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Loads Providing Ancillary Services: Review of International Experience

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Acronyms and Abbreviations

AGC	Automatic Generator Control
APX	Automated Power Exchange
AS	Ancillary Services
BETTA	British Electricity Trading and Transmission Arrangement
BUL	Balancing Up Loads
DSR	Demand Side Response
CERTS	Consortium for Electric Reliability Technology Solutions
EEX	European Electricity Exchange
ERCOT	Electricity Reliability Council of Texas
EU	European Union
EUAA	Energy Users Association of Australia
FCAS	Frequency Control Ancillary Services (Australia)
FERC	Federal Energy Regulatory Commission
ICR	Instantaneous Contingency Reserves
IDR	Interval Data Recorders
ISO	Independent System Operator
LaaR	Load Acting as a Resource (Texas)
LMP	Locational Marginal Price
MCPE	Market Clearing Price of Energy (Texas)
NCAS	Network Control Ancillary Services (Australia)
NGC	National Grid Corporation
NEM	National Electricity Market (Australia)
NEMMCO	National Electricity Market Corporation
NETA	New Electricity Trading Arrangements (U.K.)
NOK	Norwegian Kroner
NOPR	Notice of Proposed Rulemaking
ofgem	Office of Gas and Electricity Regulation (U.K.)
PJM	Pennsylvania, New Jersey, Maryland Interconnection, LLC
QSE	Qualified Scheduling Entity
RCOM	Regulating Capacity Options Market
REP	Retail Electricity Provider
RPM	Reliability Pricing Model (USA)
RRS	Response Reserve Services (Texas)
RTO	Regional Transmission Organization
SMD	Standard Market Design
SRAS	System Restart Ancillary Services (Australia)
UKPX	U.K. Power Exchange

Executive Summary

In this study, we examine the arrangements for and experiences of end-use loads providing ancillary services (AS) in five electricity markets: Australia, the United Kingdom (UK), the Nordic market, and the ERCOT and PJM markets in the United States. Our objective in undertaking this review of international experience was to identify specific approaches or market designs that have enabled customer loads to effectively deliver various ancillary services (AS) products. We hope that this report will contribute to the ongoing discussion in the U.S. and elsewhere regarding what institutional and technical developments are needed to ensure that customer loads can meaningfully participate in all wholesale electricity markets.

Approach

We conducted an initial literature review of international electricity markets and focused on those markets that had significant experience with load participation in providing ancillary services. We reviewed technical reports, market data, tariffs, and operating protocols as well as studies and evaluations prepared by consultants. Our literature review covered reliability rules, market structure and design, rules, requirements and arrangements for ancillary services, and customer experience and performance in providing these services. We also conducted interviews with grid operators, academics, regulators and market participants familiar with each market.

Not surprisingly, we found that AS arrangements vary considerably across these electricity markets. To facilitate comparative review and analysis, we developed a generic framework for characterizing ancillary services based on functional equivalency. This framework defines six generic ancillary services that are necessary for maintaining system reliability and security in electricity markets (see **Table 1**):

- Ancillary services required during normal conditions
    1. Continuous Regulation
    2. Energy Imbalance Management
- Ancillary services used during system contingencies
    3. Instantaneous Contingency Reserve
    4. Replacement Reserve
- Other Ancillary Services
    5. Voltage Support
    6. Black Start

For each electricity market, we compiled and analyzed qualitative and quantitative information on how ancillary services are provided and how loads participate and perform in their provision.

Table 1: Typology and definition of ancillary services

Ancillary Service	Description
Continuous Regulation	Provided by online resources with automatic controls that respond rapidly to operator requests for up and down movements. Used to track and correct minute-to-minute fluctuations in system load and generator output.
Energy Imbalance Management	Serves as a bridge between the regulation service and the hourly or half-hourly bid-in energy schedules; similar to but slower than Continuous Regulation. Also serves a financial (settlement) function in clearing spot markets.
Instantaneous Contingency Reserves	Provided by online resources equipped with frequency or other controls that can rapidly increase output or decrease consumption in response to a major disturbance or other contingency event.
Replacement Reserves	Provided by resources with a slower response time that can be called upon to replace or supplement the Instantaneous Contingency Reserve in restoring system stability.
Voltage Control	The injection or absorption of reactive power to maintain transmission-system voltages within required ranges
Black Start	Generation able to start itself without support from the grid and with sufficient real and reactive capability and control to be useful in system restoration.

Key Findings

- *The functional equivalency model worked well in comparing arrangements for providing ancillary services across the electricity markets considered, reflecting the similar physical requirements of any large, interconnected electricity grid.*

We found that each market incorporated all six generic ancillary services, although the nomenclature, technical requirements and procurement details varied significantly.

- *The cost of providing ancillary services in these five markets was modest, typically only about 2-3% of the total monetary value transacted.*

Despite the small dollar volume, these ancillary services markets are critical to power system security and reliability and their overall value to society is quite high, given the value that customers place on reliable electric service. Furthermore, even a small share of these very large markets offers important inducements to potential load aggregators or some large end users.

- *Customer loads are well suited to providing certain ancillary services, assuming nondiscriminatory market rules; loads account for about half of the total resources required for contingency ancillary services in the Texas and Nordic markets.*

Table 2 shows the amount of resources provided by loads (in MW) for each ancillary service as well as the market share for loads (in percent) of that ancillary service in each region/country. In Texas, ERCOT's "Load Acting as a Resource (Laar)" program has subscribed sufficient load to provide half of the total Responsive Reserve requirements. In the United Kingdom, loads provide almost one-third of frequency responsive Contingency Reserves. In the Nordic region, several of the national grid operators (e.g. Fingrid and Statnett) procure comparable amounts of load and generation to provide instantaneous contingency and replacement reserves. Norway's grid operator (Stattnett) also procures significant amounts of load to provide regulating power. Finland's grid operator indicated that they prefer loads to fast response gas turbines as a less-expensive, less-troublesome form of operating reserve (Fingrid 2006).

Table 2: Load participation and market share (%) in providing ancillary services

Region/ Country	System Operator	Continuous Regulation Reserves	Energy Imbalance Mgmt	Contingency Reserve	Replacement Reserve
Australia[1]	NEMMCO	Nil	Not Applicable	Nil	375 MW (81%)
Nordic Region	Energinet	Nil	Nil		50 MW (4%)
	Fingrid	Nil	120 MW (58%)		390 MW (39%)
	Statnett	1481 MW (65%)[2]			
	Svenska Kraftnät	Nil	870 MW (22%)		
Nordic Total		2911 MW (34%)			
U.K./BETTA	National Grid	Nil	Load provided 30% of dispatched reserve energy in 2003	160 MW (30%)	250 MW (15%)
Texas	ERCOT	Nil	Negligible	1200 MW (50%); currently limited by ERCOT rule	
Mid-Atlantic/ Midwest	PJM	Negligible[3]	Neg.	Neg.	1600 MW (100%) (Emergency);

- *There appear to be no implicit or insurmountable barriers to loads providing any of the four main ancillary services – Continuous Regulation, Energy Imbalance Management, Instantaneous Contingency Reserves, and Replacement Reserves.*

At present, customer loads are actively providing three of the four main ancillary services. Continuous regulation services is provided exclusively by generators; several system operators including PJM and CAISO are conducting pilots and developing business rules to open up this ancillary service market as well.

- *Grid operator acceptance of loads providing ancillary services happens gradually. There is a learning curve that both system operators and market participants must traverse in order to build confidence in the use of loads as a source of operating reserve and ancillary services. This learning curve can be accelerated by pilot projects, technology development, and encouragement of innovation by aggregators and third party providers.*

1 Load participation in Network Loading Control in Victoria (350 MW/350 MW in Victoria, or 100 percent) is not reflected in these numbers as well as tendering of load for seasonal operating reserves.

2 The regulating and contingent reserve requirements vary from week to week depending on system needs. The amount of load participation varies according to the auction results of the Regulating Capacity Options Market. The value shown represents a maximum level of load participation from winter 2005.

3 PJM only recently (May 2006) opened up this market to participation by loads.

In the Texas market, load participation in providing ERCOT's Response Reserving Service (e.g., instantaneous contingency reserve) was initially capped at 25 percent of the total requirement. The cap on load participation has been steadily increased and is currently set at 50 percent of the total requirement. Loads have cost-effectively and fully subscribed the capped amount. In the Nordic region, early efforts focused on very large loads (greater than 25 MW) where the investment in telemetry and frequency control equipment was easily justified. Over time the technical and size requirements imposed by system operators have been relaxed as third party load aggregators have developed and installed lower-cost communications equipment. These load aggregators targeted customers with small (500 kW) back-up generators and dual-fuel boilers as sources of regulating power and contingency reserves.

- *Compensation for loads participating in ancillary services markets can be significant, between $1.00 and $5.00 per kW per month in which the capacity is subscribed, plus additional energy payments when operating reserves are activated.*

Based on our review we found capacity payments for ancillary services ranged between $1 and $5 per kW per month across the five electricity markets. However, comparing compensation levels for ancillary services across markets is difficult, as requirements imposed on loads (or generators) to provide a specific ancillary service varies. For example, in the Nordic region, loads that bid into the Energy Imbalance Market and are compensated for their availability are also on call to provide Instantaneous Contingency Reserves and Replacement Reserves. In contrast, in Australia's National Electricity Market (NEM), loads contracted as operating reserves are only called upon in case of severe capacity shortage or system disturbance.

- *Some market designs seem to have more "market space" than others for loads to provide ancillary services.*

Tightly-pooled real-time energy-only markets such as Australia's NEM require minimal energy balancing market and relatively modest expenditures for regulating reserves, contingency reserves and replacement reserves. Other markets with market and system operating characteristics that require greater operator flexibility tend to have larger requirements for ancillary services and thus more opportunities for load to participate in providing them. For example, in the U.K., the British Electricity Trading and Transmission Arrangement (BETTA) requires significant frequency responsiveness that loads can effectively supply, while the Nordic system is capacity constrained during the long peak winter season and requires additional operating reserves that loads can effectively provide.

- *Policymakers, regulators, system operators, and load aggregators all have important roles in paving the way for more load participation in ancillary services markets.*

The markets reviewed varied considerably in the emphasis that policy makers, regulators and others placed on demand response and load participation in electricity markets. In the Nordic region load participation is viewed as a critical "pillar" of the interconnected electricity market's sustainability and reliability. Each Nordic system operator has developed "action plans" for increasing demand response in retail and wholesale markets. In Australia much electricity policy is made at the State level, and support for demand response varies according to short-term resource adequacy and the degree of retail competition. Both the PUCT in Texas and Ofgem in the U.K. have been long-standing supporters of load participation in wholesale markets; their support is reflected in high levels of load participation in both energy and ancillary services markets.

System operators strongly influence opportunities for load participation through their interpretation of reliability rules, conduct of procurements, and implementation of business rules and operating protocols. In the U.K., National Grid's strict adherence to the principle of source-neutrality led directly to business rules and operating protocols that favored load participation in BETTA's Fast Reserves and Standing Reserves markets. Australia's NEMMCO has chosen loads to provide all of the network control ancillary services requirements in Victoria as well as for temporary operating reserves required by system reliability rules.

Third parties and load aggregators have played a pivotal supporting role by providing innovations in enabling technology and market development leading directly to load participation in ancillary services markets. This role will likely continue as technology advancements open up new load aggregation possibilities extending even to household-level end-uses.

- *In a few cases, the market design and ancillary services requirements make it possible for loads to simultaneously accommodate multiple grid services needed by system operators.*

In certain Nordic markets, loads can provide multiple grid services: Instantaneous Contingency Reserves and/or Replacement Reserves and regulating power. In Statnett's Regulating Capacity Options Market (RCOM), loads bid in on a weekly basis during the winter peak season when capacity is short. Those loads selected are then on call in the regulating power market and must provide hourly bids to the energy imbalance (real time) market. If insufficient regulating reserves are available then the high bids of the participating loads are accepted in order to clear markets in real-time and set the balancing price. These same loads are also available to respond in the event of a system disturbance. In this design, a single MW of load provides three different services (price elastic bidding in the day-ahead market, participation in the real-time balancing market, and provision of manual replacement reserves), according to the needs of the market and the system operator.[4] ERCOT's Load-as-a-Resource program is also configured to allow loads acting as operating reserves to provide not only Responsive Reserve Service but also Regulation Service and Balancing Energy Service (ERCOT 2006b).

- *Loads that are well-suited to provide ancillary services include large industrial batch processes, refrigerated warehouses, electric water heaters, dual-fuel boilers, and buildings with sufficient thermal mass to retain ambient temperatures for brief periods without air conditioning.*

Loads participating in ancillary services markets prefer a steady revenue stream and minimum perceivable disruptions to their core business, easy to understand rules, effective communications with the system dispatcher, and a sense that their participation is socially

[4] Statnett has also initiated research activities into use of demand as Instantaneous Contingency Reserves, but this is not yet commercialized.

beneficial. Although customers tend to view all electricity markets as similar, operators and aggregators certainly do not view all loads as similar. Some loads are particularly suitable to providing ancillary services, especially facilities or processes that have sufficient thermal capacitance or fuel-switching capability to accommodate frequent, brief interruptions without adverse effect. These loads include industrial batch processes, refrigerated warehouses, electric water heaters, dual-fuel boilers, and any building with sufficient thermal mass to retain its ambient temperature for brief periods without air conditioning.

Suggestions for U.S. policymakers and grid operators

For U.S. policymakers and system operators interested in facilitating load participation in ancillary service markets, we offer the following suggestions based upon our review of international experience.

- The regulator and system operator are pivotal in setting and administering the technical and operating requirements for loads providing ancillary services. Of particular importance is establishing market designs and reliability requirements that are "source-neutral", e.g., the performance requirements are functional rather than prescriptive as to the resource providing the service.
- Pilot projects conducted by system operators can help establish and/or refine technical requirements that may not be source-neutral by testing innovative ways that loads can participate in ancillary services markets.
- Transparent (and frequent) procurements of operating reserves on terms that do not discriminate between loads and generation are essential.
- A predictable and steady revenue stream encourages entry by load aggregators and large customers. This typically involves reservation payments to compensate loads (and generators) for their availability as well as additional payments when the system operator calls upon loads (or generators) to respond and perform during events.
- Periodically review and adjust technical requirements, operating protocols and business rules based on actual experience, rather than retaining historical precedent.
- Assure that markets that co-optimize energy and ancillary services do not unduly penalize the ability of loads to compete in offering ancillary services, by forcing them to provide services they did not offer to supply.
- Encourage participation by third party providers and aggregators, as they are a proven source of both technical and marketing innovation.
- Remove any artificial or unnecessary restrictions to resources offering into more than one market, where consistent with overall market design, procurement arrangements and operating requirements.
- Develop a stakeholder process to work through participation details, such as technical requirements and business rules.

1. Introduction

Ancillary services are an integral part of any well-functioning interconnected power system. Interest in how ancillary services are organized and procured has increased in the U.S. over the last decade, spurred by the Federal Energy Regulatory Commission's attempts to promote more competition in wholesale electricity markets (e.g. functional unbundling of generation and transmission services). In Order 888, FERC defined six generic types of ancillary services and indicated that customer loads should have opportunities to participate in these markets as part of its overall goal to facilitate more competitive markets.[5] Specifically, FERC has indicated that "demand must have the opportunity to supply operating reserves if it meets the necessary operational requirements, which should be designed to enable demand response participation" (FERC 2002a).

The potential benefits of load participation in ancillary services markets include: (i) improved *system reliability*, as participation by loads provides system operators another option to support local reliability and ameliorate transmission congestion, or reserves shortages; (ii) improved *market efficiency*, as more competition in ancillary services markets may reduce costs; (iii) improved *risk management*, as both market participants and system operators have more choices in how they hedge their exposure to ancillary service price volatility;[6] (iv) *market power mitigation*, as load participation reduces the ability of generators to bid up the price of ancillary services; and (v) improved *system efficiency and planning*, as the availability of loads may reduce the requirements for out-of-merit, reliability-must-run, and other reliability-induced uneconomic operations (NARUC 2002).

This study examines the relationship between market design and ancillary services provision in selected electricity markets, with a focus on the potential role of customer loads. The primary objectives of our comparative review are to identify specific approaches (e.g., reliability rules, market designs, institutional arrangements, technologies, procurement processes) that have proven successful in facilitating participation by customer loads in providing ancillary services. We also explore the potential application of these approaches to U.S. electricity markets.

This report is timely given increased interest in the potential role of loads providing ancillary services in several U.S. regional power markets. In May 2006 PJM opened most of its ancillary services markets to participation by customer loads (PJM 2006a). ISO New England and the California ISO (CAISO) are conducting pilots to test the feasibility of smaller loads participating in various ancillary services markets (i.e. ISO-NE Demand Response Reserves Pilot and the CAISO/CERTS Spinning Reserve Demonstration Pilot).[7] Our intent is that this comparative review of experience with loads providing ancillary services in other electricity markets will contribute to this process.

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[5] The ancillary services listed include: 1) Scheduling, system control and dispatch, 2) voltage control, 3) regulation and frequency response, 4) energy imbalance, 5) operating reserves-spinning reserves, 6) operating reserve-supplemental reserve.

[6] In some market designs market participants can choose whether to self-provide, bilaterally contract, or purchase ancillary services from the RTO.

[7] See ISO-New England Demand Response Reserves Pilot at http://www.iso-ne.com/genrtion_resrcs/dr/sp_proj/pilot/index.html and CAISO/CERTS Spinning Reserve Demonstration pilot at http://certs.lbl.gov/certs-loadkey-drsrdp.html

We also note the growing volume of research suggesting that some loads have characteristics that are particularly well-matched to provide certain ancillary services: the ability to be quickly cycled on and off, high availability levels during periods of most-likely need or highest value, very rapid response, inherent redundancy, and locational dispersion (ORNL 2004a). Moreover, ancillary service costs may increase in the future either through retirements of many older marginal generation units, increasing fuel prices, reduced reserve margins, or increased concentration of generation supply ownership. Both of these factors argue for system operators to consider greater participation by loads in providing ancillary services.

The remainder of this study is organized as follows. In section 2, we describe the methods and sources used in this study, including our efforts to define generic ancillary service functional requirements in order to facilitate our comparative review of five electricity markets. In section 3, we briefly review the major features of the five electricity markets included in this study. In section 4, we provide detailed descriptions of the ancillary services arrangements in the five electricity markets, including physical system requirements, procurement processes and technical requirements for load participation. We also summarize the extent of load participation in providing ancillary services in each market, including actual performance during system events, and a description of the barriers to additional load participation in providing ancillary services. In section 5, we synthesize and present major findings of our comparative review.

2. Conceptual Overview and Typology of Ancillary Services

This chapter describes our research approach and presents the ancillary services typology we developed to facilitate comparative review of how loads provide ancillary services in different electricity markets.

2.1 Approach

The research approach consisted of five steps: (1) selecting regional electricity markets to be examined; (2) reviewing the available literature; (3) conducting a telephone/email survey of practitioners familiar with each electricity market (e.g., system operators, regulators, consultants/academics, load aggregators); (4) preparing detailed summaries of load participation in each electricity market reviewed (see Appendices); and (5) synthesizing results and key findings.

2.1.1 Selecting Electricity Markets for Review

We limited our study to countries and regions with well-established wholesale electricity market designs and system operators with significant experience under that market structure. The United Kingdom (U.K.) market was included because of its long experience with electricity market reform and its current market design that emphasizes bilateral long-term contracts and bilateral day-ahead trading for most electricity transactions, with the system operator mostly responsible for Balancing Services. The Australian electricity market was included because of the excellent documentation available and the many entry points for demand response in its retail and wholesale markets. The Nordic trans-national electricity market was included as it combines central day-ahead and spot energy-only markets with AS provided by national grid operators. Due to limited resources, we did not include other restructured electricity markets such as Alberta, New Zealand, other countries in the European Union, or the Southern Cone (e.g., Chile and Argentina). We also included two U.S. electricity markets that represent differences in design of organized markets: PJM, whose multiple centrally dispatched day-ahead and real-time markets are representative of other ISO/RTOs in the Northeastern U.S., and ERCOT, which features an emphasis on bilateral transactions and a small spot energy market together with other essential balancing services.

2.1.2 Technical Approach

We reviewed the English language literature for the five selected electricity markets, focusing on how ancillary service needs are determined and provided and what technical requirements (e.g., size, performance, telemetry and metering) are placed on ancillary service providers. We supplemented these materials with surveys and telephone interviews of grid operators, market participants, regulators, and academic observers for the three international markets.

We prepared summaries of the three overseas electricity markets, which included the following:[8]

- Overall electricity market structure, including wholesale energy and ancillary markets;

[8] Separately-bound Appendices provide detailed Market and Program Descriptions for Australia's NEM, the U.K.'s BETTA, and the Nordic Power Pool

- Reliability requirements for ancillary services resources;
- Market rules pertaining to ancillary services;
- Market statistics and trends in ancillary services;
- Participation and performance of customer loads in providing ancillary services.

2.2 Typology of Ancillary Services

Electric power systems have two unique requirements which must be continuously satisfied in order to maintain overall system stability and reliability: (1) maintaining a constant balance between generation and load, and (2) managing power flows within the constraints of individual transmission facilities. In most electricity markets, these operational requirements were historically managed by vertically integrated utilities as a normal part of the electricity business. With industry restructuring (and functional unbundling), the services needed to meet these operating requirements have been broken out and provided for separately. The FERC has defined ancillary services as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system", and has provided broad oversight and guidelines regarding their provision and pricing (FERC 2002a; see Orders 888,889, and 2000).

Balancing generation and load instantaneously and continuously is difficult because loads and generators are constantly fluctuating. Minute-to-minute load variability results from the random turning on and off of millions of individual end use devices. Longer-term variability results from predictable factors such as daily and seasonal usage patterns. Generators also introduce unexpected fluctuations because they do not follow their generation schedules exactly and may trip unexpectedly due to equipment failure. The output from wind generators or other distributed energy resources adds another dimension of resource variability. The requirement for self-scheduling or operator-provided scheduling by and for multiple market participants – generators, load serving entities, retailers and large customers – introduces small errors which can affect upward or downward system balancing needs in unpredictable ways (ORNL 2004b).

Every market design must grapple with the optimal approach to provide these ancillary services (e.g., lowest cost, most reliable, lowest market concentration, greatest flexibility). Review of U.S. and international electricity markets shows that there are many possible arrangements, and that gradual improvements in market design, including ancillary services arrangements, are typical.

While there is considerable functional similarity in ancillary services across markets, there is also significant variation in how the services are organized, procured, and priced. To facilitate our comparative review, we have created a typology of ancillary services based on a functional analysis of power system operational requirements. We identify six discrete ancillary services that are necessary in power systems, irrespective of market structure and design (see Table 3). In our typology we try to avoid terms with specific meanings in particular electricity markets in favor of a generic terminology that can be used to characterize ancillary grid services across different market structures and designs.

Table 3: Typology of Ancillary Services

Ancillary Service	Description		
	Response Speed	*Duration*	*Dispatch Frequency*
Normal Conditions			
Continuous Regulation	Provided by online resources with automatic controls that respond rapidly to operator requests for up and down movements. Used to track and correct minute-to-minute fluctuations in system load and generator output.		
	~1 min	*Minutes*	*Minutes*
Energy Imbalance Management	Serves as a bridge between the regulation service and the hourly or half-hourly bid-in energy schedules; similar to but slower than Continuous Regulation. Also serves a financial (settlement) function in clearing spot markets.		
	~10 minutes	*10 min to hours*	*10 min to hours*
Contingency (Disturbance) Conditions			
Instantaneous Contingency Reserves	Provided by online resources equipped with frequency or other controls that can rapidly increase output or decrease consumption in response to a major disturbance or other contingency event.		
	Seconds to <10 min	*10 to 120 min*	*Hours to Days*
Replacement Reserves	Provided by resources with a slower response time that can be called upon to replace or supplement the Instantaneous Contingency Reserve in restoring system stability.		
	<30 min	*2 hours*	*Hours to Days*
Other Services			
Voltage Control	The injection or absorption of reactive power to maintain transmission-system voltages within required ranges.		
	Seconds	*Seconds*	*Continuous*
Black Start	Generation able to start itself without support from the grid and with sufficient real and reactive capability and control to be useful in system restoration.		
	Minutes	*Hours*	*Months to Years*

Continuous Regulation reserves and Energy Imbalance Management continuously maintain the generation and load balance under *normal* conditions. Two additional ancillary services – Instantaneous Contingency Reserves and Replacement Reserves – restore the generation and load balance in the event of a system disturbance or contingency (e.g., the sudden, unexpected loss of a generator or transmission interconnection). Voltage Control and Black Start are not likely to be provided by responsive loads, but are included for completeness. Voltage support involves the control of reactive power to maintain acceptable voltages throughout the power system under normal and contingency conditions. Black Start provides the generation resources necessary to restart the power system in the unlikely event of a major blackout. These ancillary services are described in more detail in the following sections.

2.2.1 Continuous Regulation

The Continuous Regulation service matches aggregate generation with aggregate load on an ongoing basis. This service is primarily provided by a dedicated resource, usually a generator, whose output is adjustable via Automatic Generator Control (AGC) or equivalent so that the dispatcher can accommodate the minute-to-minute fluctuations of load and generation.

Continuous Regulation is essential in maintaining system frequency. If generation exceeds load then frequency rises. If load exceeds generation frequency falls. Continuous Regulation is also important in controlling inter-area power flows. If generation exceeds load within one balancing area, then power will flow over the transmission line ties to adjacent areas. Continuous Regulation can be dispatched (controlled) based on either frequency or inter-area tie flow or both. The control mechanism is different in different parts of the world based both upon physical characteristics of the power system (size and stiffness) and control philosophy. In North America power systems, frequency is typically tightly controlled (+/-0.035hz). In other regions of the world, frequency is allowed to drift over a larger range (e.g., +/-0.5Hz in the UK). There are advantages and disadvantages to each approach. One implication of these alternative control mechanisms is that regulating units can be controlled based upon frequency in the UK, while in North America, they are typically controlled through a central AGC which takes both inter-balancing area tie flows as well as system frequency into account.

2.2.2 Energy Imbalance Management (Load Following)

Energy Imbalance Management is needed to ensure that generation and load schedules are balanced over short time frames so that markets clear and the physical system is in balance. Regardless of electricity market design, system operators must always reserve sufficient resources to ensure that aggregate energy supply and demand are continuously balanced. During peak periods (either summer or winter), the tendency is for some generators to fully bid into the day-ahead market in anticipation of a higher price, resulting sometimes in insufficient moderately-priced capacity available for final balancing. This creates a need for whoever is financially exposed to high prices in the imbalance market to acquire a hedge in the form of additional operating reserves. Similarly, in electricity markets with centralized pool dispatch, there is a need to provide incentives for resource owners – generation or loads – to carry out dispatch instructions that may vary from the day-ahead schedule due to real-time balancing needs. In PJM, for example, the incentive comes in the form of a multi-settlement system where resource owners receive a real-time Locational Marginal Price (LMP) greater than the day-ahead LMP if they alter their day-ahead schedule to suit the dispatcher’s real-time requirements. Energy Imbalance Management also serves a financial function, as the market-clearing price(s) establishes the financial exposure of buyers (sellers) who are short (long) in the spot market.

Continuous Regulation and Energy Imbalance Management, along with the operation of day-ahead and hourly energy markets, are sufficient to control the interconnected system under normal operating conditions.

2.2.3 Instantaneous Contingency Reserves (ICR)

Normal system operations are infrequently punctuated by unexpected generator outages and transmission line failures. Planners account for these situations by making sure system operators have a coordinated set of operating reserves that can respond to contingencies without affecting overall reliability. The concept and application of Instantaneous Contingency Reserves is surprisingly consistent across electricity markets, although the exact requirements vary (e.g., response time, duration, volume).

Instantaneous Contingency Reserves (ICR) operates to restore the balance between generation and load after the sudden unexpected loss of a major generator or transmission line. Power system frequency drops suddenly when generation trips (see Figure 1). Since there is insufficient time for energy markets to react, the dispatcher must have enough Instantaneous Contingency Reserves available to compensate for the worst credible event, or contingency. For example, in the Texas power system, the simultaneous loss of two nuclear plants is recognized as the worst credible event and ERCOT maintains ~2600 MW of ICR. As shown in Figure 1, frequency-sensitive generator governors respond immediately to stop the frequency drop, returning the system frequency to 60 Hz within 10 minutes.

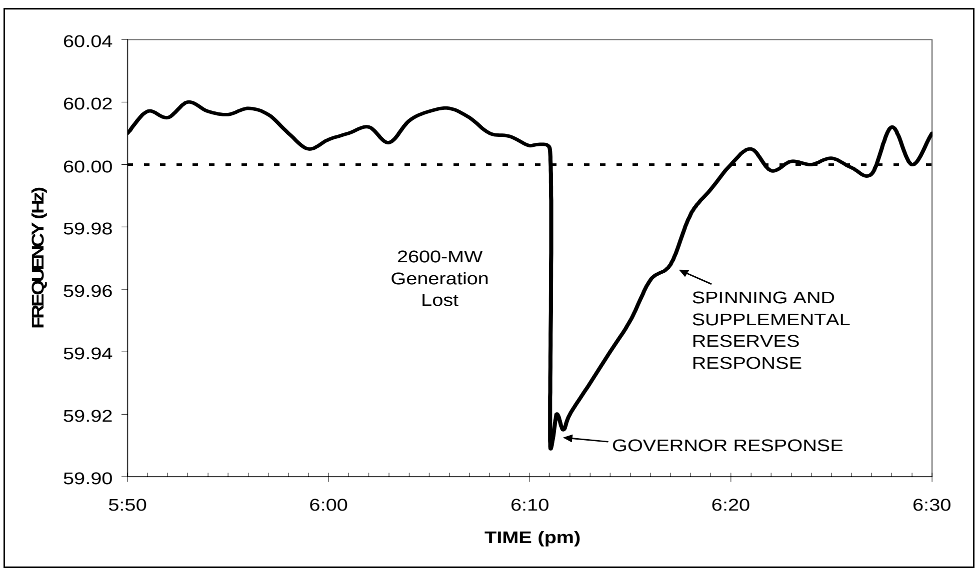

Figure 1. Use of Instantaneous Contingency Reserves to Restore Stability

The capacity resources providing ICR are typically much larger and called upon less frequently than those required for Continuous Regulation. The cost of ICR are driven by the resource’s opportunity costs, since any capacity held back as an operating reserve cannot participate in the bilateral or spot electricity markets.[9] Speed is critical for restoring system stability due to unexpected events, and Instantaneous Contingency Reserves are therefore distinguished according to how quickly they can respond. Reserves that are synchronized to the system (sometimes called "spinning reserves") or equipped with frequency relays can respond almost immediately and provide frequency support or voltage support for a short duration (minutes to hours). If the contingency persists, then it becomes necessary to replace or supplement ICR with additional operating reserves (i.e. Replacement Reserves). All five electricity markets utilized this cascading approach for ancillary services to manage system contingencies.

2.2.4 Replacement Reserve Service

Replacement Reserves have slower response times but are capable of responding over longer durations. They are typically used to supplement or replace Instantaneous Contingency Reserves in restoring frequency and preserving system stability. Replacement Reserves cover a broad spectrum of resources, response times, durations, and activation methods (e.g., automatic or manual). These reserves must be able to respond within 15-30 minutes in our functional typology (see Figure 2). Replacement Reserves are often high-cost generators that do not normally bid into bilateral or spot markets and can start within 30 minutes, or loads that can be interrupted on 15 or 30 minutes notice. Replacement Reserves are called upon infrequently but must be reserved through ongoing capacity payments to be available on short notice and at all times.

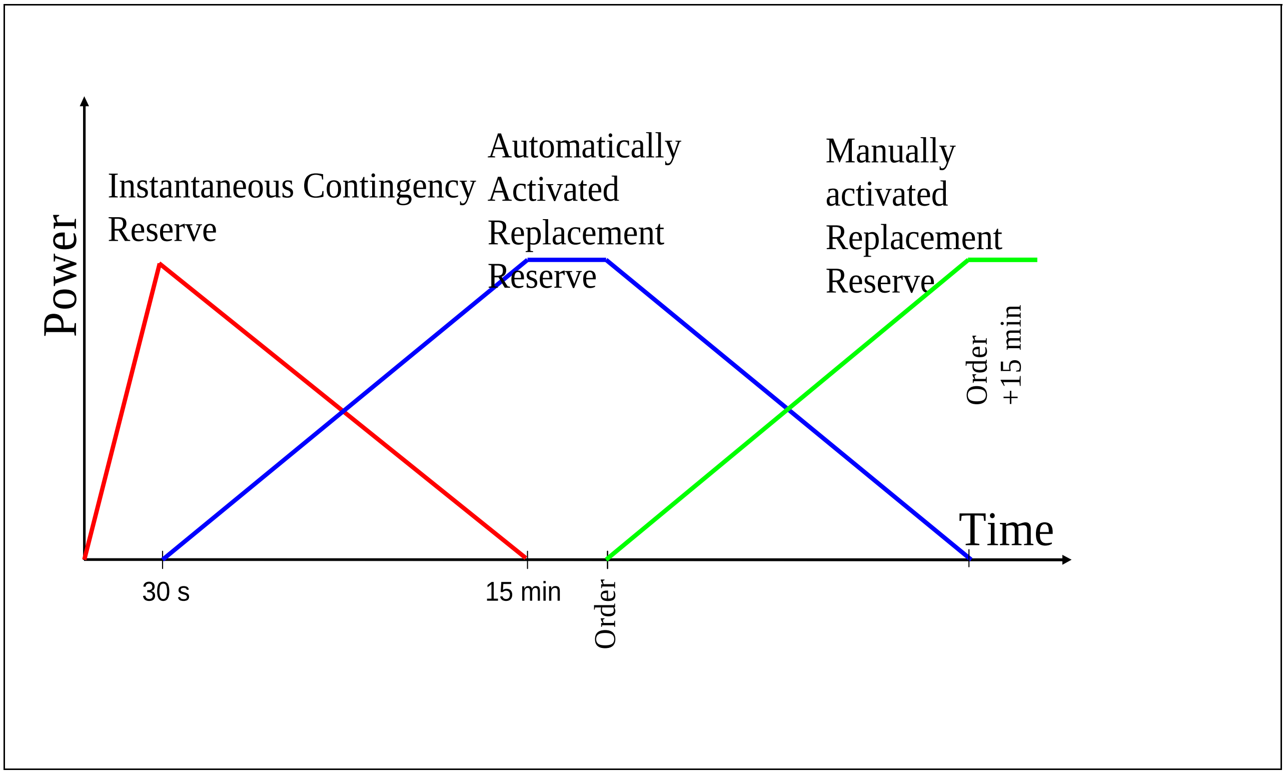

Figure 2. Cascading Contingency Reserve Arrangements

9 Reservation (capacity) payments for Instantaneous Contingency Reserves are typically less than payments for Continuous Regulation.

Replacement Reserves are the ancillary service with the largest load participation, as the requirements specified by system operator for response time and communications and control are relatively "load-friendly." The combination of a steady revenue stream from capacity reservation payments plus the infrequency of operation is attractive to customers and load aggregators.

2.2.5 Severe (Multiple) Contingency Reserves

Severe, or Multiple, Contingency Reserves are not an ancillary service *per se* but are part of the system emergency practices of all system operators. All power systems are susceptible to collapse under certain foreseeable but highly unlikely contingencies or combinations of contingencies. Although large power systems are designed to withstand credible single contingencies, such as the sudden loss of any single element (sometimes called an N-1 contingency), it would be uneconomical to plan and build a power system that was immune from all possible contingencies, such as the loss of two or more large generators or transmission circuits.

However, power system operators do consider credible multiple contingencies, often called N-2 or Category C contingencies, and provide operators with emergency procedures to deal with them. For example, in North America, a significant amount of load is attached under-frequency and under-voltage relays. Additional load is attached to relays that are under the command of system operators and can be shed "manually" within 10 minutes. The basic requirements are established by NERC and the exact amounts are specified by the Regional Councils (NERC 2004). It is noteworthy that these reserves are exclusively comprised of loads (although involuntary and uncompensated) that respond very fast and are relied upon as a stopgap to prevent system collapse. We found a similar practice was used in the Australian electricity market, which relies on uncompensated under-frequency load shedding when transmission outages plus heat-induced demand volatility combine to create a multiple contingency event.

2.2.6 Other Ancillary Services

Other ancillary services, including Voltage Support and Black Start Service, are not addressed in this study, primarily because they are not of commercial interest to loads and are unlikely to become so in the future. However, these other ancillary services are crucial for the proper functioning of synchronized generation and transmission networks and often accounts for a large share of total ancillary services expenditures (FERC 2005).

- *Voltage Support Service*. Reactive power, just as real power, must be balanced throughout the power system. Failure to do so can result in voltage collapse and cascading blackouts. Static reactive power support is provided by capacitors embedded throughout the grid, while dynamic reactive support must come from generators, synchronous condensers, or dynamic transmission devices. To date there have not been any loads that are capable of supplying dynamic reactive reserves to the power system.[10] Reactive supply is typically not procured through competitive markets (ORNL 2006a).

[10] Large variable frequency motor drives or solid-state uninterruptible power supplies could conceivably be built with dynamic reactive power capability for grid support.

- *Black Start Service.* The system operator must have resources available to restart the power system in the event of a massive blackout. Black Start Services must come from generators that can start on their own and that have enough real and reactive capability to energize transmission and restart additional generators (ORNL 1999). Loads themselves are not able to supply this service, although loads can be useful in the process of re-energizing the interconnected system (NYISO 2004). Loads associated with large generators might have sufficient capability to be useful as black start units.

3. Market Descriptions

Wholesale electricity markets vary considerably in their design with periodic and ongoing refinements/changes to market and business rules. Thus, we do not attempt a comprehensive or even systematic description of the five electricity markets reviewed, other than to point out some general tendencies and broad parameters that affect how loads participate in these markets (see Table 4). For example, it is instructive to categorize a market design in terms of: (i) the dominant form of electricity transactions, e.g., through centralized, bid-based pools or through bilateral trade;[11] and (ii) the extent and type of markets administered by the grid operator (e.g. energy-only vs. energy, capacity, transmission rights). Our brief review of these five mature electricity market designs is limited to a discussion of how the market design and structure affects the prospects for load participation, especially in the provision of ancillary services markets.

3.1 Australia's National Electricity Market

In Australia's National Electricity Market (NEM) wholesale trading in electricity is conducted via an energy-only, single auction spot market, where supply and demand are instantaneously matched in real-time through a centrally-coordinated dispatch process.[12] The NEM is very close to a pure market pool design, as Generators offer to supply the market with specific amounts of electricity at particular prices, and the system operator's dispatch engine determines the most cost efficient resource mix, taking into account both the need for energy and the need for operating reserves. The system operator then dispatches these generators into production (NEMMCO, 2005). For each 30-minute interval, a zonal price is determined for each of the six regions of the NEM.

The number of formal Market Participants in the NEM is fairly limited and includes:

- *Market Generators*, who sell their entire electricity output through the spot market and receive the spot price at settlement. *Scheduled Market Generators* are larger than 30 MW, while *Non-scheduled Market Generators* are smaller or have intermittent production characteristics (e.g., wind generating units).
- *Market Network Service Providers* (including Transmission Network Service Providers and Distribution Network Service Providers), who own and operate networks linked to the national grid. They pay market participant fees and obtain revenue from trading in the NEM.
- *Market Customers,* who purchase electricity supplied to a connection point on a NEM transmission or distribution system for the spot price. Market customers include *Electricity Retailers,* who buy electricity at spot price and retail it to end-users and *End-use Customers,* who buy directly from the market for their own use.

In 2005, there were 102 NEM market participants, primarily generators and market customers, and about 176 TWh of electricity transactions were settled based on the pool price (NEMMCO

[11] In organized markets that feature centralized pools, it is worth noting that a significant share of energy is procured through bilateral forward contracts between load serving entities/retailers and generators.

[12] In a Single Auction Power Pool only suppliers submit their bids and these bids are then stacked in increasing order of prices. The highest priced bid that intersects with the system demand forecast determines the market price.

2006a). As an energy-only single-settlement market, the NEM is prone to price volatility, especially during the hot summer months. Market participants in Australia manage the risks associated with their activity in several ways: (i) by entering into financial contracts (contracts for differences) with other parties, wherein they agree in advance a price they are willing to pay or receive regardless of spot price outcomes; (ii) by trading in a variety of over-the-counter (OTC) financial instruments (derivatives and electricity swaps) whose value is linked to movements in the spot price of electricity; and (iii) by acquiring electricity futures contracts whereby they contract to buy a fixed quantity of electricity at a fixed price over a fixed time period; and (iv) through physical hedging agreements with retail customers for both economic and emergency load shedding (NEMMCO 2004).

The National Electricity Market Management Company (NEMMCO) is the system operator and is governed by statutory National Electricity Rules. A regulator and market monitor oversee NEMMCO's operations. The Rules establish a Reliability Panel, which determines power system security and reliability standards and sets guidelines and policies governing NEMMCO's exercise of its authority to arrange for sufficient reserves. One way that resource adequacy is addressed is by requiring NEMMCO to competitively tender for additional operating reserves whenever a reserve shortfall is forecast within a six month period (AEMC 2005).

Expenditures for regulation and contingency reserves in the NEM are small – only $20 million in 2005. Expenditures for voltage support were considerably larger ($51 million) and even black start expenditures totaled $8 million (NEMMCO 2006a). As a percentage of overall market volume, Total AS expenditures in the NEM in 2005 were less than two percent, or about $0.37 per MWh of electricity delivered.

The main entry points through which loads can participate in the NEM include: (i) bilateral contracts between Retailers and end-users or aggregators, through which Retailers gain a physical hedge against high prices in the real-time market; (ii) participation in ancillary services auctions by Market Customers; and (iii) tendering for demand side resources in anticipation of operating reserve shortfalls or to provide network ancillary services at the regional level.

Table 4: Electricity market characteristics

Country/Region	Texas	United Kingdom.	Nordic region (Nordpool)	Australia	U.S. mid-Atlantic
Predominant Form of Electricity Transactions	Bilateral	Bilateral	Mixed	Pool	Pool[13]
System Operator	ERCOT	National Grid	Energinet.dk, Fingrid, Statnett, Svenska Kraftnät	NEMMCO	PJM
Peak Demand (GW)	60.5	61	66	31	144.7
Total Electricity Sales (TWh)	350	350	400	176	700
Annual Revenues ($ millions)	20,000	28,000	7,221	4,500	
Energy Markets	Imbalance	Balancing	Day-ahead Intra-day	Real-time	Day-ahead Real-time
Annual Energy Transacted by the System Operator (TWh)	40	30	170	176	400
Capacity Markets	None	None	None	None	Daily Monthly
Other Markets	Regulation Svcs Reserve Svcs Other Svcs	Short-term Bilateral PX Futures Contracts Reserves	Forward Mkt Balancing Mechanism Regulating Reserves Operating Reserves	Forward Contracts Market Ancillary Svcs	Transmission Rights Forward Energy Reserves Ancillary Services
Congestion Management	Zonal prices		Zonal prices and Counter trades	Zonal prices	Locational marginal prices

[13] On an annual basis over 50 percent of energy transacted in PJM is based on bilateral contracts; some of these contracts are indexed to LMP prices.

3.2 PJM Interconnection, LLC

PJM Interconnection operates the largest centrally dispatched electric grid in the world, serving nearly 20 percent of the U.S. economy from Chicago to the Atlantic Ocean and from Virginia to Pennsylvania. PJM's footprint comprises a population of 51 million, over 1,000 generating sources with a cumulative capacity of over 160,000 MW, a peak demand of 144,796 megawatts, and annual energy deliveries of 700,000 GWh (PJM 2006).

PJM operates a variety of markets, including day-ahead and real-time energy, daily, monthly and multi-monthly capacity, a Financial Transmission Rights (FTR) market, and two ancillary services markets – regulation and spinning reserve. PJM is also developing a forward energy reserve market for implementation in the 2006-2007 timeframe. On a day-ahead basis, PJM market participants can either submit bids to the ISO and be centrally dispatched or opt out of centralized dispatch by submitting bilateral schedules (self-scheduling). Any shortfalls in self-scheduled load or generation are balanced by PJM in the real-time market. On an annual basis a little more than half of the electricity deliveries coordinated by PJM are through internal bilateral transactions, with most of the balance transacted through the day-ahead and real-time markets. However, the entire volume of scheduled load and scheduled generation is used to set the Locational Marginal Price (LMP) and determine any congestion charges that would affect the sales or purchase price at the delivery point. The day-ahead market helps resolve congestion problems, as buyers and sellers adjust their bids to minimize uneconomic congestion charges and submit revised bids into the real-time market.

PJM's capacity and FTR markets plus multi-settlement energy markets are useful in meeting the needs of the system operator, regulators, and market participants. A financially-binding day-ahead market (DAM) allows participants to obtain price certainty for services scheduled to be delivered in the next day, while participation in real-time markets are attractive to generators and loads, who can follow operator's second by second dispatch instructions. Capacity markets and requirements for LSE's to acquire capacity reserves assures resource adequacy.

PJM operates two ancillary services markets – a system-wide Regulation Reserves market and four regional Synchronized Reserves markets. Ancillary services providers submit hourly bids on a day-ahead basis that are then cleared and dispatched on an hour-ahead basis. A recent development is that load is now allowed to provide both regulation and spinning reserve in PJM (PJM 2006a). Although PJM dispatches ancillary services on a co-optimized basis using the PJM dispatch engine, it allows resources to establish different prices for each ancillary service and energy.

In 2005, total costs for continuous regulation reserves were $545 million, while the cost of spinning reserve was another $100 million. Operating reserve credits needed for real-time energy imbalance management accounted for another $541 million. Total ancillary services expenditures were $1.62 billion (excluding compensation for reactive power), about two percent of PJM's total market turnover and costing $1.17 per MWH of electricity delivered (PJM 2006c and d).

Loads are able to participate in most of the PJM markets, through the PJM-sponsored Emergency and Economic Load Response Programs, through daily and monthly capacity auctions in which load-serving entities must participate, or by participating in one of many retail demand response programs offered by retail Load Serving Entities. In addition to the recent opening of ancillary services markets to load participation, PJM is also developing a forward energy reserve market that may provide additional opportunities for participation by loads (PJM 2005).

3.3 Nordic Region

The four economies comprising the Nordic region (Denmark, Finland, Norway and Sweden) were among the very first to restructure their electricity industries. Established in 1993, Nord Pool was the world's first multinational power exchange. Nord Pool operates several regional financial and physical markets for energy, most notably a forward market (Eltermin and Eloptions), a day-ahead market (Elspot), and an intra-day market (Elbas). Of the 400 TWh bought and sold within the Nordic region, about 176 TWh are transacted through Elspot and Elbas and the balance were bilaterally transacted. Separate day-ahead bidding areas are established and any congestion encountered in scheduling day-ahead transactions is reflected in zonal price differentials. (Nord Pool 2006). The Nordic electricity market can be characterized as a mixed pool/bilateral design.

Ancillary services expenditures including balancing costs incurred by balance-responsible market participants are significant. This trans-national system, required 30.3 TWh of real-time balancing energy purchases at a cost of $1.05 billion plus regulating reserve volume of 9 TWh at a cost of $245 million (Statnett 2006a); these transactions represent ~10% of the total amount of electricity bought and sold in the Nordic region.[14] Each national system operator had a different set of ancillary services costs according to their procurement arrangements and reserve requirements.

Loads participate in both the regional energy and regulating power markets and provide additional operating reserves procured via bids or bilateral contracts by the four national grid operators. Aggregators have started to play an important role in configuring loads and offering them into various power markets.

3.4 ERCOT

The Electric Reliability Council of Texas (ERCOT) is the Independent System Operator for the State of Texas. ERCOT manages the scheduling of power on an electric grid consisting of 78,000 megawatts of generation capacity and 38,000 miles of transmission lines in order to keep electric power flowing to approximately 20 million Texans.

[14] Total ancillary services costs for Svenska Kraftnät including disturbance reserves, primary regulation and high load reserves were $42.5 million (Nordel 2002). Fingrid's annual costs for fast disturbance reserves (gas turbines and disconnectable loads) were $12.5 million in 2005 (Fingrid 2006). RCOM capacity payments by Statnett to loads and generators were $9.3 million in 2005 (Statnett 2006a), while reported system-wide ancillary services costs were $67.2 million (Statnett 2006b). Total 2004 ancillary services payments by West Denmark were $65 million (Elkraft 2005a).

Over 95% of the electricity bought and sold in ERCOT is through bilateral contracts between generators and load-serving entities. Scheduling is performed by Qualified Scheduling Entities (QSEs), who are the only entities certified to schedule, bid and financially settle with ERCOT for energy and capacity. Retail Electric Providers (REPs) and other load serving entities contract with a QSE to provide scheduling services, including self-scheduling of prorated ancillary services obligations allocated to REPs by ERCOT. In many cases, the REPs may be part of the same company as the QSE, and thus may contract for energy supply through direct agreements with generators. These bilateral contracts are confidential, so prices paid for the overwhelming majority of energy on the ERCOT market are not available to other parties (ERCOT 2006a).

ERCOT is responsible for collating the schedules submitted by the QSEs and dispatching generators and loads in real time. ERCOT also determines the amount of ancillary services and operating reserves required and assigns responsibility to procure them to the individual REPs. REP's have the option of self-arranging reserves, but if they are not, ERCOT will purchase the necessary reserves on the REP's behalf. ERCOT holds auctions on a daily basis to satisfy requirements for regulation, instantaneous contingency reserve, and replacement reserves.

Energy imbalance is a key issue for an energy-only market based on bilateral contracts. ERCOT operates a "thin" balancing pool of energy that allows market participants to acquire additional resources needed to balance generation and load in real time. ERCOT looks at the balance between supply and demand for each 15-minute interval and, if a generation shortage is anticipated, buys additional "balancing energy" on behalf of the market. This process sets the Market Clearing Price for Energy (MCPE). REPS are financially responsible for any shortage, thus creating an incentive to hedge against any shortfall by procuring additional generation or load reduction.

Expenditures for ancillary services in ERCOT are significant - $316 million for regulation, $336 million for instantaneous contingency reserves, and $64 million for replacement reserves.

ERCOT makes extensive use of load response. Load is allowed to provide responsive reserve (spinning reserve), non-spinning reserve, replacement reserve (30 minute response), and balancing energy. Over 1100 MW of loads are qualified to provide spinning reserve and over 1200 MW of loads are qualified to provide non-spinning reserve. Over 1100 MW of load response was delivered during an April 2006 frequency excursion (PUCT 2006). Responsive load is currently limited to providing half of the contingency reserves until system operator experience is gained. Interestingly, not a single load has offered to provide balancing energy while responsive load is providing as much contingency reserve as allowed. This may indicate that load response duration is more limited than response speed (ORNL 2006b).

3.5 United Kingdom (U.K.)

The British Electricity Trading and Transmission Arrangement (BETTA) has been in place since 2005. Prior to that, the U.K. market design was based on a power exchange, of which the centrepiece was a compulsory, day-ahead, last-price auction called the English Power Pool. National Grid Company (NGC) is the system operator and operator of several special markets serving all of the UK, except Northern Ireland.

Power transactions in the current BETTA scheme are based on bilateral trading of electricity contracts between generators, suppliers, traders and customers. Almost all electricity (>90%) is bought and sold by bilateral contracts between buyers and sellers in over-the-counter markets or in power exchanges such as the London-based UKPX or other European power exchanges (e.g., APX or EEX). A small amount of sales (<10%) are made in the Balancing Mechanism, a tool that NGC uses to ensure that supply and demand match on a second by second basis. The Balancing Mechanism is one of several "special markets" which NGC operates to regulate system frequency and voltage, provide rapid frequency response in case of disturbances, and provide for additional standing reserves for very low system frequency or to replace the rapid frequency response reserves. Aggregated loads have been participating in all three of these "special markets" since the late 1990s.

4. Ancillary Services Arrangements in Selected Electricity Markets

This section provides an in-depth examination of the arrangements for ancillary services in the five electricity markets considered, including the type and extent of load participation. We found that not only is each power system unique in terms of generation mix, transmission characteristics, market design, credible contingencies, and reliability rules, but the technical requirements and opportunities for load participation vary according to economic and technical characteristics and the ongoing give-and-take between system operators, market participants and regulators. We focus on the four generic ancillary services described in Section 2 - Continuous Regulation, Energy Imbalance Management, Instantaneous Contingency Reserves, and Replacement Reserves - and highlight the extent of load participation, barriers to additional load participation, and actual performance of loads providing ancillary services. In Table 5, we classify and map the specific ancillary markets and services in each country/region into our four generic ancillary services.

4.1 Determining Sufficiency of Regulation and Reserves

Continuous Regulation requirements are determined by the allowable frequency fluctuations about the nominal grid frequency, the magnitude and variance of the load from second to second, the size of the region, the response time for generators to ramp-up and ramp-down their output, area control error (ACE),[15] and rules on islanding and zonal self-synchronous operation. The U.K. imposes regulation size requirements as a function of the load condition; thus they can vary significantly over the course of the year. The Nordic countries set them as a minimum size requirement for the region plus an additional self-provision requirement for each national system operator. In relative terms compared to system peak demand, Continuous Regulation reserves requirements were somewhat lower for PJM (possibly due to its larger size) and the Australian NEM (see Table 6).

[15] Area control error (ACE) measures the instantaneous MW imbalance between load plus net interchange, and generation.

Table 5: **Classification of ancillary services in five electricity markets**

Market	Continuous Regulation	Energy Imbalance Management	Instantaneous Contingency Reserves	Replacement Reserves
NEM	Regulating Raise Service Regulating Lower Service	30-minute Spot Market	Fast Raise Service Fast Lower Service Slow Raise Service Slow Lower Service	Delayed Raise Service Delayed Lower Service
Nord Pool	Frequency Controlled Normal Operation Reserve (FCNOR)	Regulating Power Market (RPM)	Frequency Controlled Disturbance Reserve (FCDR)	Fast Active Disturbance Reserve (FADR)
BETTA	Mandatory Frequency Response	Real time Balance Mechanism	Fast Reserves	Standing reserves
ERCOT	Regulation Up (URS) Regulation Down (DRS)	Upward Balancing Energy Svc Downward Balancing Energy Svc	Responsive Reserve Service (RRS)	Non-Spinning Reserve (NSRS) Replacement Reserve (RPRS)
PJM	Regulation Market	Real Time Energy Market	Synchronized Reserves Non-Synchronized Reserves	30 min Synchronous Reserves Non-Synchronous Reserves

Energy Imbalance Management arrangements vary considerably across the five markets. In multi-settlement pool markets, energy imbalances are accommodated by day-ahead auctions and real-time auctions covering the same short time intervals, making it possible to minimize any forecast or scheduling shortfalls and resolve any network congestion difficulties. In PJM for example, loads and generators that can follow the dispatcher's balancing requirements in real time are compensated via operating reserves credits, with the costs allocated according to the market positions of other market participants at settlement. In the U.K. market operated by BETTA, energy imbalances are managed using a physical balance mechanism, which receives offers and bids for energy within one-hour of real-time to balance the transmission system and manage grid constraints, and an imbalance settlement process which settles discrepancies between contracted electricity and that which market participants actually generate or consume. In the NEM, generators submit a schedule of quantity and price offers for every 5 minutes of every day by noon the previous day, which NEMMCO uses together with its own regional forecasts of demand to determine which least-cost mix of generation will satisfy forecast demand in each 5-minute period. In Nord Pool, the national grid operators maintain a mix of dispatchable operating reserves, including a Regulation Power Market (RPM) that reserves a certain amount of capacity (and load) to provide last-minute power reserves for balancing. Finally, ERCOT operates a thin real-time balancing market that accounts for about 5-7% of the total energy scheduled by ERCOT in any given period. ERCOT looks at the balance between supply and demand approximately 30 minutes prior to each 15-minute interval, and as necessary will buy additional "balancing energy" on behalf of the market. As part of settlement ERCOT determines which market participants were actually short, and assigns the cost of balancing energy accordingly.

Instantaneous Contingency Reserves requirements are driven by the system operator's requirements to maintain frequency within acceptable limits during the largest single credible contingency event. The basis for contingency planning is typically an unplanned outage of the largest single generation unit or transmission interconnection less any implicit load frequency response.[16] The Instantaneous Contingency Reserve requirement was about 1 to 1.5 percent in four of the five wholesale power markets, but almost 4 percent in ERCOT (see Table 6). These differences reflect the size of the contingent generator or interconnection as well as reserve sharing arrangements and of course load frequency response.

[16] Implicit load frequency response is a function of the amount of rotating machinery (motors) connected to the system. As frequency drops most AC motors slow down, consuming less power. As the amount of power consumed by these machines is a function of their rotational speed, the demand for power will fall (or rise) with falling (or rising) frequency, thus reducing the contingency reserve requirement. In the case of Australia's NEM, load frequency response acts to reduce the amount of Instantaneous Contingency Reserve requirements by about half (NEMMCO, 2005).

Table 6: Regulation and reserves volumes

Market	Peak Demand (GW)	Regulation and Reserves Volumes			
		Continuous Regulating Reserves (MW)	Imbalance Mgmt (Twh)	Instantaneous Contingency Reserves (MW)	Replacement Reserves (MW)
Australia NEM	31	130 Raise 130 Lower	Spot Market	350 Fast Raise 100 Fast Lower	350 Slow Raise & Lower 400 Delayed Raise & Lower
PJM	131.3	1000	Less than 5 % of total transactions	75 % of largest system contingency, or about 1,825 MW	3,400
Nord Pool	67.8	600	30.3*	1000	5,020**
U.K. BETTA	61	550-1260 (varies by season)	3 % by volume of energy	353	2,900[17]
ERCOT	60.5	580-1000 Raise 500-1,300 Lower	15, or about 10 % of total transactions	2,300	1,250

We see the greatest variability in the types of resources utilized to fulfill Replacement Reserves requirements. In Australia, the NEM has both synchronized Slow Raise and Lower Reserves (on line in 60 seconds) and non-synchronized Delayed Raise and Lower Reserves (on line in five minutes). In the U.K. a portion of the Replacement Reserves are spinning reserves and the balance is off-line until called upon. Similarly, in the Nordic market, their Replacement Reserves (called Fast Acting Disturbance Reserves) must meet the minimum requirement of replacing depleted contingency reserves but also comprises other capacity resources (e.g., gas turbines) that national governments have required the system operators to procure above and beyond ancillary services needs. In North America, we classify both non-spinning reserves and supplemental reserves as Replacement Reserves.

The different system characteristics, market designs and system operations procedures result in certain types of resources being used interchangeably to meet the day-to-day regulation and reserves needs of system operators. This is true in both the Nordic region and in ERCOT. However, if we combine the categories of Instantaneous Contingency Reserves and Replacement Reserves, we see more uniformity across the five markets in terms of operating capacity requirements – roughly 4.7 percent for Australia, for example. Only PJM, with its very large system, maintains seemingly low operating reserves for contingency needs (just 1.6 percent).

[17] This value comprises both synchronized and non-synchronized reserves and thus should be distributed between the Instantaneous Contingency and Replacement Reserves.

4.2 Ancillary Services Procurement Arrangements

The procurement arrangements for ancillary services across the five markets are compared in Table 7. We offer the following observations on the variety of approaches used to procure ancillary services in the five selected electricity markets.

First, there is a clear trend toward market-based procurement for most ancillary services. For example, in Australia's NEM ancillary services were initially provided under long-term bilateral contracts, almost exclusively with generators. During the first three years of operation, ancillary services costs accounted for almost ten percent of total market turnover [NECA 2003]. These high costs, ostensibly due to bulk procurement from a limited number of generators, led to the introduction of a market-based system for procurement of the most frequently–utilized ancillary services. Since 2001 NEMMCO has operated auction markets for the delivery of frequency control ancillary services (FCAS).[18] The introduction of these markets drastically reduced the cost of frequency-controlled ancillary services, from A$110 million in NEM's first full year of operation to just A$27 million in 2002 [Outhred 2004]. Similarly, Statnett introduced its Regulation Capacity Option Market (RCOM) in an effort to reduce the high cost of reserving sufficient operating reserves to accommodate regulation and energy imbalance needs.

Second, in some markets, ancillary services are procured by the system operator and in other markets are determined and allocated by the system operator but arranged by market participants. In ERCOT, market participants are allowed to self-provide ancillary services; ERCOT also operates a real-time ancillary services market for Continuous Regulation, Imbalance Management, and Instantaneous Contingency Reserves to correct any deficiencies at the expense of the market participant who is short. Each Qualified Scheduling Entity (QSE) is responsible for procuring these services, either by self-providing, purchasing from another QSE, or purchasing from ERCOT. Market participants that self-arrange must ensure that whomever they contract with are registered with ERCOT, meet all technical requirements, and are dispatchable as needed under ERCOT's emergency operations protocols [ERCOT 2006a]. The participation of loads in providing ancillary services is streamlined by two standing arrangements - the Load Acting as a Resource (LaaR) program for loads providing contingency and replacement reserves and the Balancing-Up Load (BUL) program for loads providing imbalance energy.[19] The QSE (or ERCOT in the case of balancing-up load) has a choice of which ancillary service auction(s) that each load will bid into. A load can bid into more than ancillary services auction, but can only be selected once for each interval (ERCOT 2006a). It is unclear whether the option for self-provision (vs. centralized procurement) is beneficial in stimulating more participation by loads, although the high levels of load participation in ERCOT's ancillary services suggests it might.

[18] NEM continues to purchase network control ancillary services (NCAS) and System Restart Ancillary Services (SRAS) through long-term bilateral agreements.

[19] Only loads equipped with telemetry equipment and under-frequency controls and capable of responding within 10 minutes are allowed to provide instantaneous contingency reserves.

Table 7: Comparison of ancillary services procurement arrangements in five electricity markets

	System Operator	Continuous Regulation	Energy Imbalance	Instantaneous Contingency Reserves	Replacement Reserves
Australia's NEM	**NEMMCO**	Market participants make offers at 5 minute intervals for each FCAS product on a day-ahead basis. NEMMCO's dispatch engine produces co-optimized energy & FCAS bid stack and dispatches sufficient resources to meet requirement			
Nordic Power Market	**Energinet.dk**	Tenders & bilateral contracts with generators	Market participants submit bids in the Regulating Power Market on an hourly basis for the next day. Size and price of regulating objects (Up or Down Generation or Load) are stacked and dispatched in merit order	Tenders & bilateral contracts with generators & loads	Long-term bilateral contracts w/ Loads & Generators
	Statnett	Monthly or weekly auctions for supplemental fast operating reserves via the Regulating Capacity Options Market.		Monthly or weekly auctions for supplemental fast operating reserves via the Regulating Capacity Options Market. Participants are obliged to submit bids in the Regulating Power Market	
	Fingrid	Generators or loads submit regulation bids to the regulating power market. Other holders of capacity can participate through their balance provider.		Generators or loads submit regulation bids to the regulating power market. Other holders of capacity can participate through their balance provider.	Annual tenders & long-term contracts with generators & loads
	Svenska Kraftnät	Annual tenders & long-term contracts with generators, esp. hydro			
BETTA (U.K.)	**National Grid**	Competitive tendering and bilateral contracts on an annual or monthly basis.	Operator receives offers and bids for balancing energy within one-hour of real-time. This is the only hour-ahead trading allowed.	Standing Reserves contracted through competitive tendering. Synchronized and non-synchronized reserves used interchangeably.	
Texas	**ERCOT**	QSEs self-arrange or purchase from ERCOT in AS Mkt during Day-Ahead Period.	QSEs can balance on behalf of market participants or sell/purchase from other QSEs.	QSEs self-arrange or purchase from ERCOT in AS Mkt during Day-Ahead Period.	
Mid-Atlantic/Mid-West	**PJM**	Resources make hourly day-ahead offers, changing quantity up until one hour before dispatch. PJM co-optimizes & selects units up to the requirement. Regulation Market clears hourly in conjunction with Spinning Reserve Market.	The real-time energy balancing market calculates clearing prices every five minutes based on security constrained economic dispatch and bids by generators & loads dispatchable in real time	Resources make hourly offers on a day-ahead basis and can change quantity but not price up until one hour before dispatch. PJM co-optimizes & selects units up to the requirement, posting the market results and assignments. Resources may bid in as 10 minute or 30 minute Synchronous or Non-Synchronous	

Third, procurement is a two-step process in several markets - a monthly or weekly auction to procure operating reserve capacity, followed by hourly bidding into the day-ahead or real-time market. For example, Statnett's innovative RCOM (Regulating Capacity Options Market) serves to mobilize additional reserves to bid into the imbalance energy and regulating capacity markets during the capacity-short winter season. In the Nordic marketplace, hydropower usually provides Continuous Regulation reserve capacity. However, during the winter season capacity is very tight and mostly bid into the Elspot market, leaving little capacity available for balancing or regulation. Network constraints further exacerbate this problem. The RCOM program mobilizes additional capacity both from generators and loads via a weekly bidding process. Statnett reviews the bid stack and volume requirements and makes weekly awards over the period November-March. Each bid accepted receives a reservation payment and is required to bid into the balancing market every weekday between 0500 and 2300.[20] Volume requirements vary according to weather, and Statnett receives more weekly bids than it needs. The mix of generation and loads procured varies according to price, as load is represented more heavily in the more-expensive portion of the bid stack (see Figure 3). During the coldest winter weeks, when demand is high and generation capacity tight, load can comprise half or more of the weekly RCOM volume (Statnett 2005a).[21]

Fourth, in some cases a tendering process and entry into bilateral contracts with generators or loads is used to procure Instantaneous Contingency Reserves and Replacement Reserves. For example, Fingrid has contracted its assigned Frequency Controlled Disturbance Reserves and Fast Active Reserves requirement via long-term bilateral contracts with gas turbines and very large individual industrial customers, typically primary industry, heavy metals, and forest and forest products (Nordel, 2004). At present, there are seven large customers providing 120 MW of frequency-controlled disturbance reserve and 400 MW of fast active reserves. The bids from demand resources received in Fingrid's annual tendering process amounted to a bigger capacity than required, a clear signal of amply available DR resources [Fingrid Oyj 2005a].

Tendering can also work on short notice to acquire operating reserves on an as-needed or emergency basis. NEMMCO operates in accordance with statutory National Electricity Rules, which requires competitive tendering for additional operating reserves whenever a reserves shortfall is forecast for the next peak season. This requirement came into play in 2005, as forecast reserve shortfalls in Victoria and South Australia led NEMMCO to issue an invitation to tender for 500 MW of additional short-term reserves. NEMMCO procured a total of 375 MW of reserve capacity, with conditions ranging from 1 hour per day to 15 hours per day and limits on the total hours of usage, all from loads (NEMMCO 2006d).

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[20] However, the resource owner does set the bid price.

[21] Statnett supplements the regulating reserve capacity available from the RCOM through additional bilateral contracts with generators, large industrials and aggregators.

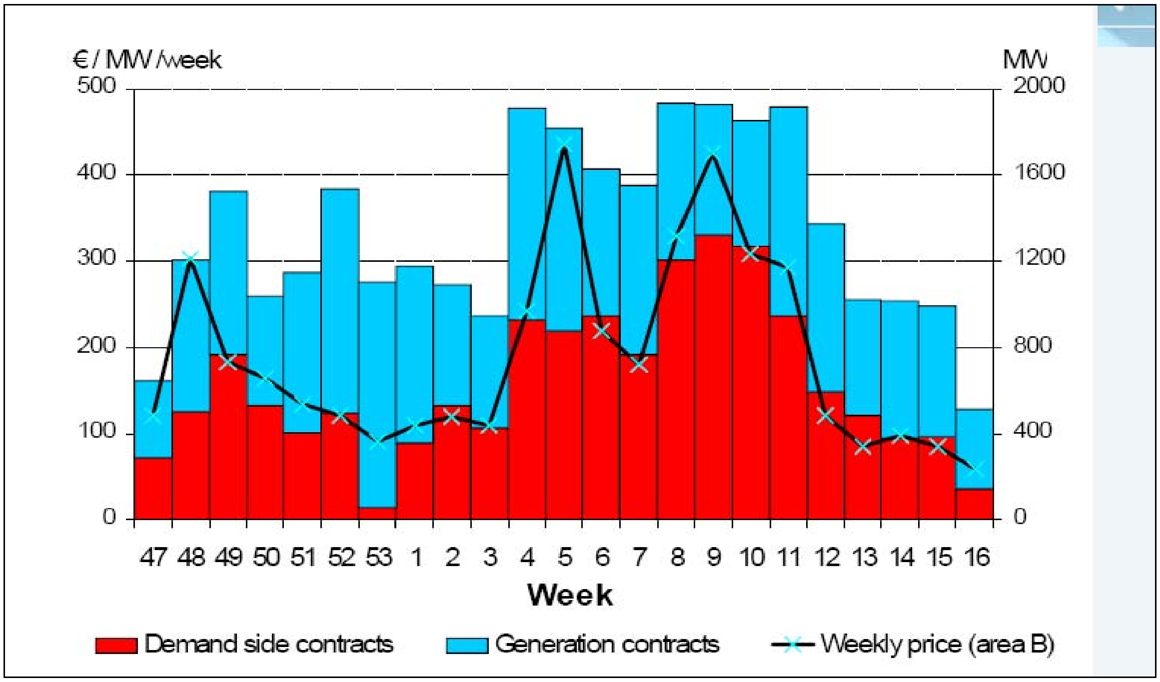

Figure 3: RCOM Volume and Price, Winter 2004-2005 (IEA 2004)

4.3 Compensation Arrangements for Ancillary Services Providers

Compensation arrangements vary by market design. The most common arrangement is availability or reservation payments made on a per-unit capacity basis over the period the capacity is made available to the grid operator. For example, for loads reserved in Fingrid's regulation bank, the capacity payments were $1,800/MW in 2005 for an entire year ranging down to $0.3 per MW for a single hour of availability. If the customer was actually called upon by the grid operator to reduce their load there is an additional activation payment based on the spot energy or imbalance energy price.

Capacity reservation payments are very attractive for customers inclined to make their load available as an operating reserve. Customers generally are not interested in frequent load reductions, but are willing to offer their load resource to the operator on a standing basis for curtailment under exceptional circumstances. In the UK, for example, the grid operator offers reserve tenders for a 6-month period at a negotiated capacity price (nominated in £/MW for the duration). Such a compensation arrangement works equally well for loads and for gas turbines or older thermal units which are uneconomical except during high-cost peak periods.

Total compensation from capacity payments and accepted load reduction bids can be substantial. For example, Nordisk Energikontroll is a third party aggregator that specializes in configuring large boilers to bid into Statnett's RCOM. The preferred operating mode of these boilers is with electricity; however, they are capable of switching back and forth between electricity and oil on very short notice. Nordisk Energikontroll submits their option price bid for an aggregated 10 MW of demand into the RCOM auction on a weekly basis during the five winter months, including associated costs (fuel, labor) should their option be called. The weekly option price bids vary according to both electricity and oil market conditions, but typical values are in the range 1000-2000 NOK/MW (US$150-300/MW per week). Under these market conditions it is possible to accumulate 300,000 NOK in turnover (~US$45,000, or about $1,000 per MW per month) in capacity payments.

In Australia, Energy Response Pty Limited (ERPL) is a commercial firm specializing in aggregating demand side resources (DSR) in response to operating reserve tenders from NEMMCO or individual network service providers. ERPL has contracted and registered more than 300 MW of loads, including pre-testing to ensure curtailment quantity, reliability, temperature sensitivity, and communications connectivity. ERPL responded to NEMMCO's recent tender for short-term operating reserves, and its bid of 125 MW of configured operating reserves was accepted. The total worth of the contract to provide reserves over a three month period is estimated at $1.2 million ($3,300 per MW per month), inclusive of availability payments, dispatch payments, and operating costs (Energy Response, 2005). These payments for availability would be supplemented by energy payments for curtailed energy priced at the sport market price, which can spike as high as A$10,000 per MW.

ERCOT's Load Acting as a Resource (LaaR) program mobilizes sufficient load to meet 50 percent of its total requirements for instantaneous contingency reserve (e.g., Responsive Reserve Service) and replacement reserve (e.g., Non-Spinning Reserve Service and Replacement Reserve Service). In 2005, the LaaR program was oversubscribed. Total awards to loads participating in providing operating reserves were $71 million in 2005, or $4,930 per MW per month, inclusive of availability payments, dispatch payments, opportunity costs, start-up costs, and operating costs. Once again, this award is a capacity payment only, with additional energy payments based on the market-clearing price for energy set in the imbalance energy market (ERCOT 2006a).

Comparing compensation levels for ancillary services across markets is difficult, as requirements imposed on loads (or generators) to provide a specific ancillary service varies. For example, in the Nordic region, loads that are compensated for their availability and bidding into the Energy Imbalance market are also on call to provide Instantaneous Contingency Reserves and Replacement Reserves. In contrast, loads contracted as operating reserves in the NEM are only called upon in case of severe capacity shortage or system disturbance. However, as described above, we found capacity payments to range between $1,000 and $5,000 per MW-month across the five markets.

4.4 Technical Requirements for Loads Providing Ancillary Services

The technical requirements and practices associated with each type of ancillary service are summarized in Table 8. We found that the requirements on generators and loads are for the most part equivalent. However, some technical requirements and practices represent potential barriers to load participation, in particular minimum load size, real-time telemetry, and co-optimization.

Technical requirements are more stringent for resources providing Continuous Regulation and Instantaneous Contingency Reserves, as these are most critical to the system operator's ability to quickly react to sudden changes in generator output and fluctuations in frequency and voltage. Reserves providing these ancillary services are often activated directly or automatically via generator controls or frequency response. The continuous and real-time output adjustments needed to provide Continuous Regulation has up until now limited the scope of participation by loads in this market.[22] However, as of May 1, 2006, PJM has opened up this market for load participation and Nordel is considering a similar move (PJM 2006a; Nordel 2006a).

Advanced telemetry or SCADA was required for most operating reserves, with the exception of some replacement reserves. Size requirements varied considerably, from 3 MW to 25 MW, but these requirements are relaxed in some cases to allow for participation by load aggregators.

Synchronized on non-synchronized resources providing Instantaneous Contingency Reserves can respond automatically to dispatch signals from the grid operator or in response to under-frequency relays. Non-synchronized or supplemental resources providing Replacement Reserves can respond to dispatch signals directly from the grid operator or via their retailer, service provider or load aggregator. Commercial frequency response services offered in the U.K. are designed to accommodate frequency responsive resources that are not dispatched by the grid operator, instead functioning autonomously by means of an under-frequency relay. This particular frequency service has been utilized by the U.K. system operator for almost ten years, and provides the grid operator more flexibility compared to the mandatory frequency response service terms contained in the U.K. grid code [National Grid 2006].

ERCOT and the Nordic region have the most stringent telemetry rules. In ERCOT all resources providing ancillary services must have real-time monitoring requirements (e.g., SCADA or similar arrangement), including under-frequency disconnect relay status. Because of the primacy of the QSE-load relationship, QSE's typically arrange for and manage the communications and control links between the participating loads and the dispatcher. ERCOT then dispatches loads via the QSE when required.[23]

Nordel's four TSOs require that each resource providing frequency-controlled reserves must provide extensive information to the dispatcher in real time, including operational status, frequency, frequency control dead band, and regulating capacity. PJM requires uploading of 1-minute or less metering for its Regulation and Spinning Reserve markets. Telemetry requirements for Replacement Reserves are significantly lower.

There is a modest trend overall towards reduced telemetry requirements and reduced minimum size requirements, two of the main barriers to increased load participation in providing ancillary services. The Danish system operator relaxed the telemetry requirements for the fast active reserves for purpose of a pilot study to assess the responsiveness and reliability of load customers. Elkraft also relaxed the lower size limit on any single reserve resource, thus allowing aggregation, in order to accommodate smaller loads. Both PJM and ERCOT require only Interval Data Recorders (IDRs) instead of telemetry for loads participating in real time energy or energy balancing markets. However, each resource within an aggregated load block has to be metered to

[22] This is not necessarily a reflection of the load's inability to follow minute-by-minute system operator's instructions. In some cases reliability rules or grid codes specify generation to fulfill the continuous regulation function.

[23] The three-step communications and control chain (ERCOT-QSE-LaaR) did not function as well as expected during the April 2006 activation of ERCOT's Emergency Electric Curtailment Plan. ERCOT is looking into how to streamline the response time of responsive reserves (ERCOT 2006).

verify performance, using interval meter data downloaded on a day-after basis rather than the stringent SCADA requirement.[24]

Table 8: Technical requirements for ancillary services

Ancillary Services	Service Requirements	Australia	Nordic Countries	UK	ERCOT	PJM
Continuous Regulation	Name	**Regulating Raise & Lower Svc**	**Frequency Controlled Operating Reserves**	**Mandatory Frequency Response**	**Regulation Service Up/Down**	**Regulation**
	Load Participation	no	no	no	no	yes
	Minimum Size		25 MW	required for gensets >300 MW	1 MW	1 MW
	Metering requirement	scada	scada	scada	scada	scada
	Other Requirements			(primary) response <= 10 sec. (secondary) response <=30 sec. and sustained <=30 min.		
Imbalance Energy	Name	**Spot Market**	**Regulating Power Market**	**Real Time Balancing**	**Upward Balancing & Downward Balancing Svc**	**Real Time Energy Market**
	Load Participation	yes	yes	yes	yes	yes
	Minimum Size				1 MW	1 MW
	Metering requirement	scada	scada	scada	IDR meter	IDR meter
	Other Requirements					
Instantaneous Contingency Reserve	Title	**Fast Raise & Lower/ Slow Raise & Lower**	**Frequency Controlled Disturbance Reserves**	**Fast Reserves**	**Responsive Reserve Services**	**Syncronised Reserves**
	Load Participation	yes	yes	yes	yes	yes
	Minimum Size		1 MW	50 MW non-aggregated 70 MW aggregated	1 MW	1 MW
	Metering requirement	real-time metering		scada	real time metering and relay status reporting	less than 1 min scan upload in evening
	Other Requirements		varies by country	response <=2 min. sustain >=15 min. no more than 1 activation per day	ISO dispatch control and under-frequency relay	response <= 10 min. can be aggregated no more than 25% of total reserves from load
Replacement Reserve	Title	**Delayed Raise & Lower Svc**	**Fast & Slow Active Reserve**	**Standing Reserves**	**Non-Spinning Reserve Services; Replacement Reserve Svcs**	**Non-Synchronized Reserves**
	Load Participation		yes	yes	yes	
	Minimum Size		not specified	3 MW	1 MW	
	Metering requirement		interval meter	during activation in real-time: 1 minute interval scans	real time metering	
	Other Requirements			response time: <=20 min. sustain reserve >=2 hours	response time: <=30 min. sustain reserve >=1 hour	

[24] A drawback of this approach is that the system operator does not have direct feedback on the response and performance of the demand resource.

4.5 Load Participation in Ancillary Services Markets

The extent of load participation varies considerably across the five markets and across the generic ancillary services products. We found the greatest amount of load participation in the ancillary services markets operated by ERCOT, the Nordic grid operator, and National Grid in the U.K. (see Table 9). In the Nordic markets, loads may participate in three of the four ancillary services mechanisms - Energy Imbalance Management, Instantaneous Contingency Reserve, and Replacement Reserves. Demand response resources had a total subscribed market share of about one-third in the entire Nordic region for all four ancillary services categories. This regional average masked considerable variations across individual TSOs. Statnett had by far the deepest load participation as a result of its RCOM, with over half of total ancillary services needs provided by participating loads. Fingrid also delivered impressive results as participating loads provide more than 50% of its Energy Imbalance and Contingency Reserve requirements and 40% of its Replacement Reserve requirements. SvK delivered about a 25 percent market share for load participation across three ancillary services products as a result of its very successful 2005/2006 annual tendering for Frequency Controlled Disturbance Reserve (FCDR) and Fast Active Disturbance Reserve (Nordel 2006a). Energinet.dk has had a low level of load participation in its ancillary services markets so far, although this may also change as the Danish DR Action Plan is implemented.

Table 9: Load participation in providing ancillary services

<table>
<tr><td>Region/ Country</td><td>System Operator</td><td>Continuous Regulation Reserves</td><td>Energy Imbalance Reserves (Load Share/AS Total, in MW)</td><td>Contingency Reserve (Load Share/AS Total, in MW)</td><td>Replacement Reserve (Load Share/AS Total, in MW)</td></tr>
<tr><td>Australia's NEM[25]</td><td>NEMMCO</td><td>Nil</td><td>Not Applicable</td><td>Nil/860</td><td>375/460</td></tr>
<tr><td rowspan="4">Nordic Region</td><td>Energinet</td><td>Nil</td><td colspan="2">Nil/165</td><td>50/1220</td></tr>
<tr><td>Fingrid</td><td>Nil</td><td colspan="2">120/205</td><td>390/1000</td></tr>
<tr><td>Statnett</td><td colspan="4">1481/2105</td></tr>
<tr><td>Svenska Kraftnät</td><td>Nil</td><td colspan="3">870/3782</td></tr>
<tr><td>Nordic Total</td><td></td><td colspan="4">2911/8642</td></tr>
<tr><td>U.K./BETTA</td><td>National Grid</td><td>Nil</td><td>Load provided 30% of dispatched reserve energy in 2003</td><td>160 MW</td><td>250 MW</td></tr>
<tr><td>Texas</td><td>ERCOT</td><td>Nil</td><td>Negligible</td><td colspan="2">1200/2400 – currently limited by ERCOT rule</td></tr>
<tr><td>Mid-Atlantic/ Midwest</td><td>PJM</td><td>Negligible[26]</td><td>Neg.</td><td>Neg.</td><td>1600 MW (Emergency);
2200 MW (Economic)</td></tr>
</table>

[25] Not reflected in these numbers are load participation in Network Loading Control (350 MW/350 MW in Victoria, or 100 percent) and tendering of load for seasonal operating reserves

[26] PJM only recently (May 2006) opened up this market to participation by loads.

ERCOT had by far the largest quantity of demand participating in its operating reserves, despite a "cap" on load participation set at 50 percent of the total 2400 MW static requirement. This quota was fully subscribed by loads participating in the LaaR program throughout 2005 (see Figure 4). With 96 participants bidding in 1800 MW of load, capacity payments to loads for Responsive Reserve Services were $71 million in 2005 (ERCOT 2006b).

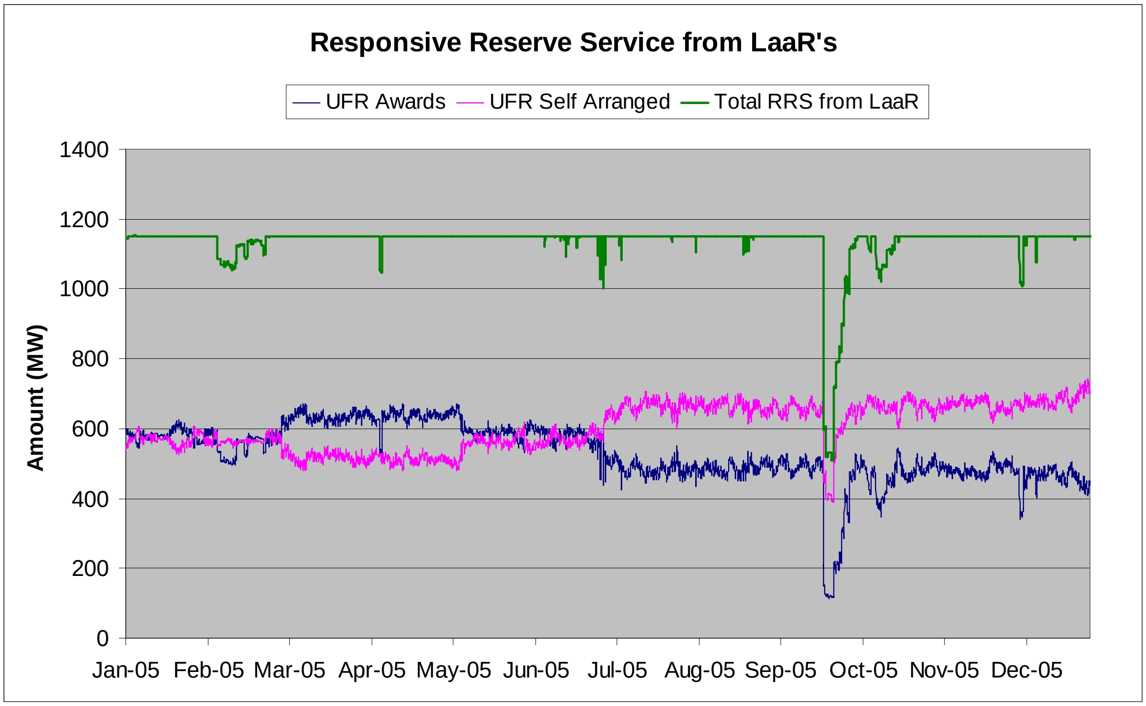

Figure 4: Load Participation in ERCOT's RRS Market (Source: ERCOT, 2006b)

Estimating the amount of demand response participating in NEMMCO's FCAS bundle of services is difficult because the FCAS payment scheme does not involve capacity payments. Market Participants and Scheduled Loads can bid qualified loads into these markets, but there is no guarantee that their bid will be low enough in the bid stack to be selected. However, there is some evidence to suggest that NEMMCO's use of co-optimized dispatch of energy and ancillary services may discourage load aggregators from submitting bids because of customer concerns regarding the frequency of being dispatched.

Thus far, the two NEM entry points that have enjoyed substantial load participation are tendering for temporary operating reserves and bilaterally contracting to provide network control services at the regional level. As part of the reliability safety net, 375 MW of short-term load-based operating reserves were procured in 2006 (NEMMCO 2006d). All of the reserves selected were based on provision of loads. Total availability payments for these operating reserves were estimated at $3.5 million. Load is also contracted for bilaterally for provision of network control ancillary services. Loads provided the entire 350 MW of network loading control with payments totaling about $400,000 in 2005 (NEMMCO 2006c).

PJM recently announced it has opened all of its ancillary services markets to load participation (PJM 2006a). However, at present there is no appreciable demand response participation in its Regulating Reserves or Spinning Reserves markets. A considerable amount of load from the Active Load Management Program and Emergency programs participate in providing non-synchronized operating reserves.

The UK was one of the first countries to utilize loads to provide frequency and fast reserves. Load aggregators have been successfully marketing eligible ancillary services to large industrial loads for more than 10 years. A key reason for this early market participation were source-neutral market and reliability rules that provided a level playing field for participation by both load and generation resources. At present, load resources provide about 30% of the secondary frequency response service (comparable to spinning reserves in US wholesale markets) using under-frequency load shedding control strategies with varying frequency thresholds. By establishing gradual aggregate load control over a range of frequencies, the load resources provide functionality equivalent to the droop control of a generator. Likewise, load resources provide ~30% of the standing reserves (i.e., Replacement Reserves). Load aggregators have gained considerable practical experience in load characteristics of different end-users and how to design of aggregated load portfolios that minimize the risk of underperformance in providing various ancillary services. Based on these experiences, UK load aggregators are now recruiting smaller industrial and large commercial customers with short-term load flexibility in order to increase their load-based resource portfolio (Bailey 2006).

4.6 Overcoming Barriers to Loads Providing Ancillary Services

The barriers to load participating in ancillary services are similar to the barriers to loads participating in energy or capacity markets, with three important additions: (i) more-rigorous technical requirements imposed by the system operator for purposes of dispatchability and monitoring; (ii) reliability rules and grid protocols developed during a period when generation was the only sources of ancillary services; and (iii) co-optimization of energy and ancillary services or dispatch rules that discourage load participation because of a high frequency of activation and the potential for long-duration reductions when dispatched.

4.6.1 Constraints on the Customer's Ability to Participate

Not all end-use customers have the flexibility to configure their loads for participation in wholesale electricity markets. Typical constraints on the ability of a customer to participate include: (1) the impact of stopping and starting equipment on output, production costs, and equipment life; (2) lack of expertise in modifying facility consumption patterns and responding to dispatcher activations; and (3) the need for investment in enabling technology, including load control and communications and verification equipment.

The customer's own constraints are often the primary factor given the considerable technical requirements placed on operating reserves. These technical requirements include stringent telemetry requirements comparable to that installed on a large generator, very rapid response times (seconds to minutes), large minimum load block requirements, and the ability to cycle off and refresh quickly and frequently. Configuring loads to meet these requirements is expensive, and many loads simply cannot meet them.

4.6.2 Non-Source Neutral Reliability Rules and Dispatch Practices

A second barrier to the participation of loads in providing ancillary services stems from the way power system reliability rules are written. Until recently, reliability rules have historically reflected the capabilities of the generation units that were the only resource available to provide energy, capacity, or grid services. Such a source-preferential approach works when only generators participate in the market place, but breaks down when there are multiple types of resources available with varying capabilities and limitations.

There are many examples of reliability rules that reflect generator limitations rather than system reliability needs. A partial list includes:

- Minimum run times
- Minimum off times
- Minimum load
- Ramp time for spinning reserve
- Accommodation of inaccurate response
- Limiting regulation range within operating range to accommodate coal pulverizer configuration.

Specifying resource attributes is necessary to procure the type and mix of regulation and reserves that the power system requires. However, the resource attribute specifications should be performance-based, not source-prescriptive. Going further, system operators should consider specific accommodations for demand-side resources and technologies, similar to those provided for generators. A partial list of load attributes and features that should be considered include:

- Maximum run time
- Value of capacity that is coincident with system load
- Value of response speed
- Value of response accuracy
- Match metering requirements to resource characteristics.

The experience of BETTA offers a formula for avoiding unnecessary limitations on the suitability of loads to provide ancillary services. The British regulator Ofgem, together with the system operator (National Grid), made sure that both the market design and the reliability rules were source-neutral, thus providing a level playing field for participation by both load and generation resources.

4.6.3 Co-optimization and Loads

Joint optimization of energy and ancillary services markets is practiced in several of the electricity markets that we reviewed (e.g., PJM and the Australian NEM). The objective of joint optimization is to minimize the total cost of providing sufficient capacity to meet forecast demand for both energy and ancillary services. In order to implement co-optimization each resource must allocate its available capacity between energy and ancillary services and provide a bid for the total cost of providing all products. The effective cost for a resource to provide multiple products depends on its offer prices as well as the product substitution cost, which arises when a resource has to reduce its use of capacity for one product so that the capacity can be used for a different product. This product substitution cost plus its bid price is included in the resource bid (IEEE/PES 2005).

Co-optimization can have the undesired consequence of barring some resources from participating in ancillary service markets. Energy-limited (e.g. some hydro resources) and emissions-limited generation and loads with limited response duration are at a disadvantage if there is not a mechanism in the implementation of co-optimization that will let the resource opt out of being dispatched in the energy market.[27] The problem arises because some generators and loads have limited response *duration* capability. They can fully provide contingency reserves but they are not able to provide hour after hour of energy. Some responsive loads (e.g., air conditioning loads) can respond extremely rapidly but may not be able to sustain load response for more than several hours. Thus, these types of load resources tend to have energy cost curves that rise dramatically with duration. Some load resources can be quite economical for 30 minutes or more but are likely to be uneconomic if load curtailments are required for four to eight hours. Moreover, without differentiation in the co-optimization algorithm, the load participant may be in and out of the energy and reserve markets with frequent load reduction activations that are generally not desirable.

Unfortunately, some power markets that co-optimize energy and ancillary services do not recognize this rising cost curve. They take the energy cost supplied with the contingency reserve bid and apply it to the energy market as well. This works well for most generators but when applied to the energy and emissions-limited generators and to some loads it simply forces them to withdraw from the ancillary service market as they can not risk being deployed (or curtailed) for hours.

It is possible to overcome the co-optimization barrier if the market design provides load (and generation) resources with the ability to declare itself unavailable for the energy markets. The CAISO currently does this and NYISO will implement this feature in the spring of 2007. The problem does not arise in ERCOT because energy is traded in the bilateral market. PJM provides a partial solution by allowing resources to submit different bids to the energy and ancillary service markets. ISO-NE does co-optimize and this could limit participation of loads in their ancillary service markets.

4.7 Mobilizing Loads to Participate in Ancillary Services Markets

How loads are mobilized to provide ancillary services varies according to the market design and the relationships between the system operator, load serving entities, other market participants, and end-use customers. The presence of a commercial energy services industry, especially load aggregators, is crucial to how these relationships develop. A pattern typical of several markets is for the system operator to first seek participation by very large wholesale customers who are market participants themselves. Once the viability of loads providing ancillary services is

[27] This is because each hourly bid must specify the capacity block size (MW), the energy price, startup cost, availability, and resource-specific characteristics such as ramp rate, minimum and maximum run times. The dispatch algorithm then minimizes the cost for providing energy and ancillary services in one objective function with individual energy and reserve constraints.

proven, smaller loads and third party aggregators enter the market place and the volume of load participation increases rapidly.

4.7.1 Mobilizing Loads and Customers in the U.K.

The pool of potential customers whose loads can participate is constrained by stringent technical requirements set by the system operator. In the U.K. the initial candidates to provide frequency responsive load were large industrial customers such as cement works, arc furnaces, and gas separation plants [Bailey, 1998].[28] Among smaller industrial customers, additional resources include cold storage distribution centers and other types of industrial refrigeration. Load aggregators target this market sector because the thermal mass of a refrigerated warehouse provides the ability to manipulate significant load blocks with very little impact to the customer.

The first frequency response contract was established by Yorkshire Electricity Group in 1996, for approximately 50 MW. It involved large cement works with very stable loads [Bailey 1998]. In 2003, the available frequency responsive load was increased to 110 MW. Gaz de France, a demand response aggregator, aggregated 13 cement works site for this service [Bailey 2004]. In terms of electric energy displacement, load side frequency response has increased from 2.6TWh to 2.8TWh in the period of 2002-03, which represents a 29% share of the total market for frequency response.

National Grid and Ofgem (the regulator) have actively sought to increase the participation of loads in BETTA's so-called "Special Markets" through pilot projects. In 2004 the Demand Turndown Pilot was introduced, which targeted large customers with back-up generators and/or significant load reduction capabilities that could be aggregated and bid into the Balancing Mechanism as warming reserve. The objective was to increase competition in the balancing services market by increasing the amount of contingency reserve resources (i.e. customer loads).

4.7.2 Mobilizing Loads and Customers in the Nordic Region

Statnett's experience in mobilizing customer participation includes the following effective ingredients:

- *Steadily overcome cultural barriers to participation in electricity markets.* Over the past few years there has been a gradual evolution of large industrial customer attitudes towards participating in Nord Pool's markets, from "this isn't really my business" to "show me the money and we can work together."[29]

- *Conduct frequent auctions for regulating reserves regardless of current need.* Statnett conducts weekly auctions for regulating reserves even if the need is not very great, which ensures that end-users stay in practice and engaged.

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[28] Cement plants alone are estimated to have a resource potential of about 50-90 MW.

[29] However, some large factories and facilities are very electricity price-insensitive and are not interested in cooperating with TSOs or aggregators.

- *Take into account the customer's ability and limitation to perform.* Most loads are limited in their ability to perform. Smelters, for example, cannot be controlled for more than four hours. Loads not able to deliver over the full required duration of four hours or not able to operate at the required frequency can still participate, but the price-per-MW paid to them is adjusted downward.

- *Encourage third party aggregators.* The bulk of the 1200 MW of load bid into Statnett's RCOM comes from large industrial customers - aluminium smelters, metal processing, and the forestry, pulp and paper industry. However, the program accommodates other businesses and business models, including aggregators focusing on particular market niches. These niches include large electric boilers, especially if they have oil-firing capability, customers with back-up or emergency generators; and medium-sized customers with controllable loads that can be aggregated. These load aggregators utilize sophisticated communications and control technology that allows the system operators to constantly monitor the interruptible load capability.

- *Minimize rules and requirements.* Statnett does not require some loads to meet the same stringent communications and telemetry requirements as generators. A common communications modality is interval meters and an internet-based communications system (Statnett 2005b).

Pilot projects are important because they build confidence on both sides of the equation – the system operator and the participating load. Elkraft launched large industrial and small residential pilot projects in 2004 in order to analyze the barriers to increasing demand response participation in the market. About 17 MW of back-up generation and 3 MW of load curtailment resources signed up for the industrial pilot to be used as fast active disturbance reserves. The back-up generation load resource consists of individual generators in the 500 kW size range aggregated over 26 primarily large facilities (hospitals, computer center, airports, telecommunications or commercial customers (e.g., frozen goods warehouse, public ice arena). These generators can be remotely activated and offered for regulation and balancing power needs, meeting the 15-minute activation time required [Elkraft 2005b]. As part of the pilot operation the system operator relaxed the lower size limit on any single reserve resource, thus allowing aggregation, and agreed to a less-stringent telemetry requirement (internet based communication system rather than SCADA). The pilot effort was successful enough that Energinet.dk will include this class of load resource as part of its effort to acquire 150 MW of DR-based disturbance reserves by 2010.

Other pilot efforts underway by Nordic research organizations (SINTEF and VTT) are looking into aggregating small commercial and household electric end-uses, such as space heating and water heating, to provide operating reserves. These loads are coincident with balancing needs and easy to control and aggregate. It is estimated that there is 16,000 MW of electric space heating load in the four Nordic countries (Jensen 2005). These small residential loads can be interrupted immediately for limited duration, making them capable of providing both reserve capacity and balancing energy in the Elbas or regulating power markets.

4.7.3 Mobilizing Loads and Customers in ERCOT

The system operator can play a pivotal role in mobilizing loads to provide ancillary services. ERCOT in particular has a very active outreach program, in concert with wholesale market participants (REPS and QSEs), that allows direct engagement with end-use customers interested in participating in ancillary services markets. ERCOT has created several load-friendly program designs as a way of mobilizing retail loads to provide ancillary services within the overall context of the ERCOT market design and the REP relationship with its retail customers. End-use loads may participate in the Load Acting as a Resource (LaaR) and Balancing-Up Loads (BUL) programs by contracting with their REP to provide imbalance energy or contingency reserves. This also provides REPs with added flexibility in terms of providing for the ancillary services volume allocated to them by ERCOT (see Table 10).

Table 10: ERCOT's Ancillary Services Customer Interfact (ERCOT 2006a)

Type of Service	Down Reg	Up Reg	Resp Res	Non Spin	Replacement	Up BES	OOME
System Response to instruction:	Must be on AGC	Must be on AGC	AGC or Relay action	Resp w/in 30min	Response as bid	Response w/in 10min	
Generation Resources	X	X	X	X	X	X	X
Load with Under frequency relay installed and capable of being deployed within 10 minute notice			X	X	X	X	X
Load with real time telemetry and that can be deployed within 30 minute notice				X			X
Balancing Up Load (BUL)						X	

Retail customers with under-frequency relays and quick response capability can participate in providing contingency reserves (instantaneous and replacement) plus the energy imbalance ancillary services markets. Retail customers with telemetry and 30 minute response capability can participate in the replacement reserves market only. By packaging the ancillary services opportunities in this way ERCOT is able to standardize the offering for participation by loads and simplify the process of QSEs and REPS in self-arranging their ancillary services requirements. The participation of loads in the Responsive and Non-Spinning Reserve categories up to the full 50 percent quota allowed is evidence that this is a successful approach. No loads have offered to participate in the energy imbalance, indicating that load response capability may be better matched to the supply of contingency reserves than they are to the supply of energy.

5. Findings

5.1 Loads Provide Ancillary Services Only to the Extent that Market Design Allows

Some market designs appear to be more "load-friendly" than others. For example, a real-time energy-only market with a tight pool such as the NEM requires no energy imbalance market and relatively modest expenditures for regulating reserves, contingency reserves and replacement reserves. Total expenditures for operating reserves were only $20 million in 2005, only 0.5 percent of total market turnover and less than the expenditures on reactive power. There appear to be larger opportunities for loads to participate via hedging and load shedding arrangements between Electricity Retailers and Network Service Providers and their retail customers rather than from bidding into NEMMCO's established ancillary services markets. Two important exceptions are the Network Control Ancillary Services and the occasional tendering for temporary operating reserves, both of which have been dominated by participation of loads.

The ERCOT and Nordic market designs have considerably more "market space" for loads. In the Nordic design there is a particular niche for demand response that stems from the TSO's responsibility to provide sufficient operating reserves. Both Statnett and Energinet.dk are responsible for providing sufficient reserves to accommodate imbalance energy requirements, with any incremental cost not charged to balance-responsible market participants uplifted and allocated per the transmission tariff. These TSOs are also financially responsible for any forced load shedding due to insufficient operating reserves. These two grid operators are thus highly motivated to maintain a physical hedge in the form of load-based capacity options, especially during the peak winter season. This is a perfect match for participating loads, as compensation comes in the form of steady stream of capacity payments and the TSO's option to dispatch these loads has so far been used very infrequently (Statnett 2005b).[30]

In the case of ERCOT and two Nordic countries (Finland and Sweden), it is the market participants who have a clear financial incentive to acquire operating reserves, including loads. In these market designs, the market participants must provide sufficient operating reserves to cover any imbalance error, plus contingency and replacement reserves. If they do not then the TSO will procure the requisite amount for them in real-time, the costs of which are reflected at settlement. A tight balance market in particular can produce considerable real-time price volatility; Market Participants are thus motivated to enter into hedging agreements with their customers to avoid undue imbalance management cost exposure.

In the U.K., the commercial frequency response product allows customers to choose the under-frequency threshold at which the load will be interrupted. The chosen frequency threshold in turn determines the number of expected load reductions. Customers who plan to play an active role in the AS markets would choose a high threshold. This particular design provided flexibility on the customer side and favorable system response that approximates the droop control capability of generators.

[30] These operating reserves were called upon to provide instantaneous contingency response just three times in the past five years

5.2 Ancillary Services are Small, but Offer Large Opportunities for Load Participation

The cost of ancillary services provision in most competitive wholesale markets is relatively small compared to total market turnover. In the five markets we reviewed, the cost of ancillary services is between 1-3 percent of total electricity market value. However, the dollar volume of ancillary services markets is still sufficiently large to attract the interest of third party aggregators adept at configuring loads to suit niche market requirements. We can observe this targeting of niche or "special" markets in the U.K., Nordic region and even in the NEM.

So-called "seams issues" represent a market niche of particular interest. In Australia, NEMMCO is required by statute to procure incremental operating reserves if any region is forecast to have a reserve shortfall within a 2-6 month period. Although this is not formally considered an ancillary service, and the NEM is an energy-only market, it nevertheless represents a market opportunity that load aggregators have been able to take advantage of. In the most-recent tendering for short-term reserves for Victoria and South Australia, NEMMCO procured a total of 375 MW of reserve capacity at an estimated cost of $3.5 million; this reserve capacity was provided entirely by loads (NEMMCO 2006d).

Statnett's RCOM market represents another "seams issue" that created a niche market for loads providing ancillary services. In this case the seasonal capacity constraints in a hydro-dominated energy-only market create a situation where most or all of the available generation bids into the day-ahead market, leaving the system operator with insufficient operating reserves to perform the real-time regulation and balance management functions. This provides loads with the opportunity to deliver reasonably-priced operating reserves and a regulation-down function if imbalance energy prices go high enough that their real-time energy bid is accepted.

5.3 Effect of Technical Requirements on Loads Providing Ancillary Services

Technical requirements for loads participating in ancillary services are considerably more stringent than those for participation in energy and capacity markets. Technical requirements that can be barriers to participation by loads include minimum load block requirements, telemetry and control requirements, and response time and ramp rate requirements. For example, the minimum size requirement for loads is as much as 25 MW in some Nordic countries. In the U.K., the minimal size requirement for continuous contingency and replacement reserves is 3 MW. Although this is much higher than the requirements for loads participating in energy and capacity markets, it does not appear to have prevented some customers from participating.

The pattern observed in both the U.K. and the Nordic region is for ancillary services provision to be initially from very large customers (smelters, paper mills, pumped hydro) capable of fielding SCADA-quality telemetry and sophisticated frequency and voltage controls. These very large loads appear to system operators as equivalent to generators, and their effectiveness in providing ancillary services has built confidence around loads as a viable source of ancillary services. Over time and with the market entry of sophisticated third party aggregators, additional solutions have developed that have reduced the minimum size requirement and mostly solved the real-time telemetry and response time requirements. Aggregators such as Gaz de France, EffectPartner, and Nordisk Energikontroll have successfully configured niche loads such as dual-fuel boilers, back-up generators, and combined heat and power facilities to provide operating reserves that meet all the technical requirements of system operators.

Pilot projects can play an important role in determining whether certain long-standing technical requirements are truly critical to system operators. In Denmark, the TSO relaxed the SCADA requirements imposed on generators, allowing validation of load resource performance to occur in the evening of the activation day, but retrofitted the participating load resources with a wireless load control device. The TSO and the balance providers, who aggregate and market the load resources to the TSO, were able to gain enough confidence in the performance of load resources that expensive telemetry technologies can be avoided.

5.4 The Importance of Third Party Providers

We also found that load aggregators (e.g., curtailment service providers, competitive retailers) offered important innovations in both enabling technology and market development in the electricity markets that were reviewed. These third party market participants have long been active in mobilizing load participation in energy and capacity markets; their efforts to develop niche demand response applications for operating reserves and ancillary services are similarly impressive. In fact, steady progress in aggregating load for ancillary services provision will soon extend to even mass market customers. Opening up these new potential loads has been aided by low-cost communications and control equipment capable of configuring even household-level electric loads to provide operating reserves.

5.5 The Role of Policymakers and Regulators

Policy development and regulation are important in promoting load participation in competitive markets. In the Nordic region, load participation throughout electricity markets is viewed as a critical “pillar’ of the interconnected Nordic power system’s overall sustainability and reliability. Nordel, the regional coordinating body for Nordic system operators, has formed a demand response working group to work with regulators and policy makers in developing national action plans to increase demand response in both wholesale and retail markets. The result of this policy support is apparent in the very high participation of loads in Nordic ancillary services provision.

In Australia the entry points for demand response vary by state and are at least partially driven by regulators and state energy agencies. Victoria and NSW have activist regulators and a policy of financially supporting technology and project development for both demand response and energy efficiency.[31] Not coincidentally these two states have the largest amount of demand side participation, directly through retailers into the NEM or indirectly through requirements for network service providers to consider demand management in their network expansion plans.

The Public Utilities Commission of Texas (PUCT) has traditionally supported demand response, and this is apparent in ERCOT’s efforts to facilitate participation by loads in all aspects of system operations. One of the goals for the 1999 restructuring process set by the PUCT was that load resources were to have reasonable opportunities for even greater participation in energy and ancillary services markets in the future.

[31] Advanced metering to enable price response of retail loads is one area of particular interest.

In the U.K., the Office of Gas and Electricity Markets (Ofgem) has supported source-neutrality in the design of the balancing services market. This provided an equal pay for equal service notion, established from the inception of the competitive electricity market. This principle has been the basis for significant load participation in providing frequency response and reserve services.

5.6 Role of the System Operator

The system operator influences the opportunities for loads to provide ancillary services as they develop and interpret reliability rules and operating protocols. System operators have a pivotal role as an enabling and coordinating agency, especially in the more-diffuse bilateral market designs. ERCOT is a key example of system operator as load participation enabler. ERCOT actively engages with QSEs and their end-use customers in the context of the LaaR program in order to minimize barriers to entry and encourage maximum load participation. We also observe that National Grid in the U.K. was instrumental in enabling load participation in ancillary services provision by procuring these services on a source-neutral basis. Similarly, PJM staff and their stakeholders have been instrumental in developing new market rules and grid code revisions that for the first time allow loads to provide regulation and spinning reserves.

Nordic system operators are also active enablers of load participation, as they implement national action plans based on extending the market spaces in which loads can participate. A recent proposal floated by the Swedish TSO SvK would create a new frequency response scheme that would allow loads to provide regulating reserves as well as regulating power. This scheme would create a sliding compensation scale for customers willing to be curtailed due to frequency excursions – e.g., ± 0.1 Hz around 50 Hz, ± 0.2 Hz, ± 0.3 Hz, and so on. Such a program comprising frequency-controlled loads on a sliding scale would be indistinguishable from droop control on a generator (Nordel 2006b). NEMMCO has also been supportive of loads providing reserves and ancillary services. As noted before, 100 percent of both network load control in Victoria and the recently-tendered Victoria-South Australia reliability safety net were procured from aggregators offering loads as operating reserves.

Despite these successes, certain reliability rules and operating protocols may remain a barrier to wider load participation in ancillary services markets. For example, the use of real-time co-optimized dispatch of energy and ancillary services may impede the uptake of loads providing ancillary services in the Australia's NEM and the USA's PJM. These barriers are remediable at the discretion of the regulator and the system operator. However, this requires a disposition by system operators to be even-handed when considering the characteristics of multiple resources (generation and loads) and setting ancillary service rules and requirements accordingly.

5.7 Configuring Loads to Provide Ancillary Services

A customer or aggregator seeking to configure end-use loads to provide ancillary services must take into account requirements for response time, dispatch frequency, minimum load block, telemetry, automatic control, and metering. Large industrial batch processes such as smelters have traditionally been viewed as ideal substitutes for a generator, as they are large, dispatchable, and can be easily configured with SCADA systems for control and telemetry. System operators are less familiar with commercial loads, let alone mass market end-users, which makes it important to undertake pilot projects and demonstrations of the functional equivalency of these loads in providing energy, capacity, or ancillary services. System operators must be confident that properly configured loads provide a source of operating reserves that is functionally equivalent to a generator.

Demonstration projects and aggressive third party aggregators in the U.K. and Nordic Region have already identified certain types of loads that seem ideal for participating in wholesale competitive electricity markets, including providing ancillary services. A Danish pilot project involving commercial customers providing instantaneous contingency reserves is especially promising. Energinet.dk sought out customers with significant storage or process rescheduling that would allow them to disrupt their processes quickly and briefly in response to grid disturbances, which typically have a short duration (less than 1 hour). The customers selected exhibited a common characteristic – sufficient thermal storage capacitance to allow for brief interruptions in refrigeration load without adverse effect. Facilities as diverse as frozen goods warehouses and public ice arenas were found to be candidates to provide fast operating reserves – assuming they can be properly and economically configured for dispatch and monitoring as required by the system operator.

This finding has significance for demand response planners in the U.S., given the large number of residential and commercial customers with similar thermal storage capability. Most commercial buildings with concrete and steel construction as well as residential structures exhibit significant thermal capacitance that would enable them to temporarily reduce their air-conditioning load. Although not a new approach (e.g., air conditioner load control), the configuration of larger cooling loads for short-duration spinning reserve activation is just now beginning to be explored in the US.[32]

5.8 Which Market Participants are Positioned to Mobilize Loads to Provide AS?

Market design, reliability rules and system operator protocols, and AS procurement and compensation arrangements will determine the market participant(s) best suited to mobilize loads. In ERCOT, the QSEs and REPs play the primary role, as together they serve the end-use customers and provide the entry point for scheduling the ancillary services allocated by the system operator. In the Nordic markets, where the system operators are balance-responsible or outage-liable, the system operator is motivated to seek out the lowest-cost operating reserves. In the Australia NEM, it is Market Customers, including Network Service Providers and Retailers, who are motivated to hedge themselves against both energy price volatility and make arrangements for load shedding as required by NEMMCO. The U.K. market provides for aggregation to meet the 3 MW minimum for special market participation, making the supplier the logical choice to aggregate customers that have the proper load characteristics but are too small to engage in the market directly.

[32] With funding from the California Energy Commission, the Consortium for Electricity Reliability Solutions (CERTS) in conjunction with SCE and the CAISO are conducting a pilot demonstration project that is testing residential air conditioner load control configured to provide spinning reserves (CERTS 2006).

5.9 What Attracts Customers to Participate?

Loads participating in ancillary services markets want to see the same program characteristics as loads participating in capacity or energy markets – a steady revenue stream and minimum disruptions to their core activities. In the case of options market such as Statnett's RCOM, they also want the ability to set their imbalance energy bid prices high enough to avoid frequent interruptions and to guarantee sufficient compensation for any disruption should their option be called. Other features that participants look for are flexibility in accommodating their limitations, easy to understand rules, effective communications protocols especially when they are activated, and non-pecuniary encouragements that their participation is serving a broader social purpose (e.g., keeping the lights on).

Different customers have different contractual requirements. Some see a multi-year contract with guaranteed revenues as the basis for making investments necessary to minimize the inconvenience of participation. Other customers value their ability to be flexible in the short term, and thus appreciate the opportunity to bid or not bid on an hourly, daily, weekly or monthly basis.

5.10 The Outlook for Loads Providing Ancillary Services

The outlook for loads providing ancillary services is good, not least because the need for low-cost operating reserves is expected to grow. For example, the California ISO (CAISO) forecasts an increase in its need for several types of operating reserves, due to growing imports, increased forecast errors due to summertime temperature-sensitivity of peak demand, more granular (localized) AS requirements per FERC requirements, and the need to mitigate market power of existing AS providers (CAISO 2007).

System operators in Europe face steep increases in their operating reserves requirements as they add wind capacity and nuclear power generation. For example, the addition of a Finnish 1600 MW nuclear plant will increase the basis for determining contingency ancillary services for both Fingrid and the Nordic power pool overall. Similarly, the addition of numerous new wind power plants in Norway will require an increase in active reserves of Statnett to accommodate the output variability of large wind machines. Loads have an excellent chance to provide these additional ancillary services, as Nordic system operators now regard loads as a less expensive source of operating reserves than owning or contracting with gas turbine capacity (Fingrid 2006).

Conditions are also promising for a general scaling-up of loads providing operating reserves within the NEM. Demand in Australia is growing faster than capacity additions, a trend that could result in reserve shortfalls in both NSW and Queensland by 2008/2009. Furthermore, the sensitivity of system peak demand to weather is growing, as air conditioning usage becomes more widespread. This not only increases the reserve margin requirements relative to delivered energy but also makes the NEM more susceptible to weather-driven demand and price volatility. A larger role for DR in retail and wholesale markets is being supported by state Regulators in Victoria and NSW. Finally, technology for "last mile" solutions within the power sector is rapidly advancing. The Council of Australian Governments (COAG) has endorsed the provision of interval metering for all retail customers as part of its national energy policy framework (Outhred 2007), and the state regulator for Victoria has mandated advanced metering for all its regulated distributors and retailers beginning in 2008 (Victoria Department of Primary Industries 2007). There are also several trials underway of intelligent distribution networks. For example, Country Energy is fielding a Home Energy Efficiency Trial that will provide an in-home communications, control and information display platform capable of implementing critical peak pricing and load control.

ERCOT passed a milestone this past spring with the first operation of their Response Reserve Service in over ten years. Some problems were encountered with the response time of participating load portfolios; however, in general ERCOT's Responsive Reserve Service performed as designed. The RRS resource in fact would have prevented any mandatory load shedding except for the unplanned outage of an additional generating unit right in the midst of the emergency (PUCT 2006).

Tempering these upward trends in ancillary services requirements is a downward trend elsewhere in the U.S., especially in the East and far West. PJM has steady decreased its spinning reserve requirements as its footprint has grown westward. The NERC has steadily reduced the technical requirements for contingency reserve from a 10-minute response to a 30-minute response. Finally, a WECC proposes a reduction in spinning reserve requirements from current levels of 5% and 7% for each Balancing Area to a single WECC wide spinning reserve requirement equal to the largest credible contingency for the entire reliability region (WECC 2005).

6. Conclusions and Implications for U.S. Practice

There are no implicit or insurmountable barriers to loads providing any of the four ancillary services – Continuous Regulation, Energy Imbalance Management, Instantaneous Contingency Reserves, and Replacement Reserves – considered in this report. Continuous Regulation services are provided exclusively by generators, although several system operators including PJM and CAISO are conducting pilots and/or developing business rules to open up this ancillary service market as well.

The Nordic TSOs, ERCOT and the United Kingdom's NGC all exemplify good practices insofar as the system operators' role in encouraging uptake of loads participating in providing ancillary services. These three markets have almost equal participation of loads and generators in most of their ancillary services markets, with loads sharing a significant amount of total ancillary services revenues. PJM is also demonstrating a leadership role with its ongoing efforts to open up its Regulation and Spinning Reserves markets to load participation.

The outlook for additional load participation in ancillary services markets is positive. Continued load growth, retirement of older generators, greater sensitivity of peak loads to weather extremes, and higher operating costs of generators all contribute to a larger ancillary services market overall and the prospects for more competitive bids by loads. Advancements in real-time communications technologies and automatic controls suitable for configuring loads are expected to enable more participation by smaller loads that are well-suited to providing frequent and instantaneous demand response.

Third party providers and aggregators have proven their worth, both in encouraging customers to participate in configuring load-based solutions that can economically meet the operating requirements of dispatchers.

These findings and conclusions lead us to offer several suggestions for policy makers, regulators, and system operators that want to further enhance load participation in ancillary services markets:

1. Adopt the principle of source neutrality in designing markets and establishing reliability rules. Generators and loads should both be regarded as capable of providing functional equivalent ancillary services, with the differences to be worked out in grid codes and rules and reflected in market operations.
2. Accommodate the capabilities and limitations of responsive loads, just as the capabilities and limitations of generators are accommodated.
3. Periodically review and adjust technical requirements, operating protocols and business rules based on actual experience, rather than retaining historical precedent.
4. Assure that co-optimization routines do not unduly penalize the ability of loads to compete in offering ancillary services, by forcing them to provide services they did not offer to supply.
5. Undertake pilot projects to work out minimum requirements necessary for loads to provide ancillary services.
6. Encourage participation by third party providers and aggregators, as they are a proven source of both technical and marketing innovation.

7. Remove any artificial or unnecessary restrictions to resources offering into more than one market, where consistent with overall market design, procurement arrangements and operating requirements.
8. Develop a stakeholder process to work through participation details, such as technical requirements and business rules.

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