Impact of Signal Delay Uncertainties in Open Communication Networks on Load Frequency Control

E. Nobile　　S. Bhowmik　　K. Tomsovic　　A. Bose
School of Electric Engineering and Computer Science
Washington State University
Pullman, WA 99164 USA

Abstract: The need of developing a widely distributed and well interconnected communication system for managing competitive markets for ancillary services, such as load following and frequency control, has brought to light new issues related to the reliability, and sometimes to the security, of power systems. Signal delays, in such a communication system, are becoming almost physiological. The delivery time of a signal packet a generator receives from the center may become uncertain due to these delays. We intend to show how anomalous signals may impact frequency response and to propose some changes to improve the system performance.

I. INTRODUCTION

In the last few years, several attempts have been made to make the ancillary service markets competitive. A free market is now available in many areas for some of these services. These services act as a precursor for a number of new issues arising in the operation of power systems. Competition in load following or frequency control markets brings along the need for a well-developed communication system with the possibility to monitor customers and offer enhanced services. The importance of such a communication system is also underlined in the recent NERC's Policy 10. One of NERC's requirements is real-time voice and data communication that every supplier has to maintain with the operating authority at the center [1]. The supplier must be able to respond to the instructions from the authority, and the authority must be able to monitor the performance of the supplier.

The new set of guidelines requires a paradigm change in the communication system to support the required set of services. Several proposals have been made, such as building on the existing communication system, offering services via the Internet or investing in a whole new infrastructure that primarily caters to the power system. Common to these approaches will be a sharing of communication resources and an opening of the existing closed and centralized links to a more distributed and open infrastructure [2]. Hitherto communication delays, malicious signals, and so on, were not a prominent problem due to the vertically integrated structure of utilities and their use of dedicated links for communication. A widely distributed and interconnected communication system carries inevitable signal delay and other data problems.

Load following and frequency control are normally provided through Automatic Generation Control (AGC). Recently, the possibility of realizing a bilateral market for the provision of these services has arisen. In this case, a customer is allowed to enter into bilateral contracts directly with a supplier provided there exists a communication channel connecting them [3]. In both situations, a certain number of generating units receive an input, in the form of packet of data, from either the center for the AGC or from the customer for the bilateral market, through one or more communication channels, to adjust real power output accordingly. In the United States, the units receive one input around every four seconds. Due to the delay incorporated by the communication network, the delivery time of the signal packet is uncertain. This uncertainty can compromise the generator performance and, consequently, the system response. In the worst case, it can also affect system stability.

In this paper, possible performance problems related to signal are investigated. Some improvements and modifications to the communication system are proposed to help mitigate such problems.

II. IMPACT OF ANOMALOUS SIGNALS ON FREQUENCY PERFORMANCE

As a test model for the AGC, consider a system of three control areas (CA), with two, three and four generators respectively. Both generators in the first CA are under AGC, while two and three generators, respectively, are under AGC in the second and third CAs. The model for AGC is the classical one [4] in which we are not considering any bilateral contract between customers and suppliers. Further, assume that the physical infrastructure for the communication system is a distributed and shared medium with digitized signals being sent from the AGC. Finally, assume that the network may carry packets other than the AGC signals.

Fig.1 shows the system frequency and the power output of the first generator in CA1 in the ideal scenario in which all generators under AGC are receiving the signal without any delay, i.e., every 4 seconds. Traditionally, most AGC simulators have been modeled along these guidelines. With this ideal performance in mind, attention is concentrated on various anomalous signal delays pertinent from the system operator point of view. Similar delays to what we present in the following for the system operator, are liable to occur in particular channels for individual generators. Specifically, we characterize the delays as one of the following [2]:

- Constant delay
- Random delay

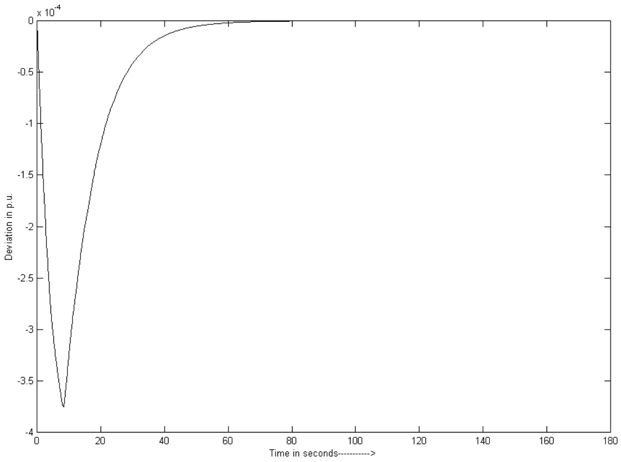

Fig. 1 Frequency Response with No Delay

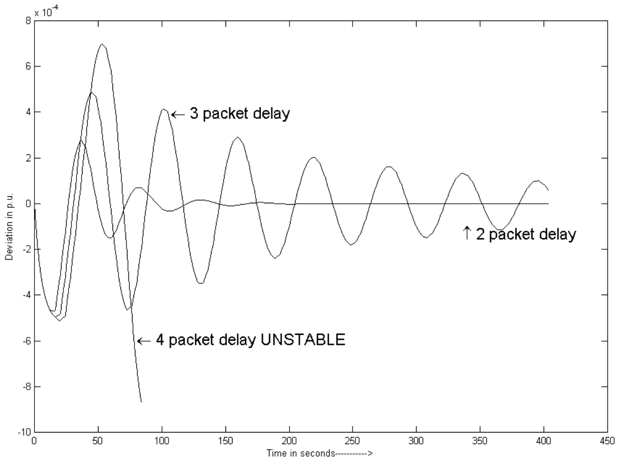

Fig. 2 Frequency Response with Constant Delay

- Exponential delay

These cases apply equally to both packet switched (i.e., Internet) and virtual circuit switching network (i.e., dedicated communication infrastructure for power systems). In the following, each of these types of errors is simulated.

Case 1 - Constant delay

This problem can occur in heavily congested networks or in the case of slow links. This situation arises due to the service time and buffer size required by routers. Typically, if a router is overburdened it tends to drop the packets (also called blocking mode), which in turn requires a retransmission of the packet inducing constant delays. Various protocols for data transmission are susceptible to slow links and induce constant delays in order to compensate for these slow bottlenecks. Only, those cases where the delay occurs at the system operators end (i.e., all the generators experience the same delays in the respective CA) are detailed. It can be shown that delays in CAs other than the one containing the load variation will not adversely affect the system frequency response.

A constant one-packet delay does not meaningfully affect the frequency response. As shown in Fig.2, increasing the delay causes the frequency response to worsen. The system remains stable, although slow to reach the steady state, until the constant delay reaches a four-packet delay. The delay that leads to instability is a function of the particular system.

Case 2 - Random delay

This particular case is motivated by the importance of communication security and fault tolerance for the power industry. In a completely open and competitive market, malicious intent and anomalous disruptions in the communication network is ineluctable. Malevolent organizations or individuals can simply induce bad data by capturing and replaying packets at random intervals. Alternatively, an antagonist could create harmful data packets and send them to the generating company. Alternatively, this scenario could represent Byzantine type network failures in which the communication system fails and cannot be detected or randomly fails and recovers. The result is a random sequence of packets arriving at the generator units.

In these simulations, each individual generator receives independent random packets. Fig.3 shows the scenario, which included a window of random data packets, followed by a recovery phase, depicting Byzantine failure with full recovery. As can be seen the system stabilizes following the recovered phase. This shows that even if the communication system behaves randomly full recovery within acceptable limits of performance can be reached when the anomalous situation is detected in a reasonable time frame.

In contrast, Fig 4 shows the scenario with a Byzantine failure without recovery or alternatively continuous malicious attacks.

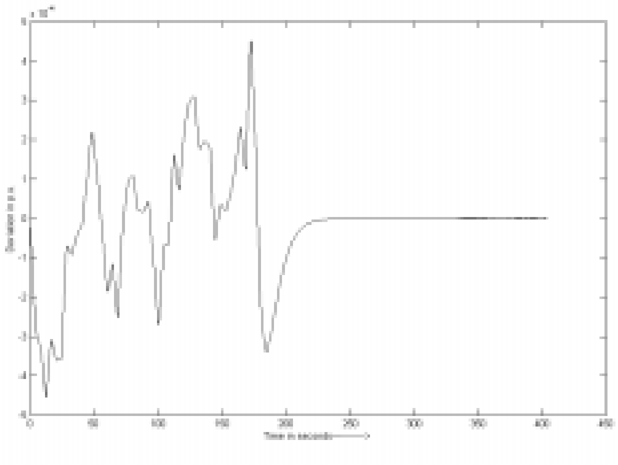

Fig. 3 Frequency Response with Random delay
(Byzantine failure with full recovery)

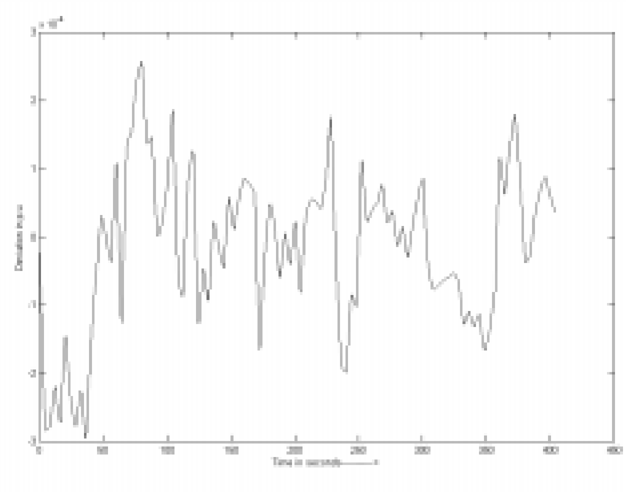

Fig. 4 Frequency Response with Random delay:
(Byzantine or malicious failure without recovery)

In this case, the system is unable to recover. The frequency randomly oscillates around the desired operating point. In some cases (not shown here), depending on the distribution of the randomness, response can become unstable.

Case 3 - Exponential delay

The final case assumes that the number of packets injected at the start node, at any instant of time, is Poisson with parameter λ. If one models the network as a lumped entity, specifically as an M/M/n queue, the delay is approximately an exponential distribution. An M/M/n queue is one in which the arrival rate is Poisson, the processing time in the queue is exponential and there are n servers processing the data packets [2]. Further, assume the situation that blocking never occurs (true for a very large buffer size and low traffic). This situation is akin to the normal low traffic situation. This case is design specifically to determine whether shifting from a dedicated network to a distributed network system will cause any new contingencies of concern.

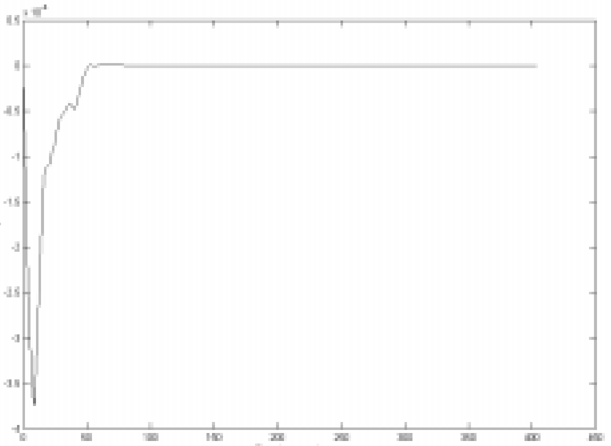

Fig. 5 Frequency Response with Exponential delay

As can be seen from Fig 5, there are no marked changes to the frequency response. This is not surprising as the network has no serious anomalies and hence does not induce any significant delay in our system. Still, this is not true, in general, since the performance, under these circumstances, is system dependent and situation where even these delays cause performance degradation may occur.

III. PREVENTIVE MEASURES

Data transmission regarding electric power control is clearly high priority traffic, which requires very stringent quality of services (QoS). The system used in our simulation is robust and can tolerate, without instability, up to three- packet constant delay. Real systems may or may not endure such a delay. The QoS is strongly system dependent and related to the typology of the signal yet it has to be guaranteed. There are a variety of approaches for dealing with the problem.

The most obvious approach is to carefully design the communication system. Whether it is more opportune to offer the service via the Internet or to build a dedicated communication infrastructure for power system is still an issue. The advantage of using the Internet lies mostly on the possibility to utilize existing infrastructures. On the other end it would be easier to avoid Byzantine or malicious events using a new infrastructure that primarily caters to the power system. One could also use the power line in the Low Voltage Distribution Network for communication services purposes [6]. Utilizing power line carriers (PLC) may represent a compromise between the above solutions, however the PLC method suffers from a number of potential problems mostly related to the quality of signal transmission.

Naturally, migrating to a better communication backbone infrastructure that consists of fast and redundant links with fast routing will lessen the possibly of delays. One may expect the use of a standardized fully distributed and shared network will enable the suppliers and customers to offer a variety of ancillary services requiring communication for coordination. This perhaps could be based on a stable set of middleware consisting of a fault tolerant abstraction able to detect failures, and perhaps, coupled with an intrusion detection system (IDS) to spot malicious intent. The system operator has to ensure a high level of availability, dependability and security, as the system is very susceptible to any anomalous behavior at its end [5]. This can be achieved by keeping several layers of redundancy and a strong data security policy. Nevertheless signal delay remains an issue under study, even the asynchronous transfer mode (ATM) transmission, which may guarantee the high QoS of power system communication, has defects [7]. Further, it is not possible based on our analysis to date to state explicitly requirements on delay statistics that could guarantee stability. Such investigation is on-going.

Still, some simple strategies will help mitigate potential problems. Clearly, some form of encryption and authentication will be required on all the packets sent to individual generators. Time stamping of the packets by some simple mechanism of sequence numbers or by maintaining a virtual clock at all nodes should protect one against random packet distributions. As a method of control, a generator could, for example, simply ignore signals arriving with an old or out of sequence time stamp. In many cases, ignoring control commands might be preferential to responding to an old command. For this reason a retransmission strategy is not recommended.

The option of shifting to manual control should be incorporated in situations where the system does not recover. In case of malicious failures with no possibility of recovering, corresponding to the response seen in Fig. 4, the system operator may need to switch from automatic to manual control to help restore the system response. The tools need to be developed to allow such actions. There may be other possibilities for stabilization by isolating offending signals or shifting to agree upon control measures in the case where a communication failure is indicated.

IV. CONCLUSIONS

In the near future, power systems will inevitably face contingencies similar to those presented in the previous section. As shown, a problem in the communication system can compromise the system integrity. Most often the anomaly slows down the system response, but in the worst case, it can lead the system towards instability or other unacceptable behavior. Subsequent investigations will be directed at situations where uncertainty occurs in particular channels for individual generators. Still, it is likely that these errors will have detrimental effects similar to those that have been seen here for the system operators. Of particular interest may be the situation when the anomaly occurs on the communication channel connecting a generator to a customer for the bilateral provision of load following. Furthermore, the scope for competitors to jeopardize other individual power entities is much greater, even if the disruptions are unintentional, and these effects must be addressed.

The ongoing deregulation process in the electricity market is creating a number of new challenges. One of the most urgent is the necessity to develop a widely well-distributed and interconnected communication system that can help the power and ancillary service markets to become more competitive as well as to offer new and improved services. Such a communication network inevitably carries some issues related to uncertain signals both in timing and quality.

REFERENCES

[1] North American Electric Reliability Council, NERC Operating Manual, Policy 10, available at ⟨http://www.nerc.com⟩.

[2] D. Bertsekas and R. Gallager, *Data Networks,* Prentice Hall, New Jersey, 1992

[3] E. Nobile, A. Bose and K. Tomsovic, “Bilateral Market for Load Following Ancillary Services”, *Proceedings of the IEEE-PES Summer Meeting*, Seattle, July 2000.

[4] A.J. Wood and B.F. Wollemberg, *Power Generation Operation and Control*, John Wiley & Sons, New York, 1984.

[5] Z. Alaywan and J. Allen, “California Electric Restructuring; a Broad Description of the Development of the California ISO”, *IEEE Trans. on Power Systems,* vol. 13, no. 4, pp. 1445-1452, November 1998.

[6] J. Newbury and W. Miller, “Potential Communication Services Using Power Line Carriers and Broadband Integrated Services Digital Network”, *IEEE Trans. on Power Delivery,* vol. 14, no. 4, October 1999.

[7] H. Doi, Y. Serizawa, H. Tode and H. Ikeda, “Simulation Study of QoS Guaranteed ATM Transmission for Future Power System Communication”, *IEEE Trans. on Power Delivery,* vol. 14, no. 2, pp. 342-348, April 1999.

BIOGRAPHIES

Emilia Nobile received her “laurea” with honors from Politecnico di Bari, Bari, Italy, in 1997. In 1998 she was awarded a scholarship from Politecnico di Bari to spend one year as a research scholar at Washington State University. She is presently a Ph.D. student at Washington State University.

Sudipto Bhowmik received the B.E. from RVCE with distinction in 1996. He worked in Asea Brown Boveri from 1996-1998.Currently he is pursuing his Masters in Washington State University from 1998.

Kevin Tomsovic received the BS from Michigan Tech. University, Houghton, in 1982, and the MS and Ph.D. degrees from University of Washington, Seattle, in 1984 and 1987, respectively, all in Electrical Engineering. He is currently an Associate Professor at Washington State University. Visiting university positions have included Boston University, National Cheng Kung University, National Sun Yat-Sen University and the Royal Institute of Technology in Stockholm. He held the Advanced Technology for Electrical Energy Chair at Kumamoto University in Japan from 1999-2000.

Anjan Bose (M’68, SM’77, F’89) received his Btech (Hons) from the Indian Institute of Technology, Kharagpur in 1967, MS from the University of California, Berkeley in 1968, and Ph.D. from Iowa State University in 1974. He has worked for the Consolidated Edison Co. of New York (1968-70), the IBM Scientific Center, Palo Alto (1974-75), Clarkson University (1975-76), Control Data Corporation (1976-81) and Arizona State University (1981-93). At present, he is the Distinguished Professor in Power Engineering and Dean of the College of Engineering and Architecture at Washington State University.