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## 1 PROLOG

I appreciate the opportunity to submit testimony for the technical conference. I have attempted to address some of the concerns raised by the commission. My submission does not address all of the points raised but focuses on a few areas for which understanding is incomplete and for which industry debate in North America is only in a nascent form.

These comments are based on my experience and research. I have provided some limited references, but the ideas and opinions expressed here are solely mine.

## 2 SYNCHRONOUS INERTIA (AS AN ERS)

### 2.1 NOT NECESSARILY REQUIRED

There has been some good work and discussion in the industry, especially from the NERC ERSTF, on synchronous inertia and methods to maintain adequate amounts. In today's large interconnected systems, as they are presently designed and operated, there is a requirement for some inertia. Minimum Synchronous inertia reserves (SIR) have been identified as an important metric, and some ideas for mandatory minimum levels of inertia have been proposed.

But, it is important looking forward to recognize that there is nothing intrinsic in power systems that makes inertia indispensable. All inverter-based inertia-less power systems have been built. (I participated in one 20 years ago[1]).

Most concerns about maintaining inertia stem from limitations of the present system, including particularly protection and control. These are absolutely legitimate concerns, but care must be exercised to avoid making policy based on the premise that such limitations cannot be economically overcome.

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[1] N.W. Miller, R.S. Zrebiec, R.W. Delmerico – GE, G. Hunt – GNB , Darrel Pierce – Metlakatla P&L; "Battery Energy Storage System for Metlakatla Power and Light," International Conference on Batteries for Energy Storage, San Juan, PR; 7/95

## 2.2 NOT ALWAYS BENEFICIAL

Included in much discussion of inertia is a presumption, only sometimes explicitly stated, that inertia is always good for the system. And, by corollary we must find ways to “cope” with declining systemic inertia and with individual inertia-less resources. This is an unfortunate oversimplification.

For example, inverter-based resources, like wind and solar generation, tend to have superior transient stability characteristics compared to synchronous generation[2]. This has some important practical implications. Export of power from remote locations in a grid (e.g. remote wind or fossil plants) will tend to have higher transfer limits with today’s technology inverter-based generation compared to synchronous machines. In simple terms, today’s inverter-based resources are less constrained and more tolerant of disturbances that will cause synchronous machines to either loss synchronism or to exhibit unacceptable oscillations. This means that more power can often be delivered with the same transmission infrastructure; a significant economic benefit.

## 2.3 BETTER BEHAVIOR IS POSSIBLE

Inverter-based resources offer the possibility for a wide range of beneficial behaviors. In this discussion, it is important to distinguish what is technically possible with inverter-based generation from what is commercially available today. With few exceptions, wind and solar generation on the bulk power system today requires an established grid frequency with a minimum system strength provided by synchronous generation. This is a key element of today’s requirement for a minimum commitment of synchronous generation. There are a number of good engineering and economic reasons why most utility-scale inverters are designed with this constraint. Reasons for the present practice include: good current sharing and natural coordination between parallel inverters, good use of converter current ratings, and good transient stability (as noted above). To date, there has been little technical or economic motivation for design of so-called “grid forming” inverters. This is changing, as a fraction of applications and operating conditions emerge in which the dependence on synchronous generation is problematic. Proven concepts exist for addressing these problems, one class of which is so-called “virtual synchronous machines”. Simplistically, these inverters act like synchronous machines. It is an attractive and conceptually appealing idea. The industry largely is capable of making inverters this way today. But some caution is warranted: blindly demanding that inverter-based generation mimic synchronous machines may add unnecessary costs and may leave potential benefits untapped. For example, synchronous machines can typically deliver roughly 3 to 4 per unit short circuit current. Making inverters capable of delivering this much current will add cost that might not produce reliability benefits. Another aspect relates to the previous paragraph: synchronous machines can be less stable.

The point of these observations is that, as an industry, we have been “stuck” with synchronous machines, for better or worse. That doesn’t mean that the behavior of synchronous machines is the best we can do. Inverters offer degrees of design flexibility that present an opportunity to do better. *It would be a mistake to create rules or policy that entrenches today’s synchronous generators as the standard of performance*.

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[2] Miller et al, Western Wind and Solar Integration Study Phase 3 – Frequency Response and Transient Stability, NREL/SR-5D00-62906 December 2014. (https://www.nrel.gov/docs/fy15osti/62906.pdf).

### 2.4 RELIABILITY OBJECTIVES (SHOULD DRIVE ERS)

Objectives to maintain frequency (and voltage) within bounds that are acceptable to system elements (especially loads), includes tolerating design basis events, returning to acceptable post-disturbance conditions and avoiding cascading failures. These objectives are built into existing reliability rules. Allowing and encouraging the evolution of new technology, particularly from inverter-based resources, that meet these objectives, without being prescriptive of the means by which they achieved, will lead to the most economic and reliable outcomes.

## 3 LESSONS FROM BLUE CUT AND INTERNATIONAL EVENTS

### 3.1 DO NOT OVER REACT AND BEWARE OF UNINTENDED CONSEQUENCES

Much of the maladaptive behavior of the utility-scale solar PV in the Blue Cut event stemmed from overly aggressive response to measured frequency. Unlike synchronous machine speed, which is often used as a proxy for system frequency, actual bus frequency is not a state variable. That means that, unlike speed, it can change instantly. Attempts to measure and *respond* very rapidly to measured frequency changes can have unintended consequences, as was the case here. Inverters were set to block "instantly" for measured frequency substantially outside of nominal 60Hz. Unfortunately, extremely fast measurements based on voltage waveforms can be misleading or even meaningless.

The cautionary lesson is that faster isn't always better, especially when responding to measured frequency. Control and protection philosophy should be guided by "as fast as necessary", not "as fast as possible". It is worth noting that majority of the inverters were very quickly modified to eliminate this particular problem – mainly by slowing down the protection so that frequency measurements were meaningful. The response of the industry to the event is representative of good practice that should be continued: (a) watch for unexpected behavior, (b) investigate and understand, (c) look for practical solutions. Overall, making sure that protective functions on inverter-based resources are (a) understood, and (b) not unduly sensitive, has become very important.

### 3.2 AUSTRALIA NEM. SOUTH AUSTRALIA SYSTEM BLACK OF 2016.

The South Australia blackout of September 2016[3] presents some useful lessons for US practice as well as at least one counterexample. The event, as with most blackouts, was complex and attributable to multiple compounded factors. The separation of a large chunk of the Australian system from the rest of the grid (the National Electricity Market, or NEM) resulted in a blackout of the separated part. The frequency behavior during the breakup was more extreme that has historically been observed. This was a combination of extreme reliance on power import on a single power right-of-way (double circuit, single tower transmission), significantly lower system inertia in the part of the system that separated, reliance on traditional under-frequency load-shedding, and unexpected protective actions by some wind generation in response to many (more than 5) successive transmission faults.

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[3] System Black South Australia 28 September 2016. Final Report March 2017. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

The event demonstrates that the more extreme risks are associated with the grid breaking up. This is also driving concerns and new requirements in Germany. NERC rules help avoid break-ups, but good practice demands that we be prepared. The Australia system blackout produces some useful learnings. Going into the storm, the system was operated under a high stress and very low inertia (in the receiving system). The stress was a consequence of the particular market response at that point. The system was secure for "credible events", as would be the case in US grids. The violent weather was not judged sufficiently threatening to warrant overriding the market. There were several lightning and wind induced disturbances from the storm. Ultimately, the unexpected response of several wind plants to multiple grid faults events -six faults in 87 seconds – was the straw that broke the proverbial camel's back. Protection, unknown to the grid operator, was set with the expectation that if the turbines were subject to more than 5 successive faults in rapid succession, then there must be something amiss on the grid and the turbines were tripped. The unexpected loss of generation in the receiving system resulted in overload of the already heavily loaded interconnection, and separation. After separation, the system power load unbalance was too great for the existing protection to save the islanded south Australian grid.

Some lessons learned from that event include the necessity to understand protective functions that might impact system dynamics for events that are significantly outside of normal design basis. Allowing for defensive operation outside of normal market conditions is important. There are provisions for such in US operation, but re-evaluation of vulnerabilities with new, high inverter/low inertia conditions is warranted. However, the Australian Energy Market Operator, has invoked new requirements that are arguably out-of-balance and at odds with accepted practice. Generation there is now expected to tolerate *any number* of grid faults of *any severity*, that could occur within the space of five minutes. They provide an example of a requirement to tolerate 15 successive, zero retained voltage faults. Synchronous generation, transmission and substation equipment, and many other power system components are not designed to tolerate such extremes, so, in practice this new regulation is singling out wind and solar generation. US practice will need to be more nuanced.

# 4 UFLS AND ALTERNATIVES

## 4.1 UNDERFREQUENCY LOAD SHEDDING (UFLS)

Another key point, reinforced by the South Australia system black, and relevant to US practice looking forward, is that traditional UFLS is not going to be enough.

At the risk of oversimplification, reduced levels of system inertia are a concern because, all other things being equal (which they never are), system frequency drops faster during loss of generation or infeed events. This is higher rate-of-change-of-frequency - "RoCoF". When pressed on why higher RoCoF is a concern, the response is often "we need time for the underfrequency load-shedding (UFLS) to act, to keep the system secure". This warrants some closer inspection.

It is a fact that UFLS has been used for more than 50 years as a bulwark of reliability, preventing cascading outages for events that are worse than N-1 NERC criteria. The arrangement has served well. But, a strong case can be made that UFLS is reaching the end of its utility, and that adopting rules and market strategies that are primarily aimed at preserving this particular facet of system practice is uneconomic.

First, as this session recognizes, distributed generation is becoming a major factor in system operation. Growth of distributed resources makes traditional UFLS progressively less effective and more uncertain. Disconnecting feeders with a significant amount of (say) solar PV in response to dropping frequency is counter to grid security. Second, even with systemically manageable frequencies, localized frequencies are becoming less anchored by inertia. Reliably measuring frequency, and rapidly differentiating between events that require response and those that don't has limits, as noted above.

But there are alternatives to UFLS. In South Australia, they have recognized that their historical approach is unlikely to be adequate, and that the economic consequences of trying to maintain higher levels of inertia than naturally occurs with economic unit commitment and dispatch are too dear. One alternative, or more precisely adjunct, to UFLS is the use of new protective schemes. These are discussed next.

The writing is on the wall: *we have to migrate away from traditional UFLS*. Creating market forces to postpone that evolution isn't doing the public any favors.

## 4.2 REMEDIAL ACTION SCHEMES AND SPECIAL PROTECTION SCHEMES (RAS/SPS)

There is a range of dependence on RAS/SPS across the US. In the west, the system relies on a variety of specific schemes to allow acceptable response to some large disturbances. For example, there has been a scheme in place that responds to trip of the Pacific DC Intertie for many years. The sophistication of such schemes is growing, as both computation and communication gets faster, cheaper and more reliable. The use of synchrophasors opens a host of new options. In the UK, these are being used to understand how and where the system is breaking up during extreme events, increasing the resilience of the system.

Nevertheless, in some parts of the US SPSs are regarded with a jaundiced eye, for some good reasons. The schemes tend to be complex, and their performance is highly dependent on both system topology and operating condition. Consequently, such schemes may need to be armed for only specific operating conditions, and they need to be monitored and updated as the grid topology changes. There is a host of risks that ensue: people that understand the schemes move on, the grid changes and the scheme no longer works as intended, the hardware and software is often customized and can be difficult to monitor, tune, repair, or replace. There are those who regard these costs as too high and who avoid SPSs, even actively working to retire those in place. But, the efficacy of a properly designed SPS can be high, sometimes removing operating constraints for huge operating cost savings and better market function. Systematic integration, development, monitoring of SPSs, including the institutional changes (and costs) needed to avoid these real concerns, can be well worth the investment. The message is a new generation of SPS/RAS will provide an important set of tools to system operation and planning. Legitimate historical concerns about the reliability of them need to be met with investment and institutional adaptation.

# 5 BLACKSTART (AS AN ERS)

One lesson, often relearned in the US, is that blackouts happen. It is incumbent on the host system operator to maintain viable plans and procedures for system restoration, as well as to make sure that there are sufficient resources available to accomplish restoration under a range of conditions. These requirements are included in NERC rules, and evidence suggests that system operators around the country are well prepared.

With few exceptions, system restoration plans rely primarily on fossil and hydro synchronous generation. When configured to provide blackstart, these resources can start with no grid and be used to initiate energization. They are "grid forming" resources, and are the essential first step in system restoration. The process of restoration can be complex, and given that components of the grid may be compromised (e.g. by a large storm or other physical disaster), there many steps and inevitable missteps during the process. It involves a lot of *a priori* and real-time bookkeeping.

## 5.1 IS THERE A LOOMING SHORTAGE?

Because of the complexity of system restoration, and the fact that present technology wind and solar generation are variable and are not grid forming, variable renewables are presently left out of system restoration plans. That arrangement works well now, but as more fossil generation retires and as some resources withdraw from offering blackstart services, it may be time to look for ways to augment the traditional resources.

## 5.2 LEAVING VARIABLE RENEWABLES OUT OF BLACKSTART IS NOT A LONG-TERM STRATEGY

At some point in the future, it is entirely likely that the penalty for leaving variable renewables out of system restoration plans will prove to be economically untenable. Bringing wind and solar into restoration planning will require some new thinking and new functionality. Even without grid forming inverters to provide blackstart, they should be able to contribute to successful system restoration after local voltage and frequency are established by blackstart units. By taking advantage of presently available frequency and voltage sensitive controls on wind and solar, they could add speed and security to the process. With future inverter designs, they should be able to provide blackstart.

This is not, in my opinion, a crisis. But some action, in the form of research and experimentation, is warranted now to avoid problems and unnecessary costs in the future.

Respectfully submitted,

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