However, generation strongly and positively depends on loads one, two, and three minutes ago.#

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*It is not possible to calculate the correlation coefficient with a 2-minute lag using the 4-minute data.

#An R^2 of 0.44 means this model explains 44% of the minute-to-minute variations in generation regulation.

These results suggest that generation follows load fluctuations at one- or two-minute averages with a lag of about two minutes.

3. 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 these 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 two 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 one, two, three, and four minutes ago. Table 1 summarizes the model parameters. According to this model, generation is three times more responsive to load one minute ago that to present load (compare the coefficients 0.203 to 0.069) and almost five times more responsive to load two minutes ago (coefficient of 0.325). These results differ from those obtained with data from the other large system in only one respect: in the other system, generation was largely independent of current load.

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

Variable name	Coefficient	t-statistic[a]
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]A t-statistic greater than 2 means that the coefficient is statistically significant at the 5% level or better.

4. LARGE SYSTEM 3

This control area provided data for one 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 (Fig. 4). 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 vs 0.4 to 0.5). In addition, current load is four times more important in explaining generation movements than are past values of load.

5. SMALL SYSTEM

The fourth system from which we obtained date differed substantially from the first two systems 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.

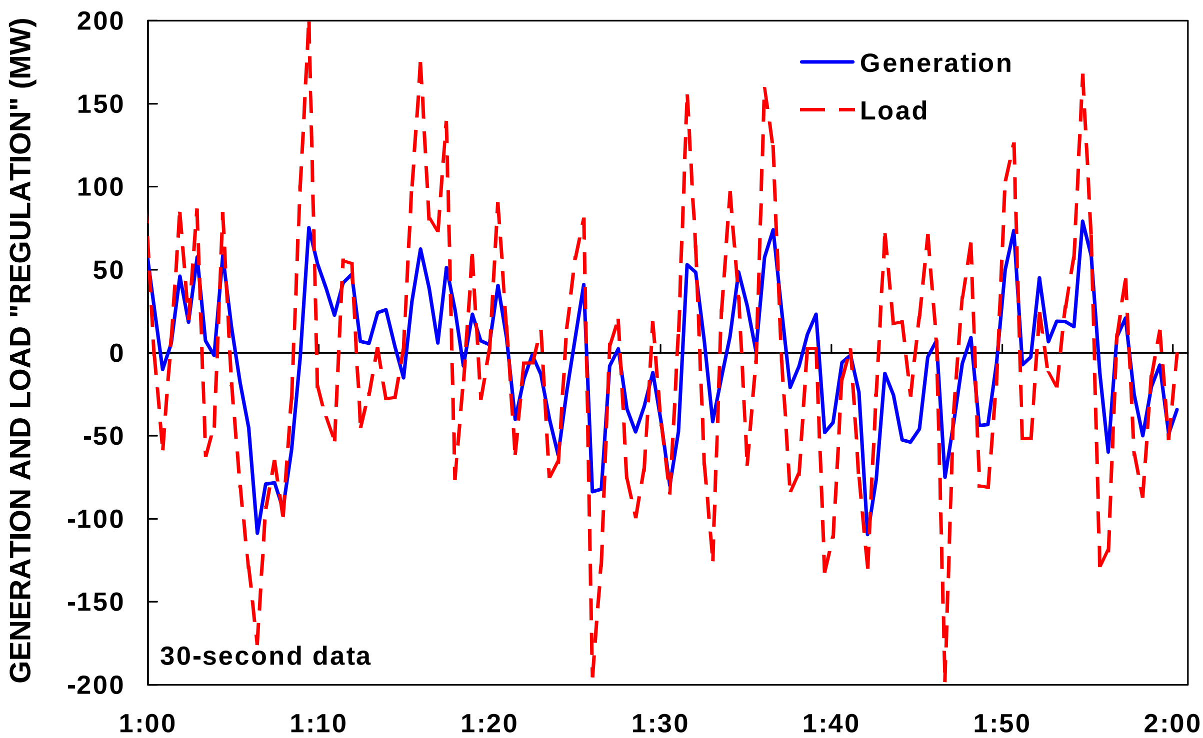

Fig. 4. **Relationship between the regulation components of generation (solid line) and load (dashed line) for large system 3.**

This system differs from the third large system 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 four minutes instead of the two minutes observed for the two large fossil-based systems. As shown in Fig. 5, the regulation component of load for this small system crosses zero 16 times during this 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 (Fig. 6). 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 one-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 nine minutes. In other words, generation follows load with a much longer lag for this system than for the two large systems.

6. CONCLUSIONS

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 paper addresses that question 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 one or more days on total generation and load. We analyzed these data to see how quickly and with how much lag generation follows load. These results tell us nothing about how rapidly generation *can* or *should* follow load. They do tell us how rapidly generation *does* follow load.

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).

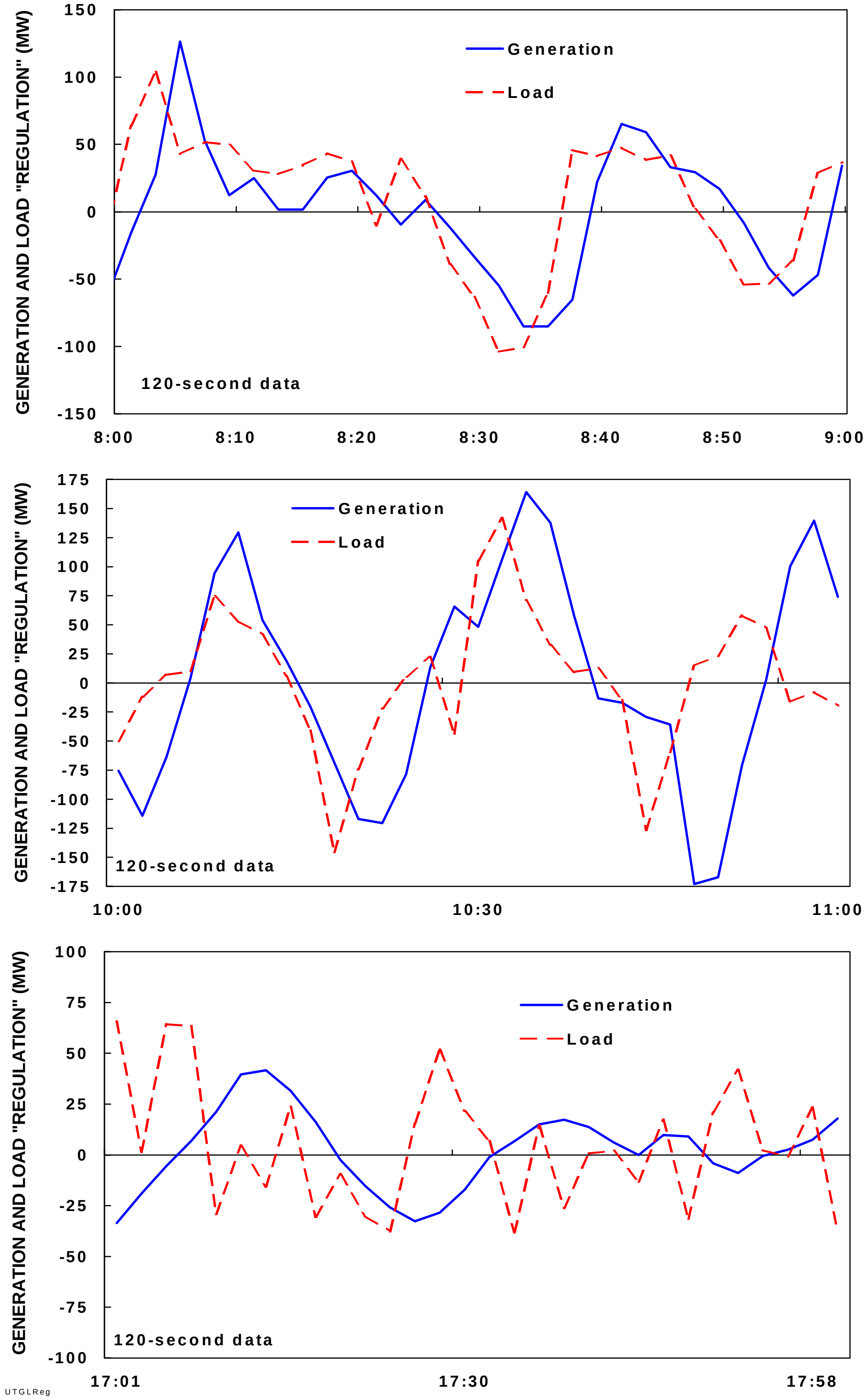

Fig. 5. **Relationship between the regulation components of generation and load with 2-minute averages from large system 1 (top), large system 2 (middle), and the small system (bottom).**

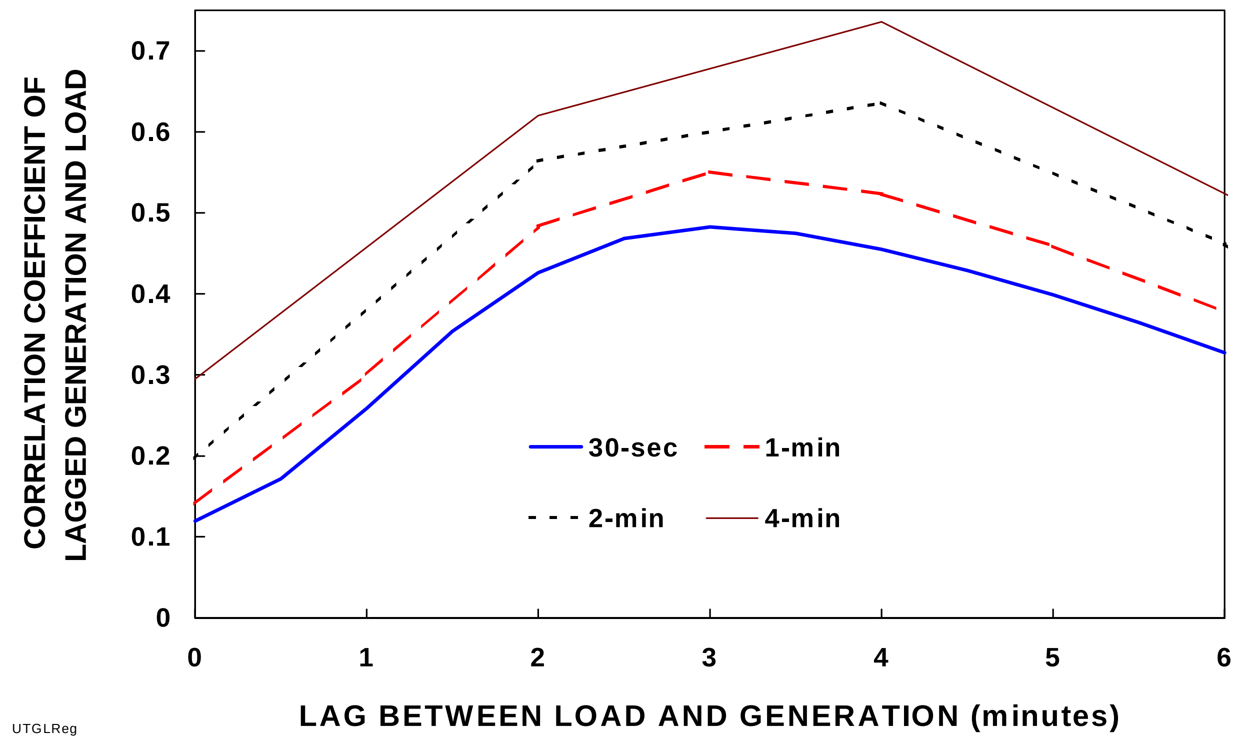

Fig. 6. **Correlation coefficient between generation and load regulation for the small system as a function of the time-averaging period and the lag between load and generation.**

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 one to two 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.

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