Thank you everyone for an interesting set of questions. I have tried to respond to all of them but it took a bit of tie to do that.

Before getting started, here are open-access or pre-print links to the academic papers I mentioned on my slides.

Title	Authors	Journal	OA Link or Preprint
Reduced-Order Models for Representing Converters in Power System Studies	Yunjie Gu, Nathaniel Bottrell and Tim Green	IEEE Trans PELS, 2017 doi.org/10.1109/TPEL.2017.2711267	hdl.handle.net/10044/1/51614
Impedance Circuit Model of Grid-Forming Inverter: Visualizing Control Algorithms as Circuit Elements	Yitong Li, Yunjie Gu, Yue Zhu, Adrià Junyent-Ferré, Xin Xiang and Tim Green	IEEE Trans PELS, 2021 doi.org/10.1109/TPEL.2020.3015158	hdl.handle.net/10044/1/82204
Impedance-Based Whole-System Modeling for a Composite Grid via Embedding of Frame Dynamics	Yunjie Gu, Yitong Li, Yue Zhu and Tim Green	IEEE Trans PS, 2021 doi.org/10.1109/TPWRS.2020.3004377	https://arxiv.org/abs/1911.01879 or http://hdl.handle.net/10044/1/88784
Mapping of Dynamics between Mechanical and Electrical Ports in Generator-Inverter-Composite Power Systems	Yitong Li, Yunjie Gu and Tim Green	IEEE Trans PS, Under Review	http://arxiv.org/abs/2105.06583
Participation Analysis in Impedance Models: The Grey-Box Approach for Power System Stability	Yue Zhu, Yunjie Gu, Yitong Li and Tim Green	IEEE Trans PS, Under Review	https://arxiv.org/pdf/2102.04226.pdf
Fault response of inverter interfaced distributed generators in grid-connected applications	Cornellis Plet and Tim Green	J EPSR, 2014 doi.org/10.1016/j.epsr.2013.07.013	https://www.researchgate.net/publication/259129545_Fault_response_of_inverter_interfaced_distributed_generators_in_grid-connected_applications

	Question	Answer
1	Are you also considering what could be happening on the demand side when looking at system dynamics and future system services for IBR dominated system?	The characteristics of demand are certainly important. They always have been but now perhaps more than ever. IBR are present on the demand side: what we might call an active rectifier is the same as an IBR. It is potentially able to offer services (especially demand-side response for frequency regulation) and is prone to unplanned control interactions like any other IBR. Even for demand-side IBR that are not offering a service, we still need to consider how they present themselves to the grid and how their impedance or dynamics form part of the whole-system model. Many traditional loads had a significant resistance and so tended to damp oscillations. An active rectifier can sometimes present negative damping and exacerbate an oscillation.
2	How is inertia of virtual sync machines calculated/defined- for synchronous machines, it's a well understood concept but for VSMs is there an industry std?	Not aware of an international standard yet but National Grid ESO in the UK, through the grid code review panel, is developing grid codes that do now refer to software-defined inertia. This is the heart of the issue really, the control loop (software) will define the amount of extra power injected in proportion to df/dt and that is the inertia. Grid code information can be found here:

		https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required Other NG ESO material here https://www.nationalgrid.com/sites/default/files/documents/GC0100%20Annex%209%20%20VSM_0.pdf
3	Are the impedances a function of operation point? Do they capture the impact of operation point on the distance to instability?	Yes, the impedances are in most cases specific to an operating point. They are a linear approximation to a non-linear system. There are attempts to extend the analysis to account for non-linear properties within an impedance description.
4	How we make grid-forming IBR a frequency-responsive element? How we make the reference active power signal?	The grid forming inverter is normally set up as a voltage source: the power that flows from it depends on its angle and magnitude with respect to the voltage at the connection point (assuming some inductive reactive in series). The frequency of the voltage source is then made dependant on the measured power flow. If the gird frequency changes, the angle difference changes and the power flow changes and then the GFM adopts the new frequency. In that respect, a GFM is already frequency responsive. You can make it have inertia by limiting the rate at which its frequency changes by adding a first-order lag after the power measurement. A consequence of that is that during a frequency transient it will sources larger powers since its angles difference with the main grid will widen further. This is what one would expect from something providing inertia.
5	Many vendors control STATCOM as grid-following (PLL based), should they be controlled as grid-forming?	I think that we will see that happen for at least some STATCOM and they will offer more of the services that a synchronous compensator offers.
6	As much as IBR can run at low/no power (as opposed to SyncGen), would current ripple/noise generated by power electronic put a limit on bandwidth and stability?	There will be stability issues to address but I don't think they are fundamentally different at low/zero real power than at other operating points. The power quality limits (limits voltage or current ripple presented to the network) do determine the size of the filter elements (LCL filters in many cases) and in turn these passive components put upper limits on the bandwidths of voltage or current control loops. In turn, those bandwidths affect stability. I think one of the reasons this becomes a difficult conversation is that the bandwidth ultimately depends on the switching frequency of the semiconductors and that is lower for high power converters. I have to note that multi-level converters used in HVDC do have very high "effective switching frequency".
7	Should we separate synchronization and rotor stability for future power system? As you know, the synchronization concept is changing	I agree that the concept of synchronisation is changing and we need to look again at what a grid needs to provide to help keep machines and inverters synchronised and what we expect machines and inverters to do themselves to stay synchronised. If the PLL of a GFL inverter is unstable, should we reduce the gird impedance or change the PLL bandwidth? What is the general rule governing those decisions? It fells similar to debates about EMC. Is the better (cheaper to society) solution to make culprit emit less EM energy or make victims immunise themselves to it.
8	For "reliable service at least cost" is cost only internalized costs, what users pay, or does it include externalized costs, forced outages, health impacts?	My normal answer would be the whole-system cost – the cost of owning and running all the equipment of the grid itself and the connected resources and the cost of outages. You keep making the gird more reliable until the cost of doing that starts to become greater than the savings in cost of outages. The difficulty is often over obtaining a sensible cost of an outage and what range of consequence like health one considers.
9	Is there a reasonable certainty that a synchronous condenser will have classical angular stability problems compared to synchronous grid-forming inverters?	I think we are still at the early stages of assessing synchronous condensers versus virtual synchronous machines and/or GFM. I think system operators are reaching for synchronous condensers because they behave in familiar ways and because the power electronic alternatives have been a bit slow in being market-ready. With things like GFM battery storage systems being considered we can look forward to some real-life comparisons.
10	Is "Grid Forming" Enough? What are the major determining factors? To answer if you need more than just grid-forming inverters?	My main point is the "grid forming" comes in many flavours (does it include inertia, does it include fault current … if so, how much). It is quite possible that some of these services could come from GFL inverters or other equipment and not GFM. That is why in G-PST we are trying to create description of all the needs and

		services and map them to resources. But this is only a start with lots more input needed.
11	Can virtual inertia ever be as good as physical inertia? As you mentioned, it requires differentiating measuring and differentiating frequency, which is slow.	I do think virtual inertia that uses direct differentiation of frequency is problematic. But adding some first-order filtering to the droop of a GFM gives a very similar effect. I think that the other services such as fast frequency response and frequency containment substitute for inertia to a large extent.
12	Can methods like you describe be turned into tools that can be used by regular utility power systems analysts? It's very complicated.	It is complicated but I think we have to take this path. It should be an exciting challenge to get the new analysis tools in place so that we can transform the system with no ill effects. A lot of analysis tools in use today came into being when problems arose decades ago. Tools to analyse sub-synchronous resonance came about after generator shafts were snapped. Our challenge is to make sure we have tools that can foresee and correct problems before they are found the hard way.
13	Regarding the work on "grey box" models - how can we understand the limiting behavior of inverters with small-signal based methods such as impedance spectra?	I think you are referring to limiting behaviour such as current limits or voltage limits which are a non-linearity. These are not captured in the family of small-signal methods and yet they are present and important. There is a rich research opportunity there on stability of non-linear systems applied to IBR networks.
14	What is the first limit you run into without synchronous machines? Fault levels for protection coordination?	I'm not sure if fault current is first but it is important and we need good foresight of the problem and solution because if the best solution turns out to be modification of the protection relays across a network then it will take a lot of time (and investment) to implement. I think the order in which issues will bite us depends on the system characteristics. The system in Great Britain is relative small and so frequency regulation is a challenge already but already there are some regions of the system where fault current levels are falling and need supplementary equipment.
15	In a synchronous machine based system, the voltage is set by these machines. Who will set the voltage signal in a 100% IBR system? do will need synchrophasors?	GFM will set voltages and, rather like setting up the automatic voltage regulator of a synchronous machine, gird operators will need o agree with GFM installations what the nominal and droop setting of the voltage function should be.
14	Can you comment on PWM saturation behavior (not current limit) of IBR vs. synch mach saturation? Such as hard vs soft or more likely to be operating near sat?	Hard versus soft limits is an interesting thought. I confess I have thought more about current limits than PWM limits recently but clearly PWM modulation limit matters just as the excitation limit of a synchronous machine matters. Perhaps we power electronic people need to help the power systems people by talking about the capability charts of inverters with all the limits recognised
15	As we loose rotational inertia from traditional generation, at what point (% of generation) is rotational inertia lost & grid stability fails and we need this?	I think we look to Ireland and Eirgird for indications of that. In their terminology they have a limit on "system non-synchronous penetration" and curtail wind to keep to that limit. But over the years the limit has been raised as experience in running the system with a high SNSP. They regularly run above 70% now and have got very close to their 75% limit. That isn't seen as the ultimate limit, it will rise as experience and services and tools all expand.
16	Why did you mention that the virtual synchronous machine (VSM) is not a grid-forming inverter?	If I said that then I must have used the wrong words. What I meant to say was that they are not identical terms. I consider that VSM is a step beyond GFM. It is a GFM that is controlled to follow the same set of differential equations as a synchronous machine in all regards. A GFM is a looser term and has some core behaviours (voltage source synchronised through droop) but does not necessarily emulate inertia (might provide a service that is a close alternative) or provide large fault current.
17	Does it seem MPPT control in either wind or solar system conflict with the requirement from GFM e.g. increasing power for virtual inertia...?	I think so. This is less obvious with a steam-turbine and synchronous machine because both parts can provide extra power in the short term but a solar plant running at MPP can't.

18	It is expected that these grid forming inverters will be significantly more expensive? If not, would it not be ok to over-deploy?	There will be some cost in perhaps having a bit more headroom on current rating to handle services on top of energy. However, I think the operating cost of operating solar or wind below MPP is more of a factor. That's why I think the role of storage interfaced through GFM and performing services is an important part of the solution.
19	GFM claims not needing PLL. In this case, how can reactive power (for voltage droop) be accurately measured in general unbalanced case?	We can still resolve measure voltage and current at the point of connection into d- and q-axis components using the instantaneous angle of the voltage reference and reactive power calculated in the normal way.
20	in a 100%-inverter-based system, frequency is controlled so fast. This fast response can affect the operation of all devices in a bad way or not?	Certainly RoCoF is becoming higher as inertia reduces and the first consequence of that in GB has been the need to change settings of protection relays that used RoCoF for loss of mains detection. We need to think about whether there are consumer devices also susceptible to high RoCoF (such as "active front end" or "unity power factor rectifier" that use a PLL). I think there are lots of open questions on how wide the frequency band should be around nominal frequency.
21	What is the interplay with distributed energy resources also IBR, with the grid larger resources?	There is much debate over whether the emphasis of grid development should be on the big or the small. Are we going to rely mostly on DER or on big resources? Each system will be a bit different I think. Offshore wind, nuclear and hydro will be big and PV could be small or big. There are things that small LV batteries can do to ease local grid constraints that large HV batteries cannot. Most systems will have a mixture of large and small resources and need to obtain grid services from both, maybe with a changing ratio throughout the days and seasons