Beyond Capacity Markets - Delivering Capability Resources to Europe's Decarbonised Power System

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***Abstract*—A closer look at the new reliability challenges associated with meeting Europe's decarbonisation targets suggests that our collective thinking will need to evolve "beyond capacity markets" in order to address them. In particular, the power system will need resources capable of rapidly changing output or flexing demand frequently and continuously throughout the year around the energy availability from variable renewables. Based on these requirements and related considerations, we develop a set of market design principles that can be used to assess the suitability of proposals intended to deliver system reliability. The proposal to introduce a capacity payment mechanism being considered for Great Britain is reviewed against these criteria. Our analysis suggests that it will not be capable of meeting the system reliability challenges or taking advantage of emerging opportunities ahead.**

***Index Terms*—Power system reliability, capacity markets, renewable integration.**

I. NOMENCLATURE

Ancillary services: Services that help the system operate continuously within required parameters (e.g., frequency and voltage range), including the ability to recover energy balance after significant unplanned changes in supply and demand.

Balancing services: Purchases and sales of energy made by the system operator close to real time that are necessary to correct current or expected imbalances between supply and demand for each trading period. Generally occur after bi-lateral physical markets have closed (gate closure).

Baseload, mid-merit, peak-load generation: Operation mode of a generating plant based on a combination of technical and commercial factors (e.g., how economically the plant can run at different load factors). Operation that occurs all or most hours is referred to as 'baseload,' only for short periods to meet system peak is known as 'peak,' and operation falling between baseload and peak is referred to as 'mid-merit.'

Capacity markets: Encompasses the range of capacity payment mechanisms designed to remunerate market participants for committing a volume of firm capacity to generate power or reduce demand by an equivalent amount during hours of system peak demand.

Capability resources: Products and services that need to be delivered to a decarbonised power system in order to maintain system reliability over both the short- and long- term. Includes capabilities that require investment in the right mix of generation, demand-side resources, storage and grid resources to deliver flexibility and other attributes necessary to cost-efficiently balance systems where there is an increasing proportion of renewable power.

Demand response (or 'responsive demand'): Customer loads that can be modulated up or down in real time in response to wholesale market conditions, expressed either in wholesale prices, via frequency or voltage fluctuations, or through arrangements allowing direct control by the system operator or a third-party aggregator.

Demand-side resources: The full range of customer-based resources (end-use energy efficiency, demand-response and customer-sited generation) that reduce energy needs at various times of the day and year—across some or many hours.

Dispatch: Unit commitment day ahead and adjustment to the output of system resources in line with real time changes in the level of demand.

Firm capacity: The volume of megawatts guaranteed to be available to provide energy to the system at any moment in time.

Load factor: A measure of the output of a power plant compared to the maximum output it could produce.

Net demand: Demand for energy not already served by the output of variable renewables.

Reliability: Ability to meet the electricity needs of customers connected to the system over various timescales even when unexpected equipment failures or other factors reduce the amount of available electricity. Consistent with current industry practise, 'reliability' can be broken down into two general categories—resource adequacy and system quality.

Resource adequacy: Enough of the right kinds of resources to match demand and supply across time and geographic dimensions and deliver an acceptable level of reliability. Traditionally a "volume-based" standard based on the amount of firm capacity available to meet system peak demand.

System administrator(s): Entities authorised to perform planning, operational or investment-related functions in power markets (e.g., system operators, planning authorities).

System peak demand: Highest instantaneous level of total energy demand on the power system over a given period of time (e.g., daily peak, seasonal peak, annual peak).

System quality: Short-term, reliable operation of the power system as it moves electricity from generating sources to retail customers, including the ability of the system to withstand unanticipated disturbances or imbalances in the system. Balancing and ancillary services contribute to system quality.

Variable renewables: A power system resource using a

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primary renewable energy source that cannot be controlled (e.g., solar- and wind-powered generation). Such resources can be curtailed if needed and to varying degrees available capacity can be held as reserve; however, their availability is significantly less controllable than conventional thermal generation.

II. INTRODUCTION

DELIVERING a reliable power supply to consumers has always been a central objective of market design and various solutions to this challenge have been adopted in Europe and elsewhere. This diversity of approach in part reflects the differences in power system characteristics, including the mix of resources used to generate electricity and to balance supply and demand.

The EU Commission has now published a suite of documents setting out the roadmap to a decarbonised economy in 2050 that highlights the required developments in the power sector [1]. This analysis confirms that the share of power generation provided by renewables will need to continue to increase after 2020 in all scenarios considered, exceeding 50% by 2030. Resource availability within Europe implies that a significant proportion of this renewable generation will need to be produced from variable renewables (e.g. solar, wind), and as such the power system assets for which they are the primary energy source are only partially controllable.

This paper sets out the future reliability challenges compared to the past, and briefly describes the general approaches undertaken to deliver power system reliability in Europe and elsewhere since the introduction of market restructuring. The nature of the reliability challenges in the context of Europe's 2050 decarbonisation objectives suggests that these approaches will not be well-suited to the task ahead, and in fact could foreclose highly cost-effective opportunities for maintaining system reliability while increasing the share of renewables in Europe's power mix. New approaches for engaging the market in delivering reliability solutions will be required, but they cannot be discovered until the debate moves "beyond capacity markets" for the reasons discussed in this paper. To enable that discovery to take place, we outline a number of key market design principles that policy makers can use as a practical screening check-list to assess the suitability of different design options to deliver reliability. This check-list is applied to the electricity market reform process currently underway for Great Britain and concludes that the approach being adopted by the Government is unlikely to address the system reliability challenge ahead.

III. FUTURE DEVELOPMENTS: CHALLENGES AND OPPORTUNITIES

A. *Challenges*

Integrated power systems require that supply and demand continuously balance to maintain a stable system frequency and reliable supply for system users. This continuous balance is achieved through ensuring that there are sufficient resources on the system to meet total demand (resource adequacy) and adjusting the output of these resources in line with real time changes in the level of demand (dispatch). Other services must be provided to maintain system quality, including the provision of frequency response and fast reserves to cope with significant changes in supply and demand that cannot be predicted or controlled (e.g., the loss of a large power generation plant).

Historically, power systems have been operated on the basis that output from generation assets can be controlled to follow changes in consumer demand. Under these circumstances, if sufficient capacity is available from those generators to meet system peak demand it is reasonably assured that they can be operated/dispatched to meet total demand at all times with an acceptable level of confidence. Therefore, the resource adequacy challenge is met by delivering a total volume of firm capacity (megawatts) to the system sufficient to meet the relatively few hours of system peak demand. Firm capacity from various types of generating plant (those operating in base-load, mid-merit, or peaking modes) can deliver firm capacity during these hours, and therefore are considered equally valuable in meeting resource adequacy requirements under this traditional view of resource adequacy.

However, the increase in the share of supply from variable renewables will change the nature of the system and the associated reliability challenges in important ways. The principle change is that it will no longer be possible to control the availability of a significant proportion of the generation capacity. At the same time this capacity is among the most capital-intensive and lowest operating cost generation on the system. Once these generators have been built, the least-cost approach is to utilise as much as possible of the energy produced when these resources are available, before turning to supply resources with much higher production costs.

The challenge for the dispatchable resources on the system is, therefore, no longer to follow changes in overall consumer demand, but rather to follow changes in the residual 'net demand' not already served by 'free' energy from variable renewables. The result of this paradigm shift is illustrated in a recent report that modelled 35% energy penetration of wind, photovoltaics (PVs), and concentrating solar power (CSP) on the power system operated by the WestConnect group of utilities in Arizona, Colorado, Nevada, New Mexico, and Wyoming [2]. Fig. 1 shows a relatively benign week when the net demand follows a repeatable pattern that is not dissimilar to the overall system demand. Fig. 2, however, illustrates a more challenging week where the profile of net demand is much more

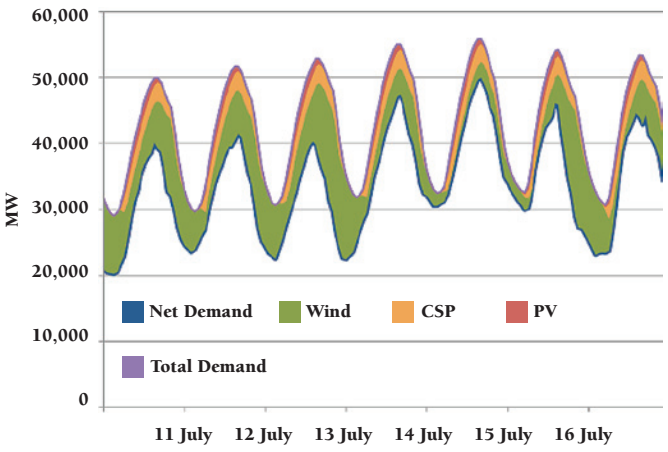

Fig. 1. Benign week modelled in the Western Interconnection Wind and Solar Integration Study [2].

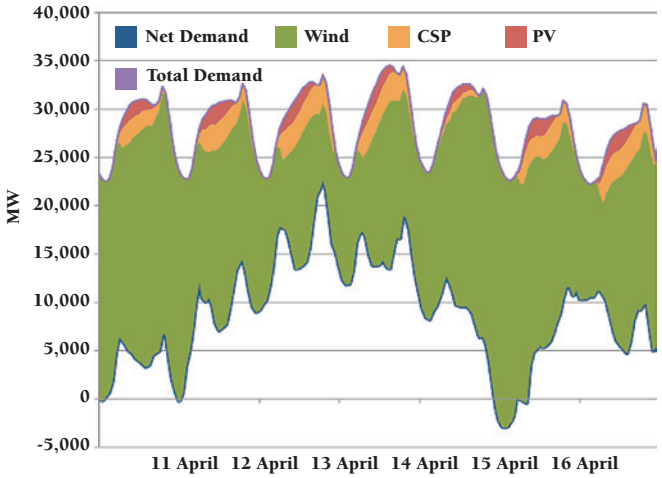

Fig. 2. Challenging week modelled in the Western Interconnection Wind and Solar Integration Study [2].

volatile than overall demand and does not follow a repeatable pattern. Dispatchable resources with the operational flexibility required by this new paradigm once constituted a limited share of the supply portfolio, but the new supply paradigm will call for flexible resources, including responsive demand, to play an ever larger role. It will be more volatile and costly to balance the system if the dispatchable resource base continues to be dominated by unresponsive generation.

An analysis of net demand therefore highlights that while having sufficient firm capacity to meet peak system demand remains necessary, it is no longer sufficient to the task of delivering power system reliability at least cost. Therefore, the quantity of firm capacity no longer constitutes the sole basis upon which resource adequacy should be determined. Put another way, the most challenging threat to reliability is no longer overall peak system demand. Instead, the biggest challenge arises when consumer demand and the availability of variable renewables is changing in opposite directions, something that (unlike the peak in overall system demand) can happen any day, every day, at any time during the day, and even several times a day. It will occur to the greatest extent in situations when demand is either: (1) increasing system peak whilst the availability of variable renewables is reducing to a minimum, or (2) falling to system minimum levels whilst the availability of variable renewables are increasing to a maximum.

These circumstances highlight that the ability of resources to respond to a rapidly changing level of net demand is as important as the overall quantity of firm capacity. In the old reliability paradigm, megawatts of firm capacity from baseload, mid-merit and peaking generation each has an equally important role to play in ensuring resource adequacy. In the new paradigm, megawatts of capacity from inflexible generation will increasingly constitute a threat to resource adequacy.

B. *Opportunities*

Whilst the deployment of more variable renewables will tend to increase the challenge of delivering system reliability, other changes can be anticipated that will offset these concerns. For example, increased deployment of advanced instrumentation and communications technology will open up the possibility that significant proportions of demand can become price responsive in a variety of ways, including via direct control technologies and smart appliances. Other technological developments might significantly reduce the costs of storage or allow significant flexibility to be incorporated into combined cycle gas turbine designs at limited additional cost.

Forecasting accuracy is also likely to improve. Experience in the operation of an increasingly large fleet of renewable plant will give rise to significant advances in the accuracy of forecasting renewable output and, thereby, of net demand. Indeed, we should expect that improved forecasting capabilities will be accessible to an increasing number of market participants, and not remain the sole province of the system administrator.

Finally, it is already widely recognised that the reliability challenges of an increasing mix of renewables will be reduced by expanding the size of balancing areas through physical interconnection. (See Section V.G. below.) As more interconnections are developed between regions, the probability of extreme events will be reduced and the range of resources able to balance the system will increase.

Having described both the future challenges and opportunities for reliably operating the power system, we turn now to a brief overview of the way in which reliability has traditionally been delivered to the power system, and the role of system administrators in that process.

IV. TRADITIONAL APPROACHES TO DELIVERING RELIABILITY

A. *System Dispatch and Delivery of Quality Services*

Most jurisdictions have established a set of mandatory or legal requirements relating to quality of supply and some single entity is accountable for ensuring that these requirements are delivered. There is, therefore, the unavoidable requirement for some entity to dispatch supply (and that part of demand that is controllable) in operational timescales to ensure energy balance across the system. This includes maintaining the capability to respond to unplanned losses in supply and unexpected changes in demand. In addition, system administrators have traditionally defined the rules by which system quality is delivered, enforced legal requirements to ensure, or established financial incentives to encourage, the provision of the requisite balancing and other system quality services.

Therefore, from the outset of electric industry restructuring, system administrators have been responsible for system dispatch and the delivery of certain system quality services to electricity markets. They have created value in the market and opportunities for market participants to deliver the required services in a variety of ways. Across many power systems, including those that are fully liberalised, this has been accomplished via some combination of regulatory mandate, direct procurement through long-term contracts or short-term markets—the latter being most common with the provision of reserves and balancing energy. Indeed, the balancing mechanism, whereby the system administrator buys and sells energy in real time to maintain system balance, has become a critical element of power market design. In particular,

this mechanism is commonly used to identify a value for uncontracted production or consumption and to establish the market incentive for forward trading.

B. Resource Adequacy

The role of system administrators in delivering system quality has not been controversial and this role is expected to remain into the future. However, the role of system administration in ensuring resource adequacy has been the subject of much debate and no consensus has emerged [3], [4]. As a result, some countries or regions have introduced capacity payments alongside energy-only markets, and others have not. A detailed review of the arguments involved is beyond the scope of this paper; however, there are two important aspects of this debate that are worth highlighting:

1. The need to increase the predictability of earnings for resources with low load factors is often cited as a key reason to introduce an administered capacity payment mechanism. Increasing proportions of variable renewables, and the volatile net demand that this will create, will tend to reduce the predictability of earnings for low load factor resources and, thereby, increase the case in favor of a new mechanism to stabilise earnings.
2. The view of reliability as a 'public good' is also a reason why many governments have established an administered resource adequacy standard that is deemed acceptable to society as a whole, supporting the case for a payment mechanism alongside energy-only markets to ensure that it is met on a system-wide basis. However, the debate also points to advances in forecasting, instrumentation, and communication technologies that may over time enable a significant proportion of demand to become able and willing to respond to short-term changes in price.

The anticipated increase in levels of variable renewables has recently re-ignited the debate over the role of system administration in ensuring resource adequacy and several European countries are now considering the introduction of capacity payment mechanisms. There are various approaches to determining and allocating capacity payments. Whether referred to as capacity markets, reliability option payments, peak load reserve tenders, or other terminology is used, they all involve administrative determinations regarding price or quantity that focus on ensuring sufficient capacity during times of system peak demand [5].[1]

As discussed above, the new reliability challenges facing the power system will not be satisfactorily addressed through ensuring there is some fixed amount of available capacity without regard to the capabilities of the capacity. The dynamic capability of these resources will become increasingly important. Indeed, there are already examples of power systems where capacity markets have operated for quite a few years, with ample margin at system peak, and yet there remains a serious reliability concern [6]. Moreover, the clear line between the capabilities required to ensure resource adequacy and quality services is rapidly blurring as the latter becomes less about ensuring that sufficient capacity is available during peak demand periods and more about delivering the capabilities required to cost-effectively meet net demand in both operational and investment timescales. Notably, the US federal power system regulator has recently adopted an approach to compensate resources that stand ready to provide suppliers of certain ancillary services more if they are also capable of ramping up or down in response to a system operator's dispatch signal [7].

Therefore, the debates in Europe over whether (and if so, how) to introduce payments for capacity alongside energy-only markets need to be redirected to a more productive exploration of options and proposals. For this purpose, we outline below a set of market design principles that move "beyond capacity markets" to provide policy makers with a screening check list for assessing the suitability of proposals intended to deliver system reliability.

V. MARKET DESIGN PRINCIPLES

A. Overarching Principle

Power markets with an increasing proportion of variable renewables will need to deliver the right kinds of capability resources (supply-side, demand-side, storage, and grid) to match demand and supply such that electricity consumers continue to enjoy comparable levels of system reliability over the coming decades at lowest overall cost. As described below, the market design must fulfill a number of requirements in order to meet this high level principle.

B. Make the most of existing resources, especially demand-response

It is likely that the innate flexibility of the power system goes significantly beyond the balancing services traditionally procured by system administrators. Experience suggests that the latent demand response capability is both considerable and highly cost-effective relative to flexible supply-side alternatives. For example, in the most recent capacity auction conducted for the PJM wholesale market,[2] the independent market monitor calculates that demand-side resources (predominately flexible, demand-response) saved customers 10-20% in reliability costs region-wide, and 30% in the constrained power zone [8]. These data suggest a total consumer savings of $1.2 billion due to demand-side participation for a single annual auction [9]. Experience with the forward capacity markets in the US, such as the one implemented in PJM, reveals that a concerted effort to design market rules to remunerate capability resources on the demand-side as well as supply will engage sizeable customer participation [10].

"Capability-based" market design that engages the demand-side has also enabled consumer aggregators to provide frequency response using innovative technology and communication

1 No single reference describes the design parameters for each capacity payment mechanism that has been explored in the academic literature or in practise. An overview of several key approaches to paying for capacity that reveals their reliance on peak demand pricing or volume-setting is presented in Reference [5].

2 PJM is the regional system operator for the largest competitive wholesale electricity market in the US, encompassing all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.

systems.[3] However, in other instances where the demand-side could contribute to the improvement of system quality there has been very limited progress in designing market rules to tap that potential. In general, it has often proven difficult to access flexible, demand-side capability resources because most of the market solutions have been designed with supply side resources in mind. The value of flexibility must, therefore, be readily accessible to potential providers of demand response.

In addition, the flexibility of existing supply-side resources can usually be improved through investment and changes in operational practises. For example, in Denmark the flexibility of combined heat and power plant, which had previously been considered inflexible, has been increased through the incorporation of heat storage [11]. Again, this requires that a clear value for flexibility must be apparent to plant operators and conversely, power plant that is not flexible or flexible enough should not be rewarded equally with assets that provide the necessary flexibility.

C. Ensure new resources have the right capabilities

Over time, existing resources will become uneconomic, often as a result of changes in environmental regulations or the cost of carbon emissions, and will be closed. This, in combination with any underlying growth in demand, creates the requirement for new resources to maintain reliability standards. Traditionally, new power stations have been built in the expectation that they will operate at base-load for 5-10 years and they have been designed to maximise efficiency, often at the expense of operational flexibility. In the future, this will not be the case and new resources are likely to be required to operate with high levels of flexibility immediately after commissioning.

Model simulations from a recent European study illustrate how dramatically different the operating requirements of the generation fleet will have to be to balance net demand by 2030 with approximately 50% total renewables in the mix (including large hydro), a large proportion of which are variable [12].

Fig. 3 presents the number of start-stops through the year in a region where the average load factor of the large mid-merit fleet is quite "typical" (58%). Over 260 start-stops per year underlie that average. This represents a dramatic change in flexibility requirement compared to current operations of mid-merit combined cycle gas plants, which typically start-stop well below 50 times a year. Consistent with these data, Siemens has recently forecasted 2020 residual demand that requires the remaining fossil-fleet needs to operate between 75% and 100% daily start-stop [13].

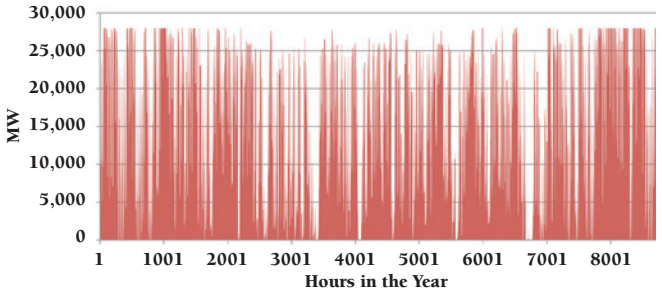

Fig. 3. Operating profile of mid-merit combined cycle gas turbines (CCGT) in 2030 for southern UK: example of large CCGT fleet with "typical" average load factor (58%).[4]

To deliver new capability resources to the system, it is therefore essential that the nature and value of the required dynamic capability is apparent to the investor and can be incorporated at the time the investment case is being considered. Again, it is important that resources that do not possess the required flexibility are not able to access this value.

D. Consistency with decarbonisation objectives

It may be that the resources that can provide flexibility most cost effectively also have high CO_2 emissions (for example, diesel generators or existing large oil-fired power plant). The carbon intensity of the resources providing flexibility should be factored into market design such that delivery of the overall carbon reduction targets is not compromised. Although this is unlikely to present a material constraint in the short term, it may become significant within a few decades given the expected decarbonisation trajectory for the power sector. A case study of the forward capacity markets in the US, for example, "followed the money" to examine what types of resources were receiving the capacity payments under that market design. The study found that the vast majority of the revenues went to existing high-emitting fossil-fueled generators, many of which had load following capabilities, but relative to the requirements of the future illustrated above would not be considered flexible enough [10]. The report's conclusions were corroborated by the independent market monitor about a year later with the release of data for the past 6 annual auctions conducted by PJM. Existing fossil-fueled resources (gas, oil and coal-fired) received 70% of the $42 billion in capacity payment revenues under those auctions and the corresponding market design [14].

E. Consistency with renewables investment

The costs associated with procuring the necessary suite of capabilities will need to be recovered in some way. This may be through allocating the costs to un-contracted parties, sharing the costs proportionately across market participants, or some combination of these approaches. It can be difficult for variable renewables to accurately forecast their output more than a few hours ahead and, therefore, achieve contractual balance. This problem can be exacerbated as a result of limited liquidity in within-day markets. Historically, it has been common to insulate renewable generators from imbalance settlement prices through a feed-in-tariff support mechanism. However, as the proportion of renewables on the system increases, it is likely that policy makers will increasingly look for ways to minimise the short-term balancing challenge, e.g., by introducing incentives to encourage accurate forecasting of output and self-balancing in the bi-lateral contract markets. If the allocation of balancing service costs results in imbalance settlement prices that are volatile and difficult to predict, then this could present a significant earnings risk to renewable generators. This, in

3 An example of these innovative technology and communication systems can be found at http://www.enbala.com/gridbalancedemo.html.

4 Source data for Fig. 3 compiled by RAP Europe in consultation with KEMA for four representative centers of gravity reflected in the model runs for Reference 12.

turn, can feed through into financing costs and even the ability to access capital for investment. It is, therefore, important that the approach adopted to deliver reliability does not lead to unintended adverse consequences for renewable investment such that Europe is unable to meet its 2050 decarbonisation targets.

F. Innovation and change

A key rationale for introducing a renewable support mechanism involves the need to drive down the costs of immature technologies that have significant long term deployment potential. This same principle should be applied to those technologies required to integrate renewables onto power systems. Certain heat and power storage technologies have the potential to make significant contributions in the future towards system flexibility and, where appropriate, it should be possible to promote the development and deployment needed to deliver future cost reductions. This logic may apply to other promising technologies such as those required to increase the potential for demand response.

More generally, it was highlighted above that the future brings opportunities as well as challenges. It is important that solutions adopted to deal with the challenges do not eliminate the potential of individual consumers to express and act upon their individualised preferences for service reliability in the future, as new technologies and communication systems emerge. Proposals should be designed to recognise these opportunities, as well as avoid foreclosing them or removing incentives to innovate. This involves a careful balancing act and will depend on judgements relating to the imminence and extent of the challenges and expectations for new solutions to emerge.

G. Future Integration with Neighbouring Balancing Areas

Cost-effective decarbonisation will require increased interconnection between regions or neighbouring power systems to facilitate the much more frequent need for transfers of low-cost energy from areas in surplus to areas where such low-cost energy can displace more costly alternatives. This increased interconnection capacity offers the potential for capability resources to be shared, reducing overall resource requirements. For this to be effective it will have to be accompanied by real-time energy balancing over wider areas, reducing the probability of extreme events and again reducing overall resource requirements. Market design should therefore aim to exploit these advantages. Rather than designing capability mechanisms in isolation, this suggests the need for some harmonisation in design across adjacent power systems or regions [15] – [17]. Therefore, reforms to address reliability challenges that are potentially scalable for a broader, regional balancing area or adjoining power markets have particular appeal. Nonetheless, differences are likely to persist in power market design across interconnectors for the foreseeable future. This speaks to the need to incorporate into reliability payment mechanisms any mitigating measures available to enable effective coupling with adjacent markets, consistent with the purpose of the European target model for market integration. [18][5]

5 For a discussion of the European market coupling model and these potential mitigating measures, see Annex 1 and 2 of Reference 18.

H. Market design check-list

The set of requirements above can be converted into a screening check-list for policy makers considering the introduction of mechanisms to address reliability, or those assessing the future integrity of existing schemes.

Does the proposed mechanism:

1. Seek to deliver the range of capabilities that system will actually need to meet net demand with an increasing proportion of renewables?
2. Maximise the potential for existing resources to deliver the necessary capabilities before resorting to incentivising more expensive new resources?
3. Seek to secure services from all potential resources, in particular, the demand side?
4. Ensure that resources that cannot provide the necessary range of capabilities (e.g., inflexible generation) are not remunerated or receive less revenue compared with those resources that do provide the capabilities?
5. Recognise the carbon content of resources procured to provide the range of capabilities?
6. Charge the costs of reliability services in a way that avoids creating earnings risks that are difficult to manage for renewable generators? To the extent that these risks are increased, does the proposal address how the potential adverse impact on the deployment of renewables can be addressed in other ways?
7. Deliver reliability in a manner that promotes future cost reductions and innovation in the provision of flexible capabilities and avoids foreclosing the market to future providers?
8. Create a potentially scalable design, including the future integration of neighboring balancing areas and the sharing of capability resources? Consider potential effects on market coupling and available mitigating measures?

A positive response to each of these questions suggests that a proposed market design is robust whilst negative responses to any of the questions should raise significant concerns.

VI. MARKET DESIGN PROPOSAL FOR GREAT BRITAIN

Great Britain (GB) has had an energy-only electricity market for over 10 years. More recently, the ability of this market design to attract investment in low carbon generation, and maintain security of supply, has been called into question. The Government has decided to address these concerns by introducing a number of significant market reforms [19]. These changes include proposals to introduce a forward, market-wide, volume-based capacity auction [20]. Although the details of the mechanism have still to be defined, this will involve the system operator identifying the total firm capacity requirements at time of peak demand several years into the future (currently, four years ahead is proposed), and undertaking auctions to meet this need. The results of these auctions will be that each unit of capacity will be paid the same amount regardless of the dynamic capabilities provided.

The following table assesses this proposal against the check-list contained in Section V:

TABLE I
ASSESSMENT OF CAPACITY MARKET PROPOSAL IN GREAT BRITAIN

Check-list	Assessment of proposal
Procure range of capabilities?	No – the mechanism is designed to reward firm capacity only. The primary way to incentivise a range of capabilities is the price available through bidding into the balancing mechanism. However, the ability of investors to act on the basis of predictions of these short term signals is a matter of debate.
Maximise potential for existing resources?	Yes – the shorter term nature of the auction will tend to favor existing resources. This is important in the GB market since a large proportion of fossil plant will face closure decisions over the coming decade.
Demand side?	Possibly – although the success in attracting demand-side resources will depend on the extent to which the system operator is incentivised to ensure they participate. There is currently relatively little demand response provided on the GB system — around 1GW is contracted with the system operator and a similar amount is believed to be contracted by suppliers to reduce peak demand [21]
Less revenue for resources that do not provide range of operational capabilities?	No – earnings through the capacity mechanism will vary according to availability at times of system peak and not as a result of the range of capabilities offered.
Recognise carbon content?	No – this incentive is restricted to the carbon cost associated with energy sales for operational assets. In particular, the procurement of inflexible capacity may lead to significantly increased curtailment of renewable generation and the cost implications of this trade-off will not be taken into account.
Avoid adverse impact on renewable investments?	Possibly – details of cost recovery not yet defined. Capacity costs may be shared equally by suppliers on a pro-rata volume basis, in which case there will be no relative economic effects between technologies. However, the costs may be recovered through higher imbalance settlement prices which will tend to adversely affect renewable generators that are unable to control their output in operational timescales.
Promote innovation and avoid foreclosure?	No – there is no discussion of the need to adapt the mechanism as the market develops. It is, as yet, unclear whether the proposals are envisaged as an enduring change to the market rules or a temporary 'fix' to be implemented only during periods of capacity shortage. Also, it is not clear how the mechanism will attract major new investments if the short term auctions fail in this regard. The most likely approach is that investors will have the option of a 'commitment period' as in the US forward capacity markets -- however, this is not discussed in the current proposals.
Market integration and sharing balancing resources?	No – the way this mechanism might continue to deliver reliability as GB becomes increasingly interconnected with neighbouring markets is not apparent. In particular, the ways in which the mechanism can be designed to operate in line with market coupling principles and potentially larger balancing areas are not addressed.

This analysis suggests that the lead option for delivering reliability in the GB market is unlikely to represent a cost-effective approach as the proportions of variable renewables on the system continue to increase. In particular, it demonstrates that traditional capacity-only oriented payment approaches will not be appropriate going forward.

VII. CONCLUSIONS

Increasing proportions of variable renewables will be a key feature of European electricity markets in the coming decades and this will change the nature of the system reliability challenge. In particular, it will no longer be sufficient or even appropriate to think in terms of providing enough power to meet overall demand. Instead, it will be necessary to focus on meeting a residual net demand, once renewable generation has been subtracted from total demand, and this will be more volatile and less predictable than overall demand. A sufficient volume of firm capacity can no longer be relied upon to deliver system reliability. Instead, system reliability will increasingly depend on resources that display a range of capabilities including the ability to rapidly and frequently change output or demand throughout the year.

Markets must be designed that deliver enough of the right kinds of resource capabilities in the context of an increasing mix of renewables and traditional 'capacity-only' markets are inappropriate to meet this requirement. It will be necessary to make the most of the flexibility of existing resources including, importantly, the demand side of the market, and to ensure that new resources possess the required set of capabilities. These objectives must be achieved in a way that does not undermine overall decarbonisation objectives or on-going investment in renewables required to meet them. Moreover, the approach must ensure that the market remains open to take advantage of the opportunities presented by developments and innovations in technology and the broader market environment. These considerations provide a screening check-list that can be used to assess the suitability of mechanisms intended to deliver system reliability.

It is tempting for market designers to take 'off-the-shelf' approaches to maintaining system reliability but these will generally have been designed to meet the needs of a market that is very different from the one we will face in years to come. The GB electricity market reform process provides an example of where the proposed market design is a standard capacity-only approach, and does not recognise the reliability paradigm shift ahead. The analysis in this paper raises serious questions about the suitability or sustainability of this market design to ensure system reliability at least cost, particularly given the level of ambition GB has set for itself to fully decarbonise the power system by the 2030s.

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IX. References

[1] European Commission. (2011) Energy Roadmap 2050. COM (2011) 885/2. Available: http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf

[2] D. Lew, D. Piwko, N. Miller, G. Jordan, K. Clark and L. Freeman, "How Do High Levels of Wind and Solar Impact the Grid? The Western Wind and Solar Integration Study," NREL/TP-5500-50057, December 2010. Available: http://www.nrel.gov/docs/fy11osti/50057.pdf

[3] EURELECTRIC Task Force Market Design for RES Integration. (2011, May). "RES Integration and Market Design: Are Capacity Remuneration Mechanisms Needed to Ensure Generation Adequacy?" Available: http://www.eurelectric.org/CatPub/Document.aspx?FolderID=1507&DocumentID=30399

[4] P. L. Joskow, "Capacity Payments in Imperfect Electricity Markets: Need and Design," *Utility Policy,* Vol. 16(3), pp. 159-170, 2008. Available: http://web.mit.edu/ceepr/www/publications/reprints/Reprint _190_ WC.pdf

[5] F. A. Roques, "Market Design for Generation Adequacy: Healing Causes Rather than Symptoms," Utilities Policy, vol. 16(3), pp. 171-183, Sep. 2009. Available: http://ideas.repec.org/p/cam/camdae/ 0821.html

[6] G. van Welie, "Integrating Policy, Planning, and Electricity Markets In New England," presented at MA Restructuring Roundtable, June 10, 2011. Available: http://www.raabassociates.org/main/roundtable.asp? sel=107

[7] Federal Energy Regulatory Commission. (2011). FERC sets new compensation method for regulation service [Press release]. Available: http://www.ferc.gov/media/news-releases/2011/2011-4/10-20-11-E-28.asp

[8] *2014/2015 RPM Base Residual Auction Results,* PJM BRA Results Report Addendum, PJM DOCS #648604. Available: PJM 2014/2015 Base Residual Auction Addendum, at http://www.pjm.com/markets-and-operations/rpm/~/media/markets-ops/rpm/rpm-auction-info/2014-2015-rpm-bra-results-report-addendum.ashx

[9] A. Dosunmu. (2011). Up in Smoke: Seven Gigawatts of Coal Retrenches from PJM. *Energy Central.* Available: http://www. energycentral.com/enduse/demandresponse/articles/2451/Up-in-Smoke-Seven-Gigawatts-of-Coal-Retrenches-from-PJM/

[10] M. Gottstein and L. Schwartz, "The Role of Forward Capacity Markets in Increasing Demand-Side and Other Low-Carbon Resources: Experience and Prospects," The Regulatory Assistance Project, May 2010. Available: http://www.raponline.org/document/download/id/91

[11] J. De Wit, "Heat Storages for CHP Optimisation," presented at the PowerGen Europe 2007 Conference, (ID-94), 2007. Available: http://www.dgc.eu/publications/pdf/jdw_pg07_HeatStorage.pdf

[12] European Climate Foundation. Power Perspectives 2030: On the Road to a Decarbonised Power Sector. Available: http://www.roadmap2050 .eu/attachments/files/PowerPerspectives2030_FullReport.pdf

[13] L. Balling. "Eco- and Climate Friendly Power Plant Solutions: Sustainable, efficient and flexible," Siemens Energy, 2011. Available: http://www.life-needs-power.de/2011/F6_Balling.pdf

[14] J. Bowring. (2011). PJM Market Review: January through November, 2010. [Power Point Slide 37]. Available: http://www.monitoringanalytics.com/reports/Presentations/2011/IMM_MC_SOM_Jan_thru_Nov_2010_20110127.pdf

[15] North American Electric Reliability Council. Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation. March 2011.

[16] H. Holttinen, B. Lemstrom, P. Meiborn, H. Bindner, A. Orths, F. von Hulle, C. Ensslin, A. Tiedemann, L. Hofman, W. Winter, A. Tuohy, M. O'Malley, P. Smith, J. Pierik, J.O. Tande, A. Estanqueiro, J. Ricardo, E. Gomez, L. Soder, G. Strbac, A. Shakoor, J.C. Smith, B. Parsons, M. Milligan, and Y-h. Wan, "Design and Operation of Power Systems with Large Amounts of Wind Power: State-of-the-art Report," IEA Wind Task 25, 2007.

[17] M. Milligan, B. Kirby, J. King, and S. Beunig, "Benefit of Regional Energy Balancing Service on Wind Integration in the Western Interconnection of the United States," presented at the 9th Annual International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Québec, Canada, 2010.

[18] P. Baker, "Advancing Both European Market Integration and Power Sector Decarbonisation: Key Issues to Consider," The Regulatory Assistance Project, February 2012. Available: http://www.raponline.org/document/download/id/4809

[19] Department of Energy and Climate Change (2011) *Planning our electric future: a White Paper for secure, affordable and low-carbon electricity,* [White Paper], Available: http://www.decc.gov.uk/ assets/decc/11/policy-legislation/EMR/2176-emr-white-paper.pdf

[20] Department of Energy and Climate Change (2011) *Planning our electric future: technical update.* Available: http://www.decc.gov.uk/ assets/decc/11/meeting-energy-demand/energy-markets/3884-planning-electric-future-technical-update.pdf

[21] G. Owen, J. Ward and M. Pooley, "GB Electricity Demand - Context and 2010 Baseline Data," Sustainability First, October 2011. Available: http://www.sustainabilityfirst.org.uk/docs/2011/Sustainability%20First%20-%20GB%20Electricity%20Demand%20-%20Paper%201%20-%20Context%20and%202010%20Baseline%20Data%20-%20October%202011.pdf

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