Question text	Response
What methods do you recommend for assessing voltage stability in a heavily meshed grid without nearby IBRs, but with LCC inverters, facing lack of Q support?	In systems with low levels (by relative MW) of IBR, a conventional P-V analysis would be a good first step for evaluating voltage stability. However, we would recommend augmenting this work with EMT simulations for set of cases showing higher risk, assuming that the LCC inverters you describe are relatively large HVDC terminals, and the direction of power flow and the controls and configuration of the HVDC LCC system can have a large impact on stability of the link and nearby system. We have not executed the dynamic Z characterization on an LCC control, each of which tend to be quite customized. But we would expect reasonably good results, that are compatable with the other resources in the system model.
The dynamic admittance you show on the y axis is a single scalar, where the x scale is frequency in dq0. Wouldn't the admittance be a matrix in the dq frame?	Yes, perturbations of the voltage phasor (magnitude and phase) result in real and reactive current flows, where the admittance is computed as a matrix of complex values. What we have plotted on slide 7 is a scalar value of the admittance, where we've already performed calculations to extract the reactive current - voltage magnitude relationship and to also account for the phase relationship between the voltage and current perturbations so that the plot is simple but still captures the important behaviors. The details of the calculations are shown in our white paper, linked on slide 7 (https://www.telos.energy/post/a-new-twist-on-old-time-tested-grid-analysis-methods)
How is the method useful incase of planning studies where detail frequency dependent models are not available?	This method is useful where IBR details (including frequency-dependent behavior) is not yet available because the frequency-dependent responses fall into ranges by technology type. So for planning cases where IBR specific details are unknown, this method allows you to evaluate technology types (synchronous machinery, GFL IBR, GFM IBR) with representative dynamic impedance values to assess the voltage stability constraints of the system in 5/10/20 year planning horizons where equipment specific details are undefined but basic technology mixes are being considered. We believe this approach provides a great deal of value, allowing for better decisions much earlier in the planning process (when technology details are not yet available).
How much importance the DZM give to the controller parameters and operating MW-MVAR of IBR ?	The IBR controller parameters, in conjunction with the IBR control structure/design for voltage regulation are very important. Parameters that specify the control mode (voltage regulation v. reactive power regulation) and parameters that influcence the response behavior (regulator gains and associated time constants) are critical and will change the frequency scan results from the IBR and therefore also change the exact dynamic impedance value associated with that resource. While the exact values of dynamic impedance will change, the range of possible values is more a function of the technology type and control structure used (SM/GFL/GFM)
Is the dynamic impedance obtained for an array of operating points?	Currently, the dynamic impedance is obtained for the full-power operating point because this is the condition in which most IBR resources are most challenged in terms of stability for fault recovery. While it is not expected that the voltage regulation dynamics would change significantly as a function of operating point, it is a good point to raise and will be considered as part of future work.
is the phase of the dynamic impedance taken into account, and how much does this influence the PV analysis?	The dynamic impedance, when applied in PV analysis, is only a reactive branch element (inductance). The solved phase angles of the machine will shift slightly as a result of this, but otherwise, there is no direct manipulation of phase angle.
How is the proposed dynamic impedance method different from the traditional PV study?	The dynamic impedance method augments a traditional PV study by integrating an additional impedance (the dynamic impedance) between the terminals of a resource in the PV analysis and the ideal source of the resource. In this way, it better reflects the resource's dynamic behavior - the behavior that strongly influences the stability of transitions caused by system disturbances - in a P-V analysis, particularly for weak systems. It is noted that the actual calculations and sequence of operations involved in inegtrating the dynamic impedance and applying it to a traditional P-V analysis are involved and care must be taken to get it right.

Is the method applicable to help screen and identify potential SSCI problem?	No, this method is not designed or intended for SSCI. The IBR models are too simple for insights to SSCI, SSTI, SSR, SSFR, etc, which demand EMT.
Slide 14. Can you comment on the importance of the choice of small 1% voltage step for impedance contrasted with short circuit used for SCR methods.	The 1% change in voltage applied is used to elicit a response in current from the IBR, and the comparison of voltage and current yield the dynamic impedance. A 1% change is used to get the response before limits become binding -- to capture the small-signal response of the IBR. Larger steps up to about 10% generally result in the same impedance values. In operating conditions that are normal or near-normal, these values do a good job capturing the "stiffness" or "strength" of the system, which is why this approach is used. For larger changes in voltage ~20% or greater -- up to 100%, which is effectively a short-circuit calculation, the resource's limits will be applied and the computed impedance value will change (and generally get larger as currents are limited). The exception is the case of synchronous machinery, where there are no current limiters applied in short time-frames. Therefore, the response from synchronous machinery in a given timeframe is less dependent on the change of voltage applied, which is why SCR methods have worked fairly well for synchronous-machinery-dominant systems. But these methods breakdown for IBR-dominant systems or regions, and one of the reasons for this is due to the current-limiting behavior of IBR, even in short time-frames.
Does the method consider N-1 or other types of contingencies?	Yes, this method can consider any set of contingencies that a conventional steady-state P-V analysis can... N-X. And because it can solve relatively quickly, it is reasonable to evaluate higher orders of contingencies that may occur in operations.
do you recommend using this method in addition to SCR methods?	Yes, especially when the resulting SCRs approach 5 or less, where the assumptions and limitations of more SCR method start to have a much bigger impact. We are currently exploring an update to SCR methods that also utilize the dynamic impedance. Please stay tuned!
what mode/frequency range the DZM is focusing on? 5-10Hz voltage magnitude oscillation correct? what about other frequencies higher ones?	The DZM is focused on the dynamic behavior of resources in the first few hundred milliseconds after a disturbance, corresponding to 5-10 Hz in the frequency domain. We have empirically found that frequencies higher than that (even shorter timeframes) are not as important to large system dynamic stability. Even under very aggressive scenarios with very high levels of IBR, we find it typically takes at least a few hundred milliseconds for instabilities of a given resource to become so severe that it impacts the larger system.
how does DMZ track the stability limit for change in inertia constant for GFM used as virtual power plant?	The DZM is focused specifically on voltage stability and reactive power response. While there are analogous methods that we have explored for active power response to changes in system frequency/angle, these are considered separately. In reality, there is some cross-coupling between active and reactive current responses and changes in voltage magnitude and voltage angle, but these are usually not dominant.
Are you able to comment briefly on why the impedance method tends to be conservative compared to the EMT results? Thanks	Yes, this relates to the selection of the dynamic impedance (reciprocal of admittance) for the resources. For resources where the admittance from the frequency scan is a strong function of frequency (as is typically the case for GFL IBR), then selecting a "most relevant frequency" of 10Hz as shown on slide 7 where the admittance is lower results in a most conservative transfer limit at the system level.
Do you consider the dynamic model in the DZM study?	The DZM is a steady-state analysis method in which the dynamic behavior of each resource is distilled into a single impedance value, which is derived from a detailed EMT dynamic model of that resource. The method can use equipment specific OEM supplied models.
Where would you put the harmonic power flow analysis among the different methods	We consider harmonic analysis as being related to power quality issues and not system stability. It is also acknowledged that some instabilities can manifest as oscillatory behavior with modes in the super-synchronous frequency range, but generally, these issues are very specific to a particular resource controller design and configuration.

could you explain more about the rational for focusing on ~10Hz as the most relevant? Thank you for sharing	We found that 10Hz in the frequency domain (reflecting what happens about 100msec after the disturbance) is most relevant to the resulting large system stability and transfer limits. When we pushed our simulations to the breaking point, we found the onset of system voltage collapse was associated with a loss of voltage regulation at the terminals of the resource in the first few hundred milliseconds following the disturbance. The terminal voltage would quickly drop, and the reactive power support from that resources would also drop with it. When doing this work, we first thought that 7Hz was a good number, but we found that the method was slightly optimistic for fault-and-clear disturbances, particularly when the scenarios included high levels of GFL resources. We observed that a higher dynamic impedance - particularly from the GFL resources - made the system level transfer limits more conservative, which we took to be desirable. It's important to note that the sensitivity of the DZM to the selected frequency is in part due to the how much the frequency scan response of the resources changes as a function of frequency -- and GFL resources tend to exhibit the greatest change as a function of frequency. If an analysis was performed with only SM and GFM technologies where the response was flatter across the frequency range (admittance doesn't change much), then the analysis would be less sensitive to frequency selected because the admittance (or dynamic impedance) would basically be the same value. You're welcome!
What is the reason choosing 10 Hz frequency for calculating impedance?	We found that 10Hz in the frequency domain (reflecting what happens about 100msec after the disturbance) is most relevant to the resulting large system stability and transfer limits. When we pushed our simulations to the breaking point, we found the onset of system voltage collapse was associated with a loss of voltage regulation at the terminals of the resource in the first few hundred milliseconds following the disturbance. The terminal voltage would quickly drop, and the reactive power support from that resources would also drop with it. When doing this work, we first thought that 7Hz was a good number, but we found that the method was slightly optimistic for fault-and-clear disturbances, particularly when the scenarios included high levels of GFL resources. We observed that a higher dynamic impedance - particularly from the GFL resources - made the system level transfer limits more conservative, which we took to be desirable. It's important to note that the sensitivity of the DZM to the selected frequency is in part due to the how much the frequency scan response of the resources changes as a function of frequency -- and GFL resources tend to exhibit the greatest change as a function of frequency. If an analysis was performed with only SM and GFM technologies where the response was flatter across the frequency range (admittance doesn't change much), then the analysis would be less sensitive to frequency selected because the admittance (or dynamic impedance) would basically be the same value.