Closure of "A Unified Approach to Transient Stability Contingency Filtering, Ranking, and Assessment"

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We are indebted to Professor S. Rovnyak for his appreciation and thoughtful comments. The questions raised in his discussion give us the opportunity to clarify some key issues of the FILTRA technique and, more generally, to elaborate further on the SIME method and its two-faceted approach to transient stability assessment and control. In the following we consider his questions in the same order as they appear in the discussion.

The first three questions refer to the filtering task of FILTRA, achieved by Block 1 in Fig. 1 of the paper.

1) We agree that it might be beneficial to sacrifice reliability for the sake of computational efficiency, especially since, as you correctly observe, many uncertainties may exist about the system parameters and modeling, the system state, and the very definition of the contingencies. Note, however, that some of these uncertainties fade as the system gets closer to real-time operation. Remember also that SIME does not introduce any additional uncertainties with respect to the time-domain program that it drives; of course, a good statistical approach could be more appropriate for handling uncertainties.

More generally, the tradeoff between accuracy and computational efficiency depends on the power system under consideration as well as the operational practices in use. The structure of Block 1 in Fig. 1 may be designed so as to comply with various requirements. For example, reference [15] of the paper uses a two-step procedure, where the first step relies on the classical power system modeling together with a tailor-made ultra-fast transient stability program. Obviously, such modeling and programs, which are found to give sound-though approximate-assessment for the system simulated in [15], would be unacceptable for other power systems (e.g., for the Hydro-Québec one). However, this tradeoff between accuracy and computing performances is not necessarily a real issue. Indeed, contingency filtering is an easily parallelizable process, where computations distributed among, say, "c" computers divide the computing time by almost c; this may allow one to consider as many contingencies as deemed *a priori* interesting without sacrificing to accuracy.

2) We also agree that we could use an adaptive OMIB model to exploit its predictive capabilities, thus speeding up the computations. This may be achieved via the 2-machine equivalent proposed in [1] or via the OMIB derived in the context of the Emergency SIME discussed in 6).

3) Admittedly, in order to discard first-swing stable contingencies one could think of "pure" time-domain simulations without using SIME, thus making it easier to implement. However, an advantage of SIME is that for first-swing unstable contingencies it provides a stability margin which can be extrapolated (or interpolated) with the margin provided by the "ranking-assessment block" (Block 2 in Fig. 1) in order to identify potentially harmful and harmless contingencies and further to rank them within each class. In addition, SIME's stability/instability conditions provide early termination reliable and objective criteria for performing time-domain simulations only during a (usually) very short time period. Finally, observe that avoiding SIME in the first block does not make implementation that much easier, since it is anyhow used in the second block.

To summarize the above discussion, the first block of FILTRA may be designed in a large variety of ways, including statistical (e.g., pattern recognition) techniques, as well as deterministic ones; and among the deterministic approaches, pure time-domain techniques as well. The point is, however, that the FILTRA software aims at achieving a unified approach to contingency filtering, ranking and assessment, i.e., much more than a mere first-swing stable/unstable assessment. Actually, in addition to filtering contingencies, FILTRA ranks multiswing stable/unstable contingencies and assesses the multiswing unstable ones in terms of margins and critical machines; it thus paves the way toward systematic and near-optimal control, i.e., stabilization procedures [see 6)].

4) You are right, contingencies declared to be "stable" and discarded in the first block are considered to be multiswing stable for a clearing time of 95 ms simulated during the maximum integration period.

5) With reference to your question about cases for which the "traditional margin," expressed by (A.1), p. 442, does not exist, we, indeed, use the "time to instability" as a handy severity indicator for ranking contingencies. Another indicator could of course be the ISGA that you propose.

Note that in the absence of the traditional margin, the time to instability is defined as the time where the "distance" between the Pe and the Pm curves reaches a minimum, i.e., when $P_a > 0$, $\dot{P}_a > 0$ (see [1] and [16]). Thus, the time to instability is defined on the basis of objective criteria, similar to those used when a traditional margin exists. On the other hand, declaring loss of synchronism when the angle difference between any two generators exceeds 360°, as you suggest, is a pragmatic criterion, largely depending on the specifics of the power system; for other systems, this angular difference could be 180°; it could be combined or not with a criterion involving generators' speed.

6) The potential benefits of using the information provided by FILTRA (margins and critical machines) for preventive control are shortly sketched in Section III-D (pp. 440–441) of the paper, where this information yields techniques able to stabilize unstable contingencies, considered separately or simultaneously. The paper addresses generation shifting techniques, although load shedding could also be considered. Note that the derived countermeasures are near-optimal with respect to the amount of generation to shift and the choice of generators involved. Nevertheless, no matter how optimal the resulting control actions, it is questionable whether the operator would decide to trigger them, unless the occurrence of a contingency is imminent.

An alternative to the preventive control actions suggested by the above "Preventive SIME" is the use of remedial control actions, as you point out. This question is addressed by the "Emergency SIME" (ES). A main difference with the "Preventive SIME" is that ES relies on real-time phasor measurements that it uses in order to:

1) predict whether the resulting OMIB is driven to instability;
2) if yes, to assess how unstable the system is going to be (in terms of the corresponding margin) and when ("time to instability");
3) assess how much generation to shed and from which generating plant(s), in order to stabilize the case;
4) continue monitoring the system to assess whether the control action already triggered in sufficient or more generation should be shed.

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This four-step procedure yields a closed-loop control which, with modern technology facilities, takes about 350 to 450 ms [16]. Note that the contingency which actually has occurred is not supposed to be known; only its effects are reflected through the incoming measurements. In addition, ES is also free from modeling and parameters uncertainties.

The ES has been simulated on real-world power systems to protect dedicated power plants: Churchill falls of the Hydro-Québec power system [1], Itaipú in the Brazilian South–Southeast power system [2], and the WSCC system [3]. It has always worked successfully, provided that the time to instability exceeds 350 to 400 ms. And although further improvements are still needed, ES shows to be an effective approach to closed-loop transient stability emergency control.

7) Finally, we seize the opportunity of this discussion to mention that in the right-hand column of p. 439, Fig. 3 has mistakenly been referred to as Fig. 1(a).

We thank again Dr. Rovnyak for pointing out interesting aspects of our work. Also, we would like to express our appreciation to the reviewers for their valuable suggestions.

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Discussion of “Gaming and Price Spikes in Electric Power Markets”[1]

Deb Chattopadhyay

Deb Chattopadhyay (Charles River Associates, New Zealand): I would like to commend the authors for presenting a simple and transparent exposure to a complex subject. The analytic framework provides an interesting premise that could very well be extended potentially in many directions including transmission, reserve, entry decisions, etc. However, the following two are of particular interest to me given the elegant economic theories that already exist, but have not been exploited to my knowledge in the context of electricity markets.

8) *Issue of Uncertainty*: Although this issue has been alluded to in the paper, it would be interesting, for example, to formally analyze how the noncooperative game solution is affected by various uncertainties that directly or indirectly affect the pay-offs. In fact, one can perhaps argue at one extreme that uncertainty itself explains the random price spikes in the presence of a steep supply curve. Although, an extension of the prisoner’s dilemma to explicitly take into account the impact of temperature, generator outage, etc., would reveal some useful insight, rather than picking such an extreme case.

9) *Information Asymmetry*: The other area, albeit more theoretical, is to consider the specific information content of the generators. Put differently, the current analysis implicitly assumes all the generators effectively have same information content. This is more often untrue—at least the presence of long term contracts, and possibly a lot more information is available to generators to be able to make a call on withdrawing capacity in a particular hour, e.g., generators may offer a portion of capacity at extremely high price when certain units of its competitor are on planned/forced outage aggravating an already tight situation. The presence of vesting contract for certain generators is another example—depending on the nature of the contract, a generator may be more or less indifferent to price spikes leaving others to take advantage of the situation.

Incidentally, I did not follow why the following comment is made in the paper “*As we explain, this gaming behavior can take place independently of market power …*” I would think that strategic withholding of capacity to raise prices above competitive level is a sure sign of market power. It seems the generators in California (and typically in most markets elsewhere) do possess such market power, and the issue really is whether they actually *exercise* such power, or whether the subject price spikes, in fact, occurred due to genuine capacity shortages. It may not be out of context to repeat that price spikes are not necessarily bad things because they may signal need for future investments in peaking generation capacity, transmission, or DSM, which indeed is a major purpose of spot prices. A steep supply curve could very well be indicative of new peaking entry opportunities, but I believe the (somewhat tenuous) argument in Section V is that it was in fact indicative of strategic withholding—again this is yet another area where further elaboration by the authors would be appreciated.

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Xiaohong Guan (**Xian Jiaotong University, China**), **Yu-Chi Ho and Dave Pepyne (Harvard University, USA)**: The authors appreciate the discusser’s interests in our paper and many valuable comments. We have the following remarks regarding the discusser’s questions and comments.

1) Uncertain factors including loads, temperature, etc., would cause the bidders to guess and game. This is the main idea of the paper. This kind of gaming behavior is so called opportunistic collusion and may not be persistent. It is often caused uncertain externalities, e.g., the outage of one or more units, as the discusser mentioned. Although in our paper, we gave a theoretical threshold to switch bidding strategies based on the subjective probability that the bidders believe. However, it is very hard to know the other bidders’ profits in Table I. Therefore (13) is only theoretically meaningful. The quantitative influence of uncertainties on bidding strategies is our work of the next step.

2) We agree the information asymmetry may give some bidders advantages so that some may game more often than others, especially when they have market power. However, the gaming be-

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