Question	Answer
Will the future actually call for less networked system with more radicalized system conditions with more Circuit breaker operations and automatic relay operations that could help isolate cascading system conditions or is networked always going to be best?	I am of the opinion that we will continue to have networked systems as the default "normal" operating condition. There are too many systemic and economic benefits to spatial diversity and just "bigness" to forgo. But, I believe we will become much more willing to break into (and reassemble from) parts, of a wide range of sizes and characteristics, as we move forward. Smarter, faster, more self-aware behaviors will make the taboo against breaking up fade.
Would you say that enhencing the capability of inverters to frequency excursions is a way to enhence the performance of grid forming inverters?	Certainly, part of the motivation for GFI is their ability to respond instantly (or in a sense "passively") to the very early stages - i.e. one of cycles - of a frequency excursion or phase jump. This is important. But remember that the difference in frequency response between GFI and today's best grid-following inverters mostly fades to inconsequential after a handful of cycles (say a few hundred ms).
if you would create a market incentives to motivate installation of Grid Forming Inverters in the grid. How would you formulate the service they should provide?	Tough one. I'm wary here: As I've said, we can and must do better than synchronous machines. But we don't know exactly what that means. My work (and others) strongly suggest that "one size" doesn't fit all. So, we need to be cautious in designing incentives or grid codes that prescribe specific behaviors. Especially, when that runs the risk of simply incentivizing "act like a synchronous machine". Wrong answer.
This is Wei Du from PNNL. For a 100% inverter-based power system. During a short-circuit fault, if all inverters limit their currents to 1.5 pu. This will cause a system-wide low voltage and affect many customers. Should IBRs have higher current ratings?	You are correct that the region or reach of the during-fault voltage depression will be probably be wider. Whether that is a problem, or exactly what sort of problem that creates is less clear. Is the most economic solution to those possible problems to add cost in the inverters, or is it better to make protective relaying more robust, or are there other options? I don't know the answer. But, I'm very wary of the presumption that we need lots of fault current, so that we can preserve decades old relays and practice. Maybe, but this needs to be examined and challenged.

if the PSSE or PACAD model shows stable results for scr value below 1, does that mean the model has some issue?	Not necessarily. The "dance" between phasor (e.g. PSS/e) analysis and point-on-wave (e.g. PSCAD) analysis isn't fully choreographed yet. For very low SCR, good engineering probably dictates that some properly vetted POW analysis be done. But, as I mentioned, POW analysis is tricky to get right, expensive, and tends to result in fewer real conditions being examined. The industry needs to figure out how to mix the two classes of analysis together better. I'm pretty adamant in my opinion that going *all* PSCAD is big mistake.
Does inverter design create the ability to remove harmful harmonics from the grid? Could SSR frequency components be actively damped using inverters with lower "latency"?	In general, this class of inverter provides a sink for low order harmonics. It's tough to create a value proposition; rather it's more of an additional benefit (icing on the cake?) Damping of SSR (and other oscillations for that matter) is clearly possible. It will "use" some of the rating of the inverter, and details always matter. e.g. modal observability and controllability needs are topological (locational) and must be satisfied.
Nihal Mohan (MISO) :Can you please talk about ability of Inverters to provide damping for small-signal stability issues?	see previous answer.
You mention that the maximum active power transfer limit by voltage stability is still there. Does this mean inverter control cannot provide ancillary support to increase the transfer capacity?	No. not at all. But impedance still matters. If the grid collapses 200 miles from the GFI, the inverter can't fix that problem, regardless of its characteristics. I've personally seen many cases in recent years where the inverter has been asked to push power into a grid that can't accept it (usually post contingency). One of "Nick's Stability Rules" is: "Don't try to push power into a sick voltage".
I have a small question. I wonder how suitable is DigSilent transient toolbox EMT? not the rms? I wonder if he could share his experience with DigSilent compared to PSCAD. Thanks	Sorry. I don't know.

I wonder also if he could share his experience with the utilities in USA and the use of generic models or specific manufacturers models in their study assessments. In Europe utilities are asking now parameters and simulations with generic models as the IEC which is not fully matured. The IEC doesn't have an inertia response model, for example. Regards	This is difficult. As I noted, the grid-following inverters have been continuously and rapidly improving for 15 years. That has made keeping the models up-to-date very difficult. Even the OEM specific models have compromises; doubly so for the generic models (I worked for years with the IEC WG on the generic WTG models). The challenge of creating meaningful generic POW/PSCAD models is amplified. I'm wary of generic PSCAD models, but I won't go so far as to dismiss them. In the end, using OEM specific models for the detailed engineering of interconnection is good practice. It is also good practice to not use "too sharp a pencil". Remember, the function of simulation is get insight. Simulations are snapshots in a continuum of operating reality. Good engineering demands that you maintain some margin from the brink.
I used to think that frequency control is going to be increasingly important, but you mentioned that future instabilities mostly arise from voltage issues. (Correct?) Then, does it mean frequency control will be less interesting/important?	No, frequency will continue to be a concern. But, for example in my "brittleness" slide, the transient instability due to the fault and line trip doesn't really look at all like a traditional power-angle (e.g. equal area criteria) instability. Everything is fast, and the mechanical states of the system are relatively unimportant. The mode of failure in that case is really a transient voltage collapse, driven by an inappropriate control response. Standard tools and metrics (of "margin") aren't well suited to looking for/checking for this type of stability risk.
I am new to grid forming and grid following. Where will you suggest to look	You came to the right place ;-) ... ESIG is the best forum in North America (IMHO). Seriously, this is pretty cutting edge stuff. The EU MIGRATE project has collected a lot of the most relevant and current material on the topic. Check their website. The recent conference is at https://www.entsoe.eu/events/2019/12/04/migrate-final-conference/. Another place where a lot of the most advanced work is presented and discussed is the annual Grid Integration Week conference. https://windintegrationworkshop.org/ 25% of the papers presented at the '19 conference in Dublin addressed GFI.

If we limit the current of grid forming inverter (during faults), do you belive it staill work as grid formming?	It's something different for sure. But, I'm not sure what grid-forming a synchronous machine does during a fault either. I believe we'll need to focus on outcomes, to determine what behavior is best. Then we can figure out what to call it.
X goes to infinity does not say SCR is Zero? We can connect grid formming inverter through long line to supply power to a remote load. In thjis case grid formming inverter staill see the impedance and controllers need to deal it.	There are different ways to calculate SCR. The generally accepted (I think?!) view of SCR, is that when there's an island (as you describe) without any synchronous resource running, the SCR is zero. Much debate is possible. But certainly, the situation you describe can not be handled by today's grid following inverters.
Is there a size (spatial and/or power) or complexity level (number of inverters) below which 100% instantaneous penetration is not a stability concern? Considering e.g. island systems with PV + battery, or 100s of kW wind-battery systems with full PE win	Small systems are simultaneously easier and tougher than big ones. Even in small systems, *something* needs to set frequency. So, for example the 1997 picture of me in the lecture was for a small (<5MW peak) system. The BESS in the picture is about 1 MW, with a (1st generation) grid forming inverter. It was able to start and supply the entire system. So, yes it's been done. But, in that small world, the inverter was master. It didn't have to "play nice" with other resources, rather it provided the leadership (grid-formation), that other resources followed. In one sense, that is easier to accomplish with smaller systems. On the other hand, small systems suffer from "granularity". It can be that just one element (like this case) is critical to success. Big systems won't tolerate that.
On the slide showing eSCR with all the power being consumed locally, how would the analysis change if the value of X is calculated after taking into consideration the local load? Thevenin X which takes into consideration local load.	Yes. This is certainly directionally correct. There's room for debate and exploration about exactly what contribution of the load (i.e. how to model it) to the Thevenin equivalent is most meaningful.
What is the fundamental difference between grid-forming and grid-following inverters? Synchronization mechanism? Both voltage control and frequency support can be supplied from grid-following inverters.	The short answer is that grid-forming establishes a voltage, whereas grid-following does not.
What controls the phaser angle of voltage relative to other points in the transmission grid that controls power flow in the DC approximation?	Hmmm. The PLL measures and communicates the magnitude and angle of the grid, to which the internal regulator of the GFI responds. When there is no voltage to measure (i.e. blackstart), the GFI uses its own internal clock to set frequency.

The control signal for inverters is local electrical variables on network. Would it be feasible to have a fast, low latency, digital communication network in parallel for control purposes?	Probably. There's some new ground to cover here with GFI. For example, will such communication be necessary or desirable to avoid undesirable interaction between the GFIs? One of the things that grid-following has been shown to be very good at, is parallel operation. They generally play nice together and don't fight. We aren't automatically assured of such nice behavior with GFI.
What stabiliity problems do you foresee with GFI?	see previous answer. There are other points that call for caution/due diligence. As I've said repeatedly, we don't want to just make GFIs look like synchronous machines. One of the stability risks will certainly be a return to transient stability problems of the type that we are well familiar with for synchronous machines. I doubt they'll look exactly the same, but that's one area of concern. That could also include new/different manifestations of damping problems. The good news is that we have vastly more control agility and options to mitigate new problems. I am of the opinion that it will take some work to find and fix all the new things that crop up. In the end, stability limits will still exist. We can hope and expect them to be less constraining that today's predominantly synchronous systems, but the new limits will need to be respected.
can a gird forming battery resolve another solar farms system strength related voltage instability.	Maybe. Probably.
(Generally) how crucial is it to utilise reactive capability of synchronous condensers to improve grid stability for IBR integration?	The VARs are actually less important than the improvement in SCR. But, as I noted, synchronous condensers are just one tool in the toolbox. There are an effective tool, and have a place. But, I am of the opinion that synchronous condensers must be evaluated in each case against other options.
What is the "latency" of today's controllers in "keeping up" with the system signal?	Latency is less of an issue for the stability issues I outlined than the reality that tracking the voltage when it is ill-mannered (e.g. jumps, is badly unbalanced, moving very rapidly) is difficult.

are grid forming inverters similar (hw speaking) to grid-following ones?	Similar, yes. Identical, no. Lot's of looking at questions of retrofitting existing grid-following to become grid-forming. Looks generally discouraging.
Can you please elaborate why typical tools such as PSS/E has limitations for stability assessment?	Phasor analysis has intrinsic limits, some of which are hit with very fast, non-linear devices like inverters.
How probable would a sustained accidential islanding event due to the event falling within the 'non-detection zone' on a Grid Following inverter system with modern inverter technology? Is that concern resigned to older inverter technologies?	hmm. See my comment on the 1st question. The *ability* of grid-forming to sustain an island is higher. One could argue that axiomatically creates a higher risk of *accidental* sustained islands. *Sooo.* I think we have some institutional work to do, to understand the risks, tolerance and *desirability* of islands with more GFI resources.
How will the average wind or solar developer me motivated to specify a grid-forming inverter? Or will TPs and TOs have to say at some point that a proposed project has to have it?	tough one. Initially, it is my expectation that some economically attractive (to a developer) applications will either not work without GFI, or that to get them to work with grid-following will take more investment in the grid than the incremental cost of using GFI (and BTW, the incremental cost of going to GFI over today's grid-following is not at all clear today). Determining that the grid "doesn't work" will likely come from the TO, so in that sense they'll have "say". Of course, they might "arbitrarily" say "we want GFI". I'm wary of that approach, as there are too many unknowns for anyone to just assume that GFI will always be an improvement. We simply aren't there yet.
Additional Questions	
In Page 14 (eSCR and beyond: Where is the power going?) you show a plot in the middle of the page. The plot shows relationship of SCR, where the power is consumed and how stable is the Inverter. My question is why do you write “note the absence of numbers, we (the industry) have not adequately explored this relationship.” I wonder if you can explain why are you saying this. also what do you mean by “stable”.	Stability limits based on eSCR have been floated at various times as we’ve gotten smarter about weak grids. They are relatively crude (the OEMs would agree, I believe) Here, I was specifically referring to the notion that more localized consumption of the power tends to stabilize the converters. There are different stability metrics you might use. I’m referring to relatively fast instabilities driven by inverter. Either negative damping, or failure to provide restoration from impulse or step stimulus. No one, to my knowledge has populated a graph like I sketched with actual numbers for a specific converter control.

You probably know that ERCOT did an extensive review (in the Panhandle area) calculating SCRs in different manners and then running simulations using PSCAD. Also, there is information of several guidelines (mostly regarding DER) : NERC Guideline – Distributed Energy Resource Modeling, September 2017, and NPCC's Guidelines, 2019. I am assuming you know all of this, so you probably mean something else. My question is: what will you like to see more of? I am in contact with Universities and I am always looking for something new we can explore. Any comment will be appreciated.	Yes, ERCOT has been one of the few cutting edge leaders in this regard. Their insights have been helpful in driving forward better controls and models. But, clear guidance for grid engineers that is not unduly conservative is needed. The point Deepak raised is a good one w.r.t. the loads part of the eSCR calculation.
Why are you saying the models used in PSS/e type of software tend to produce "more optimistic results"? (just because the PLL model?)	The PLL, or idealization of it in PSS/e, is my primary point. I can't point fingers, the standard model is based on work I lead over 15 years ago. But it's got limitations, and this is one. Having an optimistic assessment of the PLL performance can make the results look better. Of particular concern is that voltage recovery may look better than reality (or a detailed, correct PSCAD simulation). There are other compromises that go with phasor analysis. During fault behavior simulations miss a lot of detail, not least because faults are rarely balanced.
There is a trend to used "standard models" for inverter-based generating facilities in software like PSS/E. This is largely due to the fact that manufacturers consider the dynamic models and controls their intellectual property, hence they only provide models that are "black boxes" (dll files) with inputs and outputs and parameters. When confronted with results that are difficult to explain (or plain and simple do not make sense) It's very difficult to analyze if the problem is the model itself (like the PLL you mention), if a crash is a signal of instability, or if it is a numerical instability issue among other things.	I'm not sure that the OEMs get all the blame here. The user community has demanded that models be (1) accurate, (2) simple, (3) numerically robust within the constraints of PSS/e, etc. numerics and structure, (4) applicable to everybody's equipment. The "specification" is over-constrained, and so modelers, including OEMs, have to strike a balance between these 4, often mutually exclusive, attributes. They've done pretty well. Better would be good. Perfection isn't possible.

Finally, there are people out there (I do not know the cause of it) that are advocating to “always “ use tools (like EMTP) that can capture fast dynamics. Would you please share your opinion on this? I am asking this because it has serious practical implications. Normally, one received the entire eastern interconnection in a file and I do not imagine transitioning into EMTP models as a trivial issue. Studies of this EMTP-type that I came across with are always, for example, simplifying the grid by building rudimentary equivalents for the rest of the network and making many other assumptions with the potential to affect results.	I am extremely wary of this trend. There are two severe unintended consequences that can result. First, EMTP tools (I’ve referred to them as point-on-wave, POW, tools) are deeply cumbersome to use. Building huge models with EMTP is hugely labor intensive – very skilled labor at that. The potential to get worse-than-nothing results looms. Please note that it has taken years to get the PSS/e stability model of the eastern interconnection to be even remotely accurate for big stability events. With EMTP-only, we run the risk of having very detailed garbage. Second, because the models and data are so intensive, the problem is inevitably simplified, and practitioners either end up looking a very few conditions on a big model, or having a wildly simplified model. This is a terrible outcome: the North American power industry needs to be looking a MORE variations in infrastructure, MORE operating conditions, MORE disturbances, in the increasing uncertain world. Doing EVERYTHING in POW programs is a BAD idea. That is NOT to say that POW programs don’t have a place. Further, we (the industry) need to develop new ways for stability (PSS/e, etc) and POW (PSCAD, EMTP) to reinforce (advise, bound, guide, ?) each other in everyday engineering – not just for research. I would further argue that we (the industry again) are doing an inadequate job of connecting the economic/long-term simulations with our stability work. So, I see problems on both ends of the time spectrum. There is good work going on in all these areas. Smart people at work. We need to go faster!