haviors we analyzed are another kind, where power market power may not be needed. The price spikes in this case are caused by the "joint" efforts of supply bidders on the Prisoner's Dilemma psychology. The unilateral move of one particular bidder may not cause price spikes. In fact, supply bidders have an advantageous position in this game since they intend to use 5–10% of their capacity at very high prices to control the market clearing prices. If they lose they may lose awards only 5–10% of their total capacity. However, if they do cause a price spike, they get rewards 95–100% of their total capacity at very high prices. This kind of behavior is legal under the current bidding rules. We believe this is a problem with the bidding rules and market mechanisms rather than market power.

3) Although this type of gaming behavior may be considered by some economists as normal so that economic signals can be sent to investors, the price may be too high since we believe gaming and price spikes contributed partially to the collapse of the California market. Furthermore, gaming and price spikes may exist even when supply is relatively abundant. Therefore, it is important to improve the current bidding rules. The first author with his colleagues has proposed a new bidding rule based on block pricing and bidding, upon which gaming and price spikes can be significantly reduced. This work is under review by the Power Engineering Society.

Discussion of "Analysis of Load Frequency Control Performance Assessment Criteria"[1]

Nasser Jaleeli and Louis S. VanSlyck

Nasser Jaleeli and Louis S. VanSlyck [Priority-Based Control Engineering (PCE), Dublin, OH]: We thank the authors for presenting the concepts and derivations we had made in the paper's reference [6] with notations that are more familiar to statisticians, such as $E\{.\}$ instead of $AVG\{.\}$, $E\{[.]^2\}$ instead of $RMS^2\{[.]\}$, or $P\{|.| \leq \gamma_i\} \geq 0.9$ instead of $|.| \leq \gamma_i$—90% of the time or more. The extensive analytical work reported in [6] for efficient and equitable interconnected operation could have proven fruitless had we failed to communicate it within NERC. Despite the fact that our notations were less condensed than the formal statisticians' notations, it took from 1991 to 1997 working with the NERC Performance Subcommittee (PS) to affect our extensive findings to the benefit of the power industry.

We are happy to find the proposals made by the authors on the third page of the paper are identical to those we made in [6]. Unless otherwise stated, in what follows all referenced figures, equations, etc., are from [6].

The NERC Operating Committee had charged the PS to develop a new set of Control Performance Standards (CPS), reasonable compliance with which would maintain the frequency in each interconnection as acceptable as had recently been experienced. We translated year long data sets to the RMS of *T-minute sliding average of frequency error*. Fig. 3.3 on page 3-6 shows the experienced frequency in three North America (NA) Interconnections for $T = 1$ to 60 min. Throughout Section III, we advocated that the frequency target for CPS should include values of T that are much larger than one minute. We set (5.3) on page 5-2 as the interconnection target. The authors' proposed interconnection LFC performance criterion C is identical to (5.3), although (2) of the paper is missing the subscript n for ε^2.

The paper proposes monitoring the correlation of *n-sample* averages of ***ACE*** and frequency error. It then proposes obtaining the expected value of the product of these two variables over a targeted interval, and then sets the result equal or less than $-10\ B_i\varepsilon^2$ to construct criterion $\boldsymbol{C_1}$ in (3). This is simply a special case of the conclusion we made in (5.24), page 5-15, where there is no requirement that frequency bias must be constant. As proven in Section V, and explicitly and repeatedly stated on pages 5-10, 5-15, and 6-1, to satisfy (5.3), it is sufficient for every control area to meet (5.24). Further, if no control area overachieves (5.24), then meeting (5.24) by every control area becomes necessary if the interconnection is to satisfy (5.3). As a side comment, correlation between two variables is different from the expected value of the product of the two variables.

Throughout [6], we presented data, warnings, statements, discussions, conclusions, etc., that current practice and the AGC coding logic presently used by many control areas yields a frequency error that is "dependent" on time. A few of our statements are presented in the following.

Referring to curves obtained for frequency error in three NA Interconnections in Fig. 3.3, the first full paragraph on page 3-6 states:

> "These curves do not fall at the rate of $1/\sqrt{T}$ and, hence, they show there is structure in frequency error. Specifically, they show frequency error is statistically dependent on its trend over the past several tens of minutes."

Figure 3.4 on page 3-7 presents average hourly frequency error for each hour of the week over 52 weeks in the three interconnections. The first paragraph on page 3-8 states:

> "Figure 3.4 shows that frequency error has a very strong tendency of being negative during load pick-up hours, and positive during load drop-off hours. It can be concluded that during these hours there is a significant level of statistical dependency among ***ACE***s. This is a result of areas having more or less the same daily load pick-up and drop-off, and of ill-practice in generation control in at least some areas."

Table 3.1 on page 3-9 presents the RMS of the experienced frequency error clock-hour average for each hour of the day over a period of 12 months. These values clearly show the time dependency of frequency error in each of the three interconnections. Further, the last full paragraph of page 3-5 states the following. The analysis of frequency error by others indicates: "the bell curve peak shifts to the low frequency side when the pdf is plotted for load pick-up hours data, and to the high frequency side when it is plotted for load drop-off hours data. This indicates a structure in frequency error. They conclude that frequency error is statistically dependent on time of day."

Based on the above information quoted from [6] and since it is a reference of the paper, we wonder on what basis the paper assumes that the following occurs.

1) The probability distribution of frequency error and ***ACE*** is independent of time.
2) The state of these variables in one instant has no effect on the state at any other instant.
3) A collection of samples of each of these variables is a set of "independent and identically distributed r.v." (random variables).

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4) The 10-minute, or even longer, average of ***ACE*** in one control area is independent of the same in another control area.

We continue to believe our data analysis reported in [6] and, hence, we see no basis on which any of these assumptions could stand.

In setting target frequency for the above interconnections in Section 3.6, pp. 3-15 to 3-18, we realized that we could provide US control areas with the opportunity of saving hundreds of millions of dollars annually if we provided the highest allowance on the RMS of ***ACE*** several minute average. The larger the allowance, the lesser need for a control area to track load fluctuations, as the fluctuations would be served by the interconnection. This in turn would reduce the need for unit maneuvering in the control area. For realizing the same frequency, however, the highest allowance can be provided if the interconnection can be assured of independence among ***ACE***s. By realizing an ***ACE*** that has no dependency on time of day a control area can make its ***ACE*** independent of other ***ACE***s. An ***ACE*** whose several-minute averages is random, i.e., has negligible auto-correlation in all orders beyond several minutes, could have only a negligible dependency on time of day.

Whenever the dependency of ***ACE***s on time of day becomes negligible, the RMS of T clock-minute frequency error average will decay at a much higher rate than has been experienced. On this basis, we recommended the curves presented in Fig. 3.8, page 3-17, as the target frequency for the Eastern and ERCOT interconnections. They allow a much larger target for clock-minute frequency error average than was being experienced, but provide a somewhat tighter target for longer-term frequency error averages.

We believed, and continue to believe, that at least two points on each of the recommended curves should be used as interconnection LFC performance standards. We recommended one point at 60 min so that audited MWh data, instead of MW data, could be used for measuring each control area's performance. The other point could be in the range of 1 to a dozen minutes.

Some members of PS did not want any CPS to include the effects of metering and other errors inherent in interconnected operation. On this basis, these members rejected the use of audited MWh data in measuring control area performance. Some others, who had concerns about increased unscheduled power flow over their ties, adamantly advocated a CPS that explicitly requires limiting several minute averages of ***ACE***.

Under the above constraints, we recommended that NERC adopt a CPS which would measure the expected value of 10-minute average ***ACE*** times 10-minute average of frequency error. To break the impasse, however, we seized the opportunity and supported CPS_1 and CPS_2. The target for 1-minute frequency average error in CPS_1 is even somewhat larger than the target we had sought. Further, we computed the limit applied on 10-minute average ***ACE*** on the basis of avoiding any additional constraint on a control area whose ***ACE*** is independent of others. Therefore, the resulting L_{10} for all control areas became significantly larger than L_d, the limit imposed by the old A_2, and for most control areas L_{10} became two to four times of L_d. The NERC adoption of CPS_1 and CPS_2 accomplished one major objective we had, that was to provide the power industry with the opportunity of increasing its benefits from interconnected operation by hundreds of millions of dollars annually.

As indicated in Section 7.4.1 pp. 7-4 and 7-5, we believed compliance with CPS_1 and CPS_2 alone would not maintain frequency statistics at the experienced levels. The analysis performed on the frequency realized under CPS_1 and CPS_2 by various members of PS has since verified our concerns. The remedy is not to lower ε_1 by a large percentage or tightening L_{10}. If further deterioration in frequency cannot be tolerated then a CPS, as proposed in [6] and [7], that measures expected value of the product of hourly averages of ***ACE*** and frequency error should be enacted. In such a case, audited MWh data, instead of MW data, should, of course, be used.

Many control areas had a CPS_1 score higher than 180% in all the NERC CPS compliance reports we monitored during 1998 to 2000. Even among control areas that did not much overachieve CPS_2 it was rare to find one with a CPS_1 score of less than 150%. On this basis, as we expected, CPS_1 has no influence on the realized frequency. It is compliance with CPS_2, other non-CPS related NERC requirements, and continued traditional control practices by many control areas that has maintained frequency at the current experience. Without CPS_2, the RMS of all averages of frequency error could grow even further and, hence, we do not support the paper's main conclusion that "CPS_2 criterion provides no additional insight in terms of control performance and the monitoring of CPS_1 suffices."

The authors have analyzed data from different interconnections to construct Table I in the paper. We believe that if they compute RMS for 1 and 10-minute frequency error average, the former will be considerably lower than ε_1, while the latter will be about or higher than ε_{10}. If so, would this finding not go against the assumptions and the above conclusion made in the paper?

The objective of Tie Line Bias Priority-based Control presented in Section VI is to realize, with minimum unit maneuvering, an ***ACE*** that is independent of ***ACE***s in other control areas. We set L_{10} at a value that imposes no additional restriction on control areas whose ***ACE*** is independent of others. If ever control practices make ***ACE***s sufficiently independent of each other, then, as said in the third paragraph of page 6-6, continued imposition (or removal) of CPS_2 would not be an issue.

Publication of this paper encouraged us to reiterate our findings and share the constraints and incentives that led to the adoption of CPS_1 and CPS_2. We wish the authors well in all their endeavors.

Closure of "Analysis of Load Frequency Control Performance Assessment Criteria"

George Gross and Jeong W. Lee

George Gross and Jeong Woo Lee [University of Illinois at Urbana-Champaign]: We welcome the comments and questions of Jaleeli and VanSlyck and appreciate their interest in our work. We begin our response by reiterating the importance with which we view the pioneering work of the discussers [6], [7] and the key role this work played in the research reported in this paper. At the outset, we also need to emphasize that the aim of our paper was to provide a firm analytical basis for the formulation, analysis, and evaluation of load frequency control (LFC) performance criteria. We constructed a solid analytical basis by effectively exploiting the concepts of random processes and probabilistic models to develop the general criteria for LFC performance. The general LFC criterion we formulated using our analytical framework has as special cases the NERC ***CPS1*** and ***CPS2*** criteria. As a

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