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Test system requirements for modelling future power systems

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Abstract—This paper discusses the need for new test system models to be developed and made available to researchers. A number of features of such test systems are proposed. These include sufficient size and scope to allow control interactions to be studied but not so much that phenomena associated with new technologies cannot be understood. It is recalled that the performance of new technologies and their controls should be verified on a full system model that is as faithful to the real system and its parameters as possible and that this requires access to data often owned by generating companies to which system operators have access but do not feel able to disclose. Finally, arguments are presented as to why such data should be disclosed and it is recommended that regulatory authorities take steps to achieve it.

Index Terms—power system modelling, test systems, power system data.

I. INTRODUCTION

Carbon reduction targets worldwide and growth of demand in fast industrialising countries are placing new requirements on electric power systems. Generation technologies being connected now, notably for conversion of wind energy, are quite different to those that have been established over the last 40 years and conventional solutions to enhancement of network transfer capacity, such as new overhead lines, are increasingly difficult to achieve. This is mostly due to the difficulty of gaining consents causing many years of project delays and attendant high costs. In cases in which high transfers are required over distances, conventional solutions lack cost-effectiveness when compared to HVDC.

Transmission owners are faced with the need for quite innovative solutions to providing enhanced transfer capacity. System operators must address operational issues associated with new generation and greater interconnection of systems, and all parties must work to maintain and increase stakeholders' confidence in continued reliable supply of electricity. There is therefore a need to study the potential impact of innovative solutions carefully before committing to them and investing significant amounts of capital. These studies must be carried out via simulations using suitable models.

This paper describes the need for new test system models to

meet the needs of researchers, system planners and operators when addressing future power system requirements. Such models should be detailed enough to permit accurate modelling of key phenomena associated with, in particular, wind generation and HVDC, but not so large or detailed that they preclude the development of understanding of those phenomena and how they are manifested and interact on a power system. These phenomena include power flows, voltage and transient stability and damping of power oscillations. The main aim is to understand how they might be managed and what degree of coordination of controls is necessary both in the steady state and dynamically.

The paper comprises two main parts:

1. a description of the main features required of new test systems for a first level evaluation of future power system behaviour, whether by utilities, consultancies or universities. These features include: number of buses; features of network branches and the need to include equipment such as phase shifting transformers, shunt and series compensation, FACTS and HVDC; key features of generator models; and representation of loads. Suitable criteria for validation of the model are also suggested.
2. a discussion of the models and data required for planners and operators to progress to the more detailed analysis required before commitment to action. Possible actions include implementation of grid code changes, acceptance of connection applications or signing of contracts for system reinforcements. In particular, it is argued that where technical data owned by independent power producers are regarded as commercially confidential, the commercial advantages associated with keeping such data secret and disadvantages of sharing them have been overstated. It is contended that it is in the collective best interest if independent power producers in these jurisdictions become more open about sharing of data and regulators set in train reforms to industry governance that oblige their release.

A final part considers data for modelling of availability of wind power.

II. DRIVERS FOR NEW TEST SYSTEMS

Carbon reduction targets set by governments and generous incentives or subsidies are driving investment in fast growing amounts of wind generation capacity in many parts of the world. This new generation capacity has very different technical performance characteristics from conventional

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generation that utilises directly connected synchronous machines. Depending on the prevailing wind conditions and the dispatch of plant, this can lead to the system being operated with a much lower inertia than now and, depending on the location of the main wind generation capacity relative to a short-circuit fault, stability margins that are increased or significantly decreased. Furthermore, the locations of the highest wind speeds are leading to wind farms being sited quite far from the main demand centres and in places that do not directly replace existing generation capacity.

The risks to system frequency and transient stability and damping associated with new generation must be carefully understood and appropriate measures developed to allow customary standards of reliability of supply to be maintained without undue restriction of wind farm operation. The difficulty for transmission owners to obtain permission for the building of new overhead line routes or the re-building of existing routes at higher voltages means that technologies long proposed for enhancing the capacity of an existing network will have to be more widely deployed than before or used in unprecedented combinations. An example of this can be seen in Great Britain (GB) where there is much interest among generation developers in the construction of new wind farms in Scotland. The time that is expected to be taken to gain permission for the building or uprating of conventional overhead line capacity through Scotland and across the border into England and the risk of approval finally being denied has contributed to the three transmission licensees proposing the development of two undersea HVDC links in parallel with the existing AC system (known as ‘bootstraps’) in combination with a number of installations of series compensation on and around the England-Scotland border [1]. Before committing significant sums of electricity consumers’ money (for the ‘bootstraps’ and series compensation, around US\$3 billion), the transmission licensees must be confident that the proposed solutions will deliver the expected benefits in terms of increased transfers of power from Scotland without introducing new risks to system stability or of sub-synchronous resonance.

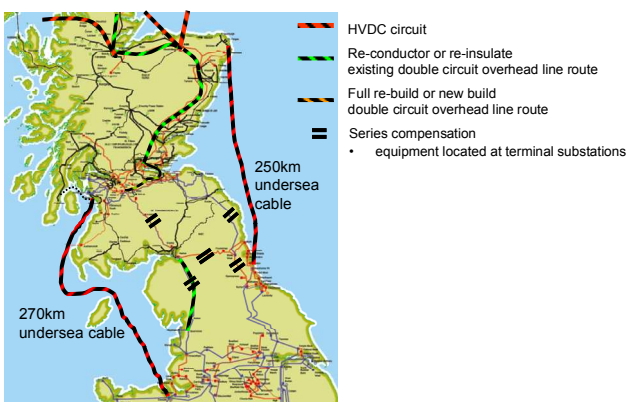


Figure 1: major reinforcements proposed in Britain to meet 2020 renewables targets [1]

Aside from accurate and relevant data (discussed in section

IV. below), studies to verify that system performance will be adequate under future conditions require suitable models. These include models of generation and power electronics and their controls, and of the network.

Ultimately, both the transmission owner and the system operator should be confident about the future performance of the system and be able to demonstrate it to other stakeholders. For that, a full and faithful model of the system should be used that includes the complete main interconnected system and all significant devices connected to it. However, to understand the effects of new generation or network technologies and how to control them, a thorough understanding of the existing system dynamics, controls, interactions, modes, and overall behaviours is required. This understanding should include answers to such questions as: How do the controls on HVDC links interact with each other and with series compensation? Will additional supplementary controls be required on HVDC and thyristor controlled series compensation (TCSC) and how can they be coordinated to support linear and non-linear system behaviour? Can the AC system support maximum flow on the embedded HVDC link and for what proportion of the time? Can controls on HVDC links and series and shunt compensation make contributions to system damping, or do they make it worse? What contribution might controls on wind farms make to system performance? Is system behaviour qualitatively the same over a wide range of initial conditions and disturbances?

To allow carbon reduction targets to be met, major network investment decisions have to be made over a planning horizon of at least 10 years. Incremental system changes, including new equipment, are relatively easy to plan. However, it is much more complex to study the impact of major step changes in the overall characteristics of a given power system that will include new generation technologies, new and previously unused network technologies and mostly unknown developments in new demand side technologies. The latter, e.g. electric vehicles, may have a significant impact on how the system is studied, planned and operated.

A prerequisite is to understand the nature of any new mechanisms new technologies introduce. To establish this understanding on a large transmission system like that in GB (standard models of which have, at present, around 2000 nodes and more than 250 individual generating units) is an almost impossible task without many years of experience already accumulated or an enormous amount of time and patience available. Even experienced engineers who are very familiar with the system and its present day behaviour will be prone to quite different interpretations of phenomena observed in simulations.

An example of this comes the experience of one of the authors. A study was conducted in 2005 of the transient stability and damping of the GB system in the presence of significant amounts of wind generation for 2020 [2].

Reduced system damping was observed when fixed speed induction generators (FSIGs) were added to replace synchronous machines. One member of the team thought this

was due to these machines adding negative damping. Another challenged this asserting that these machines inherently add positive damping in accordance with their Torque/Speed curve. A third team member thought both of his colleagues were mistaken. He argued that the torque of these machines is not in phase with speed and that there is a 90° phase lead as given by the swing equation. Depending on the phase relative to the oscillations on synchronous machines, he believed that the FSIGs should add positive damping for part of the oscillation cycle but negative damping for another part but overall the net outcome should be positive. He felt that what the first engineer had observed was correct (system damping was reduced) but that the main reason for it was that the removal of the synchronous machines also removed their power system stabilisers (PSSs) and that that had a greater net effect than the positive damping the second engineer believed would always be the net case. Finally, while the team continued to discuss what was the correct conclusion, they agreed that, in general, what would be observed would depend on how many synchronous machines are removed and that no general conclusions could be drawn.

Clear and consistent interpretation is hindered by excessive model complexity. On the other hand, an insufficiently detailed model will not reveal all the significant phenomena, not least those associated with interactions of controls on different equipment on a network (meaning that a 2 or 3-bus model is of strictly limited utility). In the end, a balance must be struck between the two extremes. This is especially the case when new technologies are being deployed whose basic individual behaviour may be understood but not their interaction with the AC power system. Experiments leading to the development of outline proposals for specification of controls on series transmission network devices are particularly unwieldy with a full model of a system with 2000 nodes and 250 machines. There is thus a strong need for a suitably sized test system for studies to allow development of understanding before validation of system designs and control specifications on a full model before placement of contracts and commissioning of equipment.

III. FEATURES REQUIRED OF A TEST SYSTEM

A. Specification of a test system

Work by the authors is ongoing to develop a suitable test system for use in study of future GB transmission system performance so a final model is not yet available for publication. However, the criteria being used for development of that model may be of interest to researchers in other places.

A wide range of technologies are being considered by transmission owners and operators to increase system transfer capacity and integrate wind farms. It should therefore be possible to use a test system model for study of the following:

- thermal, voltage, transient stability and power oscillation damping limits on power transfers.
- power transfer capacity improvements using series devices such as phase shifting transformers (PSTs), series

compensation or embedded HVDC links in parallel with the as system;

- coordination of control systems including design and simulation testing of control systems such as automatic voltage regulators (AVRs), power oscillation damping controllers on TCSCs and HVDC links, and PSTs; and
- the need for and performance of new controls on new devices such as PSSs and inertial response on converter controlled wind turbine generators. Changes in future system behaviour can be identified, e.g. changes in system frequency response and reserve needs due to reduced inertia brought about by the proliferation of wind generation and external HVDC links.

The main candidate circuits for series compensation or PSTs should be explicitly included in the network model. Direct simulation of those fault outages known to be critical on the present day system should be facilitated and the model should allow alternative generation patterns to be represented both in terms of installed capacity and dispatch of generation.

An example network model for GB is illustrated in fig. 2. This includes 28 400kV buses representing areas of the GB system and key hubs and is judged to be sufficiently detailed for study of control interactions for different patterns of generation but not so detailed as to give rise to the problems of complexity and interpretation outlined above. It represents a base case and would permit the effect of adding PSTs, TCSCs, embedded HVDC, and the locations of non-synchronous generation to be studied. (The details of such a model are currently under development and are intended to be reported in due course).

In line with the characteristics of the GB system, all the main routes between key hubs in fig 2 comprise double circuit overhead lines and are intended to represent the critical, long distance power transfer paths. While it would be possible to perform a numeric network reduction from the full system model based on a particular operating condition, some key objectives in the specification of the parameters of the branches of the representative network model should be kept in mind. The model should:

- reproduce line losses;
- preserve shunt gain on each main route;
- include variable shunt compensation at appropriate locations to represent that on the full system;
- preserve voltage angle differences between main nodes.

In order to simplify the model, exit transformers from the transmission system to distribution networks may be omitted so that loads are modelled directly on the 400kV buses. For steady state studies, constant power loads would represent a worst case. Sensitivity studies with voltage dependent loads might be carried out. For dynamic studies, loads might be represented at 400kV buses with shunt impedances.

In addition, in dynamic simulations, the network should be such that the model preserves those local and inter-area modes of oscillation that are expected to be present on the real system.

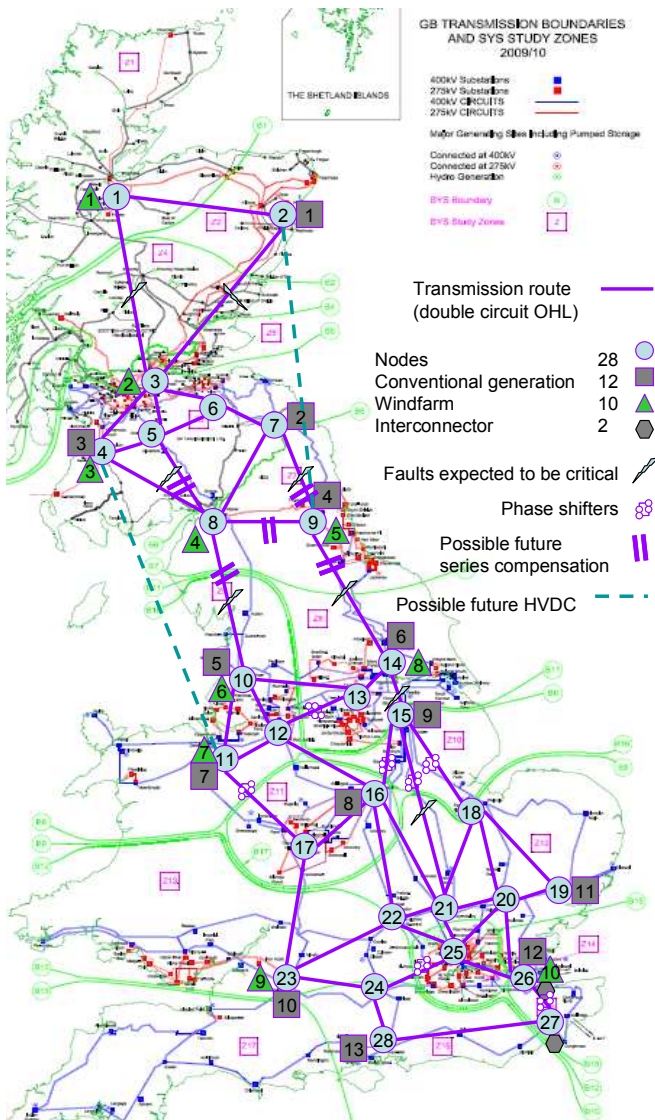


Figure 2: proposed 28-bus test network model based on GB system. (Background image from [3])

B. Generation

For dynamic simulations, synchronous generators should be modelled at the LV side of step-up generator transformers the HV side of which is connected at the local 400kV node. The positions of taps on transformers, shunt compensation and synchronous generation active and reactive power output should be determined appropriately in order to ensure adequate pre-fault voltage profile and initial rotor angle of each synchronous machine in the initial condition of each operational scenario being studied.

Equivalent circuits can be used for wind farms where each includes an equivalent machine, an equivalent transformer and some cable susceptance. Separate equivalent circuits for each wind turbine generator technology should be used.

For studies involving only steady state analysis, generator transformers can be eliminated with the generation modelled as PV buses with suitable Q limits at the HV side.

In initial studies of new network technologies, generic

models for AVR, PSS and governors may be expected to suffice. (See section C. below on dynamic performance for remarks on tuning).

Conventional generation would be represented in the test system at those locations at which large stations are expected to remain in the future scenario under consideration. Wind farms might be represented by some mix of generic doubly-fed induction generators and fully rated converter based plant. (There is now expected to be relatively little fixed speed induction generator capacity in Britain).

C. Dynamic Performance

In setting the initial conditions for dynamic simulations, generation dispatches and power transfers should be determined so that:

- post fault power flows are within post fault short-term ratings;
- the system is voltage stable (transient and quasi-steady state) with $\pm 10\%$ steady state voltage changes;
- the system is marginally first-swing stable;
- the system has marginal positive damping with a damping ratio of the worst eigenvalue of $+1\%$.

The above conditions would represent what would feasibly be possible before the addition of such technologies as series compensation or 'embedded' HVDC. The benefits of these technologies and of different controls might then be explored. Alternatively, the model might be 'tuned' to broadly represent some real system condition. This is discussed in the next section below.

D. Validation of a model

Various performance criteria have been suggested above for a test system. Although the network model suggested in fig. 2 is an attempt to represent the main hubs and routes on the present day GB transmission system, if the purpose of a test system is to understand phenomena associated with new technologies, in particular their interactions, it may be argued that closeness of reproduction of a real system is a low priority. However, while a system operator or transmission owner would, justifiably, not see the purpose of studies using a test system as being to prove or disprove the necessity of system reinforcements, other stakeholders would see these studies as helping to understand the applicability of new technologies in a very particular 'real world' context and increase confidence in them.

Recognition of other stakeholders' need for confidence may drive the designer of a test network to try to develop it in such a way as to broadly reproduce behaviours that can be seen on the real network. However, it must be recognised that the formation of a reduced dynamic equivalent is something of an art and a representative model cannot be expected to reproduce the full system's behaviour precisely. For example, a real system with 250 machines will have 249 oscillatory modes while a test system with 10 machine groups will have only 9 modes. The best that can be expected would be some kind of qualitative similarity.

Clearly, exactly what performance is seen depends not only on the scope of the model being used but also on the scenarios being modelled (in particular what generation is connected and where, and what the level of demand is), what system reinforcements can be assumed to have been carried out and what new technologies are being included. For some future scenarios it may not be possible to establish an initial condition that is stable from a voltage point of view without building in significant conventional reinforcements such as shunt compensation.

A particular near future scenario may be chosen as the basis for qualitative adaptation of a test system model to full system performance. This scenario would be one for which behaviour of the full system has already been reasonably well studied and would provide a reference. For example, for a similar dispatch of power (measured by total generation in each zone of the system and the mix between different technologies), the total power transfer across the main system boundaries should be similar in a full system model and in the test system. For a short circuit well known to be critical for the system in that future year, the critical clearing time between the full model and the test system model should be similar, and the damping coefficient should be similar. However, all users of the test system and of results from it should be well aware of the caveats associated with it. Specifically, results may indicate that particular technologies show promise and can be pursued with increased confidence in a more detailed analysis; or they may raise doubts and increase the need to look for other options for the facilitation of renewable generation. In neither case should the results be seen as conclusive.

As has already been explained, a test system model of suitable size permits a good first appreciation of system behaviour with new generation and network technologies and will aid the development of new controls. However, possible next steps such as implementation of grid code changes, acceptance of connection applications or signing of contracts for system reinforcements require testing of new technologies and controls on a detailed full system simulation that uses as accurate a set of information as possible. Issues associated with that information are discussed in the next section.

IV. ACCESS TO DATA

While it has been suggested in section III. B. above that generic models for generators, AVRs, PSSs and so on may suffice for initial exploration of the effects of new technologies, it is also suggested in section III. D. that a 'full' system model will be required for further study of system behaviour before committing to major capital expenditure, the granting of generation connection rights or the implementation of major grid code changes. In many parts of the world, such as Great Britain, such study would present a significant problem for independent researchers.

The electricity supply industry in Britain was liberalised in 1990. In England and Wales, ownership and operation of generation was separated from that of transmission and, in Scotland, transmission system operation is independent of

generation. (The transmission owners in Scotland have affiliation with generation companies).

In recognition of the system operator's responsibilities in respect of secure and stable system operation, one of the requirements of connection to and use of the system under The Grid Code [4] is that generation companies submit specific data to the system operator describing the characteristics of their plant and their controls.

Although concerns have arisen periodically regarding the accuracy of the data provided by generators, the provision of information has hitherto proved adequate to permit reliable system operation. However, these data are not normally made available to anyone else. The only exception relates to the transmission owners (TOs) in Scotland though then, for new generators, only for those judged to be within the 'zone of influence' [5] for imminent connections to the system in Scotland to allow the Scottish TOs to discharge their immediate responsibilities in respect of the design criteria of the 'Security and Quality of Supply Standard' [6].

In North America, the independent power producers (IPPs) are generally required to provide a generic dynamic model of their generator sets to be included in a large system model. The generic model is selected from among a few IEEE models [7] and parameters are tuned to make the response close to the reality. For interconnection studies, however, usually a detailed model is used by the utility and IPP, but this is normally not disclosed to others.

In projects done by consultants for utilities, the consultant usually receives a reasonably accurate model to work with. This contrasts with custom and practice in Britain where all dynamic studies are done in-house by the utility or with the support of contractors who are directly supervised by TO or system operator staff and do not take data off site.

While generic generator models may be argued to be generally acceptable, the results of system stability studies are often highly sensitive to the detail of control and protection models, in particular in their representation of non-linearities. This much was a conclusion of an investigation of a system disturbance by the Midwest Reliability Organization in 2008 [8]. In [8], it was recommended that the industry should be provided with detailed models of all aspects of third party generation – machines, protection and control.

In Australia, generation companies are obliged to provide models and data to the system operator which in turn can share the majority of the information with the 'host' transmission network service provider (equivalent to TOs in Britain) where the generator is connected. In addition, the generators are obliged to provide user guides that aid use of the models and data provided. Unlike in some other jurisdictions, any 'registered participant' in the national market can apply to be given data – in addition to generators and network service providers at transmission and distribution voltages, this includes retailers and *prospective* generators. However, only those parties responsible for ensuring system stability – the system operator and relevant network service providers – receive full block diagrams. Others receive 'black box' models

that are designed to produce suitable outputs for a given set of inputs without revealing the contents of the box [9]. (Provision of ‘black box’ models is also a feature of the North American industry). None of these parties have the right to pass models on to anyone else.

The situation in much of Europe is less developed with respect to exchange of data, perhaps largely because there are, as yet, relatively few independent operators of generation. The parameters of generators and their controls that are provided to transmission system operators (TSOs) are regarded as confidential and not shared with third parties except neighbouring TSOs. However, as is discussed in section B. below, not even positive phase network models or the capacities of individual power stations are made available outside the TSO community. (On the rare occasions on which network data is shared with third parties, e.g. universities for research studies, the names of substations and power stations are changed and no location information is provided.)

A. Non-disclosure of data

It is the opinion of the authors of the present paper that the non-disclosure of data relevant to dynamics studies on the full system is untenable.

The only party holding data relating the detailed dynamic characteristics of all transmission connected generating plant in Britain is the GB system operator (GBSO), i.e. National Grid. It has been argued by National Grid that it has this data only by virtue of the requirements put on the generators by The Grid Code [4], does not own the data and has no right to disclose it to third parties. Third parties might approach individual generating companies for data and then assume that similar generating plant owned and operated by other companies has similar characteristics. The response to such a request will depend on goodwill or whether the generating company itself has commissioned the study, in which case a confidentiality agreement will normally be put in place preventing disclosure.

While the development of the system was incremental and there was no apparent need for research into the effects of some technology ‘step change’, the main effect of the restrictions in Britain was arguably that postgraduate students lacked accurate models upon which to base their own learning of the dynamic behaviour of power systems in general and the GB power system in particular. However, as was described in section 1 above, the industry is now facing a number of major technological developments: wind energy, FACTS, HVDC and so on.

A wide range of parties now have a legitimate interest in understanding the behaviour of the future power system. In response to targets set at a European level, the UK government has set targets for the energy to come from renewables by 2020 and is anxious to facilitate the development, connection and utilisation of renewable electricity generation. It is told – correctly – by industry insiders, consultants and academics that significant technical issues need to be addressed if electricity users are to experience the reliability of supply to which they

have become accustomed and costs are not to be excessive. While it might ask National Grid to conduct research into these issues and report the outcomes, suspicions – well-founded or otherwise – of National Grid’s motives arising out of regulatory and commercial arrangements and the simple desire for more than one opinion lead it to want others to conduct studies. Members of the wind industry might similarly want to commission their own studies to test assertions by the transmission licensees that connection to the system is not possible before certain reinforcements are carried out or that particular Grid Code changes are necessary. Moreover, National Grid itself might want to commission independent studies for forestall suspicions about its own analysis. However, what could be reported would be limited; due to the non-disclosure of key data, readers of the outcomes of studies would not be able to fully test them.

B. Effects of disclosure

As has been noted above, detailed technical data describing the characteristics of existing or planned generation in the UK are the property of the generating companies.

It may be argued that such data are commercially sensitive and their disclosure would put their owners at a commercial disadvantage. However, the authors fail to see how disclosing the actual parameters of controllers that are mostly based on public domain standard IEEE controller structures would result in a commercial disadvantage. It might be argued that there would be new costs associated with the practicalities of making them available. However, the companies already have to make them available to the system operator.

For anyone receiving data relating to generator dynamics, the commercial advantage they could gain from it might be questioned. Arguably, the main commercial opportunities arise from knowing what generation capacity each company has, what type of prime mover it uses, how old it is and where it is connected. All this is already published, annually, in the Seven Year Statement (SYS) [3]. Some advantage might come from knowing a competitor’s plant’s energy conversion efficiency, but that is not passed on under the Grid Code anyway. Even reactive power and frequency response capability have default values under the Grid Code and are subject to markets in which information is published.

An alternative perspective is that of the transmission owners and operators. These are the parties that have the clearest responsibility in respect of system security and network investment and they will be sensitive to challenges being mounted to their decisions and recommendations by others who are not fully conversant with all relevant information. Certainly, such third parties should be aware that it will be unlikely that they will have better knowledge and understanding than the relevant TO or SO, even if generator dynamic characteristics were to be published. However, greater openness on the part of TOs and SOs ought to encourage greater trust in them.

A further point-of-view is that of equipment manufacturers. Manufacturers might wish to hide some aspects of their

products, assuming third parties were able to determine which generators used which manufacturer's kit. In recent times, this has applied particularly to wind turbines. In respect of power electronics based network controls, block diagram models normally suffice for system stability studies and need not reveal the detailed topologies of the equipment. In addition, it is in everyone's best interests that the system as a whole performs well and that all aspects can be seen to comply with relevant standards such as grid codes.

In some respects, researchers, consultants and investors in Britain are at a significant advantage relative to the rest of Europe in that a lot of information is already published in the SYS. As well as generation capacities and types, a full set of positive phase sequence parameters and ratings is published for the transmission network. It is a licence obligation for National Grid that it publishes the SYS, the motivation being to inform the market regarding opportunities for development of new generation capacity and to allow potential investors to study and understand the transmission power flow consequences of different developments. A strong argument may be mounted for regulators in the rest of Europe to place similar obligations on system operators there.

With such great technical challenges and opportunities now facing the industry and no sign that they will go away soon, it is important that university power engineering groups – many of which in the UK and North America were forced to scale back their activities in the 1990s and the early part of the current millennium – are able to respond. To do that, they need ready access to technical data. It is true that PhD students are likely to be daunted by the detail of models of actual AVRs or PSSs with 50 or more states, some time constants as short as 1ms, many non-linearities and sometimes significant differences in results when different software are used to model what are apparently the same controllers. However, companies that have long since downsized their own research departments are increasingly looking to universities to undertake professional analysis with industrially applicable results. To gain a full appreciation of power system behaviour, university researchers should understand the system's sensitivity to the details of control and protection models, in particular, and be fully aware of the importance of data and their maintenance.

The benefits of access to realistic data do not relate only to the discovery of solutions to technical problems. While some university studies do lead to new products or changes to industry practice, in recent years relatively few have, partly due to the nature of a PhD and partly due to the nature of research. However, a good university programme of research should always lead to new expertise being available, either in an academic position in a university or, most importantly, in industry in the form of a person with advanced knowledge who is now very well placed to propose, test and implement solutions to real industry problems. As is described in [10], the electricity supply industry in the UK has an urgent need for engineers at all levels and particularly for a critical number of professionals who can exercise what is called in [10]

“engineering leadership” and be in the vanguard of facilitation of the low carbon future.

While the need to publish the SYS on an annual basis is a licence condition, exactly what goes in it is not. The electricity supply industry regulator in Britain – Ofgem – has the power to oblige National Grid and the other transmission licensees that contribute to the SYS to change what is published. Steps might be taken by Ofgem to permit and require the publication of generator parameters provided under the Grid Code.

C. Wind power time series

As is noted in [11], there is considerable debate about the power system costs associated with wind generation. For example, what is the likelihood and spatial extent of a ‘cold, still day’ on which demand is high but wind generation is unavailable? How much operating reserve is required under different conditions? How much network capacity is required to connect a group of wind farms and be able to use them without excessive curtailment of the wind energy?

The lack of publicly available wind power time series for wind farms spatially distributed across a system prevents resolution of the debates and permits anyone to make an assertion without solid evidence. Each individual generating company has its own SCADA data recording the performance of its own plant, but is, for commercial reasons, reluctant to release such data. (The same applies for conventional plant). In Britain, National Grid has access to half-hourly data through its position as operator of the Balancing Mechanism, but generally declines to disclose it.

The above position seems strange as half-hourly data for each generating unit in the Balancing Mechanism is already published [12]. However, only the intended outputs of generators one hour ahead of real time is published – the ‘final physical notifications’ – along with bid and offer prices for decreases or increases of output, and not the final physical outputs or bid and offer acceptances. In addition, while archive data can be found at [12], only intended values can be retrieved and then only for one generating unit at a time. Again, outturn values are not available. For a website that the market operator is obliged to provide in order to inform the market, it is very difficult to get good information.

V. CONCLUSIONS

This paper has discussed the need for new test system models to be developed and made available to researchers. A number of features of such test systems have been proposed. These include sufficient size and scope to allow control interactions to be studied but not so much that phenomena associated with new technologies cannot be understood.

Notwithstanding the conventional use of generic models in test systems, it has been recalled that the performance of new technologies and their controls should be verified on a full system model that is as faithful to the real system and its parameters as possible. Third parties are increasingly being asked to carry out such studies or to verify studies carried out by system operators. This requires access to data often owned

by generating companies to which system operators have access but do not feel able to disclose.

It has been argued that the commercial advantages associated with keeping generator dynamic characteristics secret and the disadvantages of sharing them have been overstated, and that it would be in the collective best interests of the industry, innovation, the development of new 'engineering leaders' and the meeting of carbon reduction targets if regulators put measures in place permit such data to be disclosed and to oblige it to be done. It is recommended that regulators use the powers available to them to do this and that generating companies take a holistic approach and do not seek to block them.

VI. ACKNOWLEDGEMENTS

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