Resource-Adequacy-Based Capacity Market Design

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Abstract. - **Today's capacity markets may be viewed as an additional source of income for generators to compensate the money lost due to regulatory imposed caps. Those additional money flows and other design characteristics serve, theoretically, to achieve system adequacy in a market environment. In this paper, we analyze key aspects of today's capacity market designs. Our main finding is that some design elements help to achieve economic objectives but need to be modified to attain the resource adequacy objective and conversely. Based on the experience to date, we conclude that a key objective of capacity markets is to have resource adequacy by ensuring that there is sufficient installed capacity and its deliverability, i.e., the ability to effectively deliver the capacity from the sources to the existing and future loads. We argue that to reach the adequacy and deliverability objective the capacity market design must explicitly consider them and must ensure no interference with the deployment of market structures. We introduce resource-adequacy-based capacity markets. We discuss the main design elements and illustrate with design examples. Our analysis and insights can lead to the improved capacity market design that meets the resource adequacy assurance by effectively harnessing the forces of the competitive market environment.**

I. INTRODUCTION

The premise of the design of the commodity markets for electricity is that the price signals in energy-only markets reflect the values of both the electricity commodity and the capacity required for its generation. Shortages in capacity create higher electricity prices and such prices signal and provide incentives to invest in new generation plants so as to eventually achieve an appropriate level of installed capacity and thereby attain system *adequacy*.

The experiences to date indicate the failures of energy-only markets to create the appropriate incentives to achieve resource adequacy [1]. The failures are usually explained by arguing that a large part of the electricity demand, is, in practice, price insensitive due to the regulatory imposed electricity tariffs. Consequently, the value that capacity has for consumers is not reflected in the electricity prices. In addition, price caps motivated by the regulators' concern over the exercise of market power reduce the revenues that generators receive from the energy payments. This reduction in the revenues that generators receive is the well-known 'missing money' problem of the electricity markets [2]. The missing money problem is commonly used in the economic literatureas the principal cause for the inability of the electricity markets main source of problems for electricity markets to achieve resource adequacy.

A common way to attempt to solve the resource adequacy problem is the use of capacity markets. The basic product in such markets is the capacity of the resources, including demand-side resources, and the capacity obligation requires the participation of those resources in the energy markets during the specified period. Auctions are the market mechanism used to select the succesful players. The additional money flows from the capacity payments compensate the foregone money due to price caps and may be viewed as a solution to the "missing money" problem. In addition, demand side resources serve as a proxy for demand elasticity. Hence, capacity markets together with the energy markets can provide a way to have a electricity market with demand elasticity, no "missing money" problem and consequently to achieve system adequacy.

Unfortunately, several questions emerge in the current design of capacity markets and their effectiveness to attain such objective. The implemented designs of capacity markets have failed to demonstrate the ability to attain the resource adequacy. Existing capacity market designs provide payments for *all* the capacity cleared in the auction, be it base-load, cycling or peak-load without distinguishing between the capacity types. Each successful capacity market participant using any technology resource receives capacity payments in addition to the expected revenues from the energy markets. As such, the missing money problem impacts non-uniformly the various types of resources. The missing money is a problem particularly acute for peaking resources since they operate only a few hours in a year. Base-loaded units, operating around the clock, receive a continuous stream of revenues from the energy markets

[3]. This lack of differentiation among technologies raises a critical question as to how the capacity market prices can provide signals to stimulate investment in the appropriate technology mix. A different issue of the current capacity markets designs is the deliverability, i.e., the ability to effectively deliver the capacity output from a resource to existing and future loads since this aspect is not explicitly considered. We argue that for capacity markets to ensure resource adequacy both system adequacy and deliverability must be explicitly considered in the capacity market design. Moreover, such consideration must not interfere with the deployment of market structures.

In this paper, we analyze the results from and the main design elements of, the capacity market implemented in the New England ISO - the so-called Forward Capacity Market (FCM) - to illustrate several issues related to achieving resource adequacy in a market environment. We also analyze the definition of the capacity product and the auction format adopted in the FCM. We focus our attention on the attainment of physical, such adequacy or reliability, and economic, such efficiency, objectives by the current design. Our key finding is that certain design elements can facilitate the attainment of the economic objectives but need considerable improvement to also ensure that the physical objectives can be attained and conversely. Based on our analysis, we present the main design elements of resource-adequacy-based capacity markets. The key idea is to ensure that resource adequacy is attained in terms of sufficient installed capacity, the classical view of system adequacy, and its deliverability. The analysis of possible designs requires the representation of the relevant physical considerations as well as the use of markets to economically meet the resource adequacy requirements.

There are three main steps in the design of the resource-adequacy-based capacity market: definition of the product(s), specification of the auction format and design of the mechanism for clearing the market. We describe various considerations for each one of these requirements and recognize the tight coupling between them.

The remainder of the paper is in four sections. We devote section II to present an analysis of the FCM and identify specific market design issues that need to be addressed to assure resource adequacy. In section III, we focus on resource-adequacy-based-capacity markets and we describe the principal design aspects. Specifically, we focus on the definition of the capacity product and the specification of the auction formats. In section IV, we present several design examples of resource-adequacy-based capacity markets. In section V, we provide concluding remarks and directions for future research.

II. THE NEW ENGLAND FORWARD CAPACITY MARKET

We examine the Forward Capacity Market (FCM) implemented in New England ISO to identify some of the issues in capacity market design. The FCM provides incentives to meet the aim of adequate level of installed generation for the future. The FCM is performed three years in advance of the capacity obligation starting point and allows participation by yet-to-be-completed new resources, existing generation resources and demand resources. Another salient characteristic of FCM is the use of a descending clock auction (DCA) [4]. Reliability plays a big role in FCM since many decisions are made on the basis of the impacts on system reliability. A key design element of FCM is the use of de-list bids which signal the minimum capacity prices at which resources are willing to assume a capacity obligation. There are five types of de-list bids: permanent, static, dynamic, export and administrative export [4]. The FCM consists of four stages taking place along the time line and illustrated in Figure 1. During the qualification process, existing and new potential capacity suppliers submit applications to participate in the FCM and de-list bids, excepting the dynamic ones, are submitted. The second stage is the DCA stage in which players submits dynamic de-lists bids and reliability analyses are run in order to approve or reject them. After the DCA is completed, a market clearing engine is run, this process determines the final capacity prices. Finally, the last stage involves performing several reconfiguration auctions to adjust the results and improve market liquidity [4].

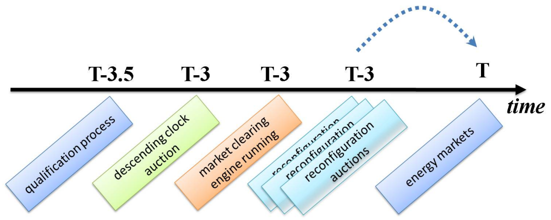

Figure 1 FCM Timeline

The fact that the floor prices were attained in the three times FCM has been implemented is a sign that that these capacity payments are truly attractive to generators and may, indeed, be interpreted as a windfall[1].

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[1] We conjecture substantial reductions in the capacity prices for the FCM to be held in 2010 due to the removal of floor prices.

	FCM # 1	**FCM # 2**	**FCM # 3**
price (*$/kW-month*)	**4.50**	**3.60**	**2.951**

Figure 2 Resulting capacity prices in FCMs

We identify three issues of interest in the FCM design which serve to motivate the formulation of the resource-adequacy-based capacity markets:

- The capacity product definition
- The use of a descending clock auction
- The definition of capacity zones

The capacity product definition

The appropriate product definition is important in any auction process. Specifically, we focus on the differentiation between existing and new capacity. In the FCM, existing and new capacity are, in general, considered as the same product and they receive the same capacity price. But, the existing and new capacity are treated differently in the FCM reliability review for the de-list bids since the review is only for existing capacity

The treatment of existing and new capacity as perfect substitutes is an open question. Similarly to the FCM, the Reliability Pricing Model (RPM) of PJM [7] and the capacity auctions held in Chile [8] treat existing and new capacity as substitutes, bundled them as a uniform capacity product. In contrast, the Brazilian capacity auction defines different products for existing and new capacity [9] having two separated auction processes. An auction for existing capacity is held, after that auction is cleared the auction for new capacity is performed. The Brazil experience has shown that price discrimination between existing and new capacity has encouraged new investment and has reduced average prices to end consumers [10].

Existing and new capacity in some aspects are substitutes. For example, they are both utilizable capacity for the system. However, they are not from the viewpoints of capacity investment and adequacy improvement. First, from the investment viewpoint, the difference is well known. Second, from the adequacy viewpoint, existing capacity can help maintain the current level of adequacy if no one wants to de-list. However, it cannot improve the system adequacy. Consequently, any improvement on the system adequacy will be performed by new capacity additions.

Accepting the above differences, would an alternative approach be to unbundle existing and new capacity, and consequently change the definition of products from a uniform capacity product to different products for existing and new capacity? We explore pros and cons of this approach in section IV.

The use of a descending clock auction

One of the key design elements of the ISO-NE FCM is the adoption of a descending clock auction (DCA). A DCA is a dynamic rather than a static auction such as the sealed bid format. The auction consists of several rounds in which the price decrease from round to round until equilibrium between supply and demand is achieved. DCA is a useful market mechanism for multi-product auctions. DCA reduces the common-value uncertainty and facilitates the packaging and bidding processes which help to provide an effective price discovery [5]. Standard DCA designs provide in each round the price and the demand excess, which the players use to fine tune their bidding strategies. Theoretically, this process helps to achieve an efficient outcome of the auction [5]. However, the needed reliability analysis and other rules associated with the use of DCA in FCM such as permanent and static de-list bids create conditions different from those associated with the typical markets in which DCA is implemented.

Several decisions of the current FCM are of a static nature. De-list bids, excepting the dynamic ones, and the decisions associated with qualification process are not dynamic processes since the participants do not change that submitted information [4]. Consequently, players are not 'using' any of the information conveyed in the rounds of the DCA to make their decisions. Just the dynamic de-list bids, in which players can dynamically withdraw from the auction based on the round price, are aligned with such dynamic characteristic of the DCA. Given all the static rather than dynamic decisions involved in the current FCM, it is not clear that the DCA dynamic advantages are exploited.

The DCA is designed for addressing the packaging issues for the bidders in the auctioning of multi-products. However, the FCM becomes a true multi-product auction only for the cases that capacity zones are needed. In the first three realizations of the FCM such situation has not occurred. Consequently, no capacity zones were defined and a single capacity product was auctioned. Hence, based on the experience, the DCA is not used for a multi-product auction.

In addition, the entire FCM process is so *constrained* by reliability considerations that the inherent dynamics in the DCA is even harder to be exploited. For example, one of the few truly dynamic elements of the FCM design, the use of dynamic de-lists bids, is under the hard constraint of the reliability considerations. Given the issues presented above, the DCA application in FCM needs to be reconsidered.

The definition of capacity zones

Another FCM design element that we address is the zone definition. From the reliability and economic viewpoints, the zone definition is a *critically* important aspect of the FCM. Transmission constraints create a locational dimension for resource adequacy. Limited transmission transfer capabilities create import-constrained areas in which there is a need for local installed capacity to meet the load. Such a locational dimension was not captured by the early implementations of capacity markets such as the ICAP market, in which the whole system was viewed as a single-bus system. Consequently, the economic signals generated by such markets were not representative of the impacts of such constraints. There was both a lack of incentives for investment in such constrained zones and a lack of compensation for locating generation in those zones. FERC strongly pushed for a mechanism to provide such locational capacity requirements [6], so as to explicitly recognize the value of installed capacity in import-constrained areas and to receive appropriate compensation for such capacity. The designation of zones in the FCM captures this locational dimension and allows price differentiation between the distinct zones. The appropriate zonal specification is key to the success of the FCM.

The current zone specification is based on the so-called load zones. Such zones are determined, in general, by geographical location and state boundaries. The zonal capacity requirements are determined by considering the inter-zonal transfer capabilities. A capacity zone is specified whenever such requirements exceed the existing installed capacity within the zone.

In the FCM design, price differentiation is possible between two capacity zones. However, such zones are defined by state and geographic boundaries without considering the reliability impacts of the generation within the zone. A review of the FCM results indicates some issues on the current approach since theoretically the capacity market auction considers the locational dimension but results in a single zone price, as was the case in the first three realizations of FCM. Moreover, the required reliability studies for determining the delisting of units within a zone is further indication of the locational dimension problems. Such studies indicate the disconnect between the market outcomes and system reliability needs and the inability of the market to send the appropriate signals.

In addition, the zone specification cannot exploit the dynamical aspects of the DCA. Indeed, the outcomes of the reliability checks required during each DCA round may override the potential benefits of the DCA information made available in each round. The reduction of capacity in the subsequent round may be driven by the reliability impacts rather than the information of the round. The inability to effectively harness the DCA information and the need for further reliability analysis are symptoms that the zone specification is unable to correctly capture the locational dimension and exploit the benefits of the DCA.

From these observations, we note that specifying a zone implies the creation of a new product. Indeed, under the DCA process, a unique price for that product results. Such a price indicates that a unit of capacity throughout the zone has a value independent of resource type, size or location within the zone. In order to avoid the need to distort the DCA signals by the reliability impact analysis, it is important to base explicitly the zone specification on reliability considerations rather than use the state and geographic boundaries. As such, once the reliability zones are appropriately specified, resulting in a new product, the DCA information can effectively be harnessed and the economic efficiency of the auction can be maintained.

The review of some key design aspects of the ISO-NE FCM allowed us to identify some specific problems in the design of capacity markets that need to be addressed to ensure that resource adequacy is attained through the capacity markets. A key issue is the economical signal the capacity market is providing and their effectiveness for stimulating investment in appropriate new generation. In addition, some design elements help to achieve economic objectives but need to be improved to achieve physical objectives, and vice versa.

III. RESOURCE-ADEQUACY- BASED CAPACITY MARKETS

In the previous sections, we explain as the main motivation for capacity markets the additional money flow to reconstruct the missing money and eventually achieve resource adequacy. We also present the experience of an actual implementation, ISO-NE's FCM, and we highlight the impact that reliability has throughout the process. To overcome the problems identified we lay out the notion of resource-adequacy-based capacity markets and we provide a conceptual framework for their design.

Resource adequacy must be the principal driver of the capacity markets and thus needs to be explicitly considered. Indeed, we consider the capacity markets as the decentralized achievement of the centralized planning process. We illustrate this vision using a multi-layer representation consisting of the market and the physical layers

We have a physical layer, governed by physical laws and soft and hard engineering constraints. It is in this layer in which the ISO must specify requirements to achieve an adequate reliability level. Indeed, this layer by itself represents the vertically utility structure of the electricity industry, and the specification of such requirements is just the old days planning process.

In the new market environment, we have also a market layer which interacts with the physical one. This layer is governed by market forces and the private interests of their players. In theory, this layer may be totally decoupled from the physical layer and all the market structures can be simply financial markets. Experience has shown that, given the salient characteristics of electricity generation, this is not the best approach and information flows and coupling between layers must occur.

We can cast various resource adequacy market approaches into the two-layer framework. The contract adequacy approach in [11] is a solution living completely on the market layer and it is entirely based on financial contracts. An intermediate scheme is the use of forward contracts as the case of Chile and Brazil [8]-[10] and the 2006 Illinois Auction [12]. In those schemes there is an underlying physical contract but there is no explicit consideration of any reliability or deliverability issues. On the other hand, ISO-NE's FCM and PJM's Reliability Pricing Model (RPM) are examples of approaches with large information exchange between the market and the physical layer. The whole set of reliability checks of FCM represent such information flows. However, as we presented in the last section, the way to accommodate such reliability checks impose a lot of friction in the market structures.

Appropriate information flows between the physical and the market layers are a must for the achievement of the resource adequacy target. Because of this coupling between the layers, we view as a first step towards the construction of an adequate capacity market the revision of the resource adequacy studies or planning process.

In [13], it is presented a resource adequacy study framework, so-called unified planning framework (UPF), which considers explicitly reliability and operational issues as constraints. Conceptually, this way to perform the planning process considers the deliverability of the capacity throughout the consideration of transmission constraints and also the reliability constraint, in this case in terms of loss of load probability, explicitly as a constraint

The decision variables are the capacity requirements of the system. The objective function to minimize is some function of such installed capacity and might consider investment and/or operational costs. The main constraint is an explicit reliability constraint, in the model presented in [13] is a composite loss of load probability (LOLP) in which both adequacy and transmission constraints are considered. Solving this chance constrained optimization problem is a real challenging problem. Approximation schemes such as the use of zones to reduce the dimensionality or deterministic bounds need to be adopted to handle this problem. Several approaches to solve this problem are presented in [13].

We present in the flow diagram in Fig. 3 the main elements towards the design and implementation of a resource-adequacy-based capacity market. In the planning side, UPF is the main element. The type of approximation to make this problem tractable is impacted by the definition of the capacity product. For example, if we decided that just the number of *MWs* is the only important attribute of the capacity product, then the no consideration of transmission constraints is the natural scheme to apply. If we want a locational component we either use the whole system or we reduce granularity utilizing zones.

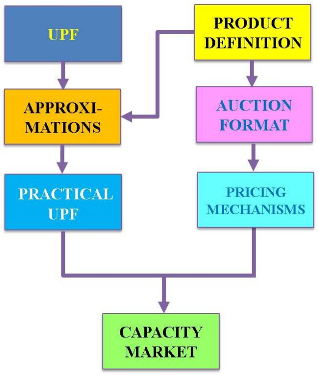

Figure 3 Resource-adequacy-based capacity market design elements

In the market side there are three main steps in the design of resource-adequacy-based capacity market: definition of products, definition of auction format and creation of prices. Such steps are tightly coupled and the product definition has a main role: What is going to be the product to be traded in these markets? The answer to this question, as we explained, will also impact the practical implementation of the UPF.

From an economic viewpoint, one main concern is to define the capacity product in such a way that competitiveness can be effectively harnessed in its acquisition. The level of detail specified in the product definition impacts the competitiveness of the market. For instance, a highly specialized product that can be provided only by a small set of suppliers creates the conditions for market power and its possible exercise.

From a physical viewpoint, however, the more specified the product, the better capturing of system need is by such a product. Therefore, the *trade-offs* between economic and physical considerations are the key challenge. For example, a single-attribute capacity product based on the number of *MWs* is an extremely appropriate product from an economic viewpoint. Any supplier of the system, anywhere and with any technology can participate in this market. Consequently, there is large scope for competition. However, from an engineering viewpoint the single-attribute *MW* cannot appropriately capture the system needs. Capacity localized in export-constrained regions is simply worthless in the event of lack of capacity outside such a region. An appropriate capacity product must attain a balance between the economic/market and engineering considerations.

A key need is to effectively represent the physical and technical considerations involved in attaining resource adequacy. Once we have a representation of the physical needs, we must determine and quantify the attributes of the capacity product that is going to be traded in these markets. In addition, the definition of the capacity product also includes the specification of the capacity contracts term such as duration of the capacity obligation and the capacity payment schemes.

The second element is the design of the auction mechanism to be used in the capacity market. The capacity product definition adopted drives the design of the auction mechanism. For example, under a capacity product based only in a single metric, say in *MW*, any auction format may be used. However, multi-attribute capacity products require either multiple sequential auctions or a simultaneous multi-product auction. The main considerations include the information revealed to the players during the auction process, the complexity of the bidding process and the design of rules to avoid strategic behavior by the players.

The third element concerns with the economic signals, i.e., the prices that are going to emerge from the capacity market. Ideally, prices should support the profit maximization of each selected bidder, under that condition they become the so-called equilibrium prices [14]. One alternative is not to have a unique 'clearing price' at all and to adopt a pay-as-bid scheme. In such a scheme, each selected bid is paid precisely the offered price. However, pay-as-bid schemes have been, in general, viewed negatively in energy market for several reasons [15]. If the same arguments against pay-as-bid mechanism are extrapolated to the capacity market, a 'clearing price' should be generated. Pricing in a non-convex environment, as the capacity market with the inherent lumpiness of the decision variables, is a challenging problem [14], the usual adoption of Lagrange multipliers of convex problems is no longer an option. An additional complication is the use of out-of-the-market payments whenever an equilibrium price does not exist, something likely to happen given the non-convexity of the problem. In such a case, a possible alternative is the specification of uplift payments.

IV. DESIGN EXAMPLES

We present examples of market designs under the premise that reliability is the driver of the capacity market. These designs, in general, may be viewed as multiple stages constructs. Some stages are based on purely financial markets, i.e., markets in which no physical constraints are considered. However, there is always an instance of the market in which reliability is explicitly considered, i.e., a market in which information flows with the physical layer happen. This sequence of stages allows the accommodation of physical and economic objectives in a consistent way. For example, dynamics auctions are adopted in stages in which no reliability checks are considered and consequently the dynamism of such mechanisms can be exploited. On the other hand, reliability checks are implemented to find additional capacity requirements, zones or transmission addition rather than to approve in the rounds of a dynamic auction for example the delisting of capacity.

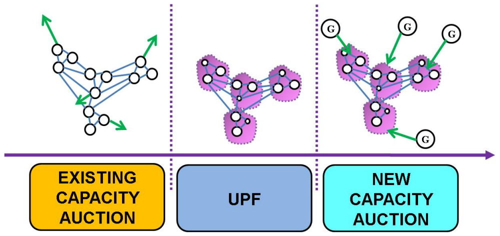

Figure 4 Design example using existing and new capacity auctions

An example of reliability based capacity market design is a sequential capacity market for new and existing generation. An illustration of this market mechanism is presented in Fig. 4. Starting from the current system, an existing capacity auction is held. Such auction does not consider any capacity zone. It is based merely on the willingness of the existing generation to stay as utilizable capacity. This stage is a merely financial structure, in which no reliability constraints are checked. A critical point on the sequential approach is how to define the requirements for the existing generation stage. One alternative is to perform a single round auction. The auction manager provides a capacity price and the players bid how much of their existing capacity they are willing to offer at that price. The setting of this price could be based, for example, on historical capacity payments. After this stage is cleared, the ‘planning’ process is performed and UPF is utilized, zones based on the impacts resources has on reliability can be defined and requirements for each zone are specified. The last stage is an auction which objective is to purchase at least cost the capacity to meet the requirements for each zone. This market is also a purely financial and a dynamic auction, as for example a DCA, with several rounds could be implemented. In this market structure, all the physical constraints are considered only on finding the capacity requirements. Hence, reliability analysis does not interfere with the deployment of the market structures.

The main advantage of this sequential approach is that the reliability analysis is simplified and unified. One of the main concerns of the current FCM, for example, is the running of reliability analysis *ex-ante* the clearing of the new capacity and the de-listing of existing units. In the proposed approach, reliability analyses are just performed on the zone definition and for specifying the requirements for each zone. During the new capacity auction, each zone is in some sense totally independent of the rest (this cannot be true for export/import constrained zone, however this dependence can be captured on the requirements for each zone), hence finding the clearing prices is also simplified.

The sequential approach seems to simplify the reliability analysis, however, would this approach be economically sound? For instance, a drawback of the sequential approach could be potential market power or arbitrage concerns. In order to avoid that, appropriate market rules must be imposed.

Another example of market design is shown in Figure 5. In this case, a purely financial market is implemented. In this market no physical constraints are considered and the whole system is represented by a single bus system. After finishing this stage reliability checking using some of the features of UPF, as for example the evaluation of reliability constraints, is implemented. As an outcome of this process, if the system still needs new generation a physical market is implemented. This physical market fully considers all the transmission constraints of the system.

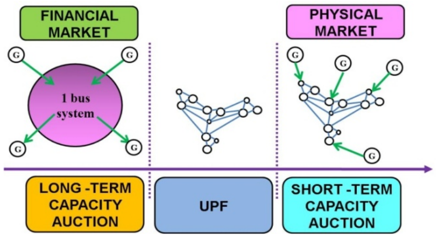

Figure 5 Design example using financial and physical capacity markets

A simpler market design, but more ambitious given the policy change needs, is illustrated in Figure 6. Similarly to the previous one, a merely financial capacity, in which no transmission constraints are considered, market is implemented. This capacity market will have as main objective the adequacy of the system in terms of total *MWs*. Hence, the traded product is simply *MW*, without any other attributes such a locational component. In this stage dynamics auctions can be adopted.

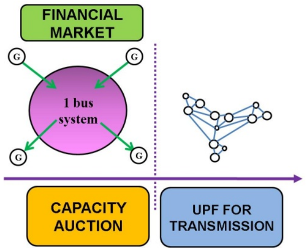

Figure 6 Design example considering transmission investments

After this market is cleared, UPF for transmission is implemented. In this setting, transmission investments are going to be the decision variables of UPF[2]. This market structure tackles the reliability problem from a new perspective, in which the deliverability of the new capacity additions are enforced by the transmission upgrades. Unlike the other market structures, just market forces drive the decision of generating companies for invest in new assets. The main challenge of this design is the policy changes needed on the transmission side.

We present several market designs which allow the achievement of reliability objectives along with the deployment of market structures. We are going to present practical implementations of these market designs in future publications.

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[2] A slightly different UPF for the one presented in section III should be utilized, in this case for transmission planning. However, the optimization problem structure is similar.

V. CONCLUDING REMARKS

In this paper, we introduce the concept of resource-adequacy-based capacity markets. We argue that system adequacy and deliverability must be principal drivers of the capacity market design. The main design challenge for such markets is to effectively accommodate both the economic and the physical objectives in a compatible manner. We illustrate the potential conflicts between economic and physical considerations in the current capacity market implemented by the New England ISO. Our key finding is that some design elements help to achieve economic objectives but need to be modified to attain the physical objectives, and conversely. We provide the main design elements of resource-adequacy-based capacity markets and provide possible resource-adequacy-based market designs which are able to accommodate to varying degrees both economic and physical objectives.

References

[1] P. L. Joskow, “Capacity payments in imperfect electricity markets: Need and design,” Utilities Policy, Volume 16, Issue 3, September 2008, Pages 159-170

[2] P. Crampton and S. Stoft, "The Convergence of Market Designs for Adequate Generating Capacity" Report for California Electricity Oversight Board, Apr. 2006

[3] Howard M. Spinner, “Generator Net Revenues and the Need to Reform PJM Capacity Markets,” The Electricity Journal, Volume 18, Issue 5, June 2005, Pages 40-50

[4] D. LaPlante et al., "Internal Market Monitoring Unit Review of the Forward Capacity Market Auction Results and Design Elements," ISO-NE document available online at http://iso-ne.com/markets/mktmonmit/rpts/other/fcm_report -final

[5] L. Ausubel, Lawrence and P. Crampton, "Auctioning Many Divisible Goods," Journal of the European Economic Association, 2004, Vol. 2(2-3), pages 480-493, April 2005

[6] FERC, Order Accepting in Part and Modifying in Part Standard Market Design Filing and Dismissing Compliance Filing. s.l. : 100 FERC ¶ 61, 287, 2002

[7] A. Caner Sener and S. Kimball, “Reviewing Progress in PJM's Capacity Market Structure via the New Reliability Pricing Model,” The Electricity Journal, Volume 20, Issue 10, December 2007, Pages 40-53

[8] L.A. Barroso, H. Rudnick, R. Moreno, B. Bezerra, “Ensuring Resource Adequacy with Auctions of Options and Forward Contracts," Power Engineering Society General Meeting, 2007. IEEE, pp. 1-6, 24-28 June 2007

[9] J. Dutra and F. Menezes, "Lessons from the Electricity Auctions in Brazil,". Electricity Journal, 2005, Vol. 18

[10] R. Moreno R., L. A. Barroso, H. Rudnick, S. Mocarquer and B. Bezerra , "Auction Approaches of Long-Term Contracts to Ensure Generation Investment in Electricity Markets: Lessons from the Brazilian and Chilean Experiences", accepted for publication in Energy Policy, 2010

[11] F. Wolak, "What’s wrong with Capacity Markets,” available online at http://stoft.com/metaPage/lib/WolaK-2004-06-contract-adequacy.pdf

[12] L. de Castro, M. Negrete-Pincetic and G. Gross, “Product Definition for Future Electricity Supply Auctions: The 2006 Illinois Experience,” Electricity Journal, September 2008

[13] F. Zhao, E. Litvinov, M. Negrete-Pincetic and G. Gross, “Probabilistic Resource Planning with Explicit Reliability Considerations,” submitted to IREP Symposium 2010

[14] R. P. O'Neill, P. M. Sotkiewicz, B. F. Hobbs, M. H. Rothkopf, and W. R. Stewart Jr., “Efficient market-clearing prices in markets with non convexities,” European Journal of Operational Research, Volume 164, Issue 1, 1 July 2005, Pages 269-28

[15] A. E. Kahn et al."Pricing in the California Power Exchange Electricity Market: Should California Switch from Uniform Pricing to Pay-as-Bid Pricing?," Blue Ribbon Panel Report, 2001

Biographies

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