Demand Response as a Market Resource Under the Smart Grid Paradigm

Farrokh Rahimi, *Senior Member, IEEE*, and Ali Ipakchi

***Abstract*—Demand response (DR), distributed generation (DG), and distributed energy storage (DES) are important ingredients of the emerging smart grid paradigm. For ease of reference we refer to these resources collectively as distributed energy resources (DER). Although much of the DER emerging under smart grid are targeted at the distribution level, DER, and more specifically DR resources, are considered important elements for reliable and economic operation of the transmission system and the wholesale markets. In fact, viewed from transmission and wholesale operations, sometimes the term "virtual power plant" is used to refer to these resources. In the context of energy and ancillary service markets facilitated by the independent system operators (ISOs)/ regional transmission organizations (RTOs), the market products DER/DR can offer may include energy, ancillary services, and/or capacity, depending on the ISO/RTO market design and applicable operational standards. In this paper we first explore the main industry drivers of smart grid and the different facets of DER under the smart grid paradigm. We then concentrate on DR and summarize the existing and evolving programs at different ISOs/RTOs and the product markets they can participate in. We conclude by addressing some of the challenges and potential solutions for implementation of DR under smart grid and market paradigms.**

***Index Terms*—Ancillary service markets, demand response (DR), distributed energy resources (DER), energy markets, smart grid**

I. Introduction

THE CONCEPT of smart grid started with the notion of advanced metering infrastructure to improve demand-side management, energy efficiency, and a self-healing electrical grid to improve supply reliability and respond to natural disasters or malicious sabotage. However, several developments have led to the expansion of the initially perceived scope of smart grid, and are helping shape the new face of the electricity industry. These include: a) emphasis on environmental protection, including renewable generation (wind, solar, etc.) and demand response (DR); b) the drive for better asset utilization, including operating closer to the "knee of the curve" while maintaining reliable system operation; and c) the need for enhanced customer choice. Fig. 1 schematically depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the place of DR and more generally distributed energy resources (DER) in the new arena.

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The authors are with Open Access Technology International, Inc. (OATI) Minneapolis, MN 55441, USA (e-mail: Farrokh.Rahimi@oati.net; Ali.Ipakchi@oati.net).

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Fig. 1. Industry drivers of smart grid.

Another emerging paradigm shift is the increased and bidirectional interaction between wholesale markets/transmission operation and retail markets/distribution operations. The expected profusion of DR, renewable resources, and distributed generation and storage at the distribution/retail level has direct implications on the operation of the transmission system and the wholesale energy markets. Enabling technologies, such as enhancements in the communication and information technologies, make it possible to turn these new resources into useful controllable products for wholesale market and transmission system operators.

Fig. 2 schematically shows the traditional utility environment in terms of the flow of power and information. Power flow is almost unidirectional from centralized supply sources (power plants) to demand, and information flow is from lower voltages to higher operational centers.

In contrast, in the emerging utility environment, both power and information flows are bidirectional as shown in Fig. 3. The emerging use of thermal storage for peak shifting, the anticipated growth and cost reduction of solar photovoltaic (PV) generation at residential and municipal levels, the anticipated shift from conventional fuel transportation to plug-in electric vehicles (PEVs), the advent of low-cost smart sensors, and availability of a two-way secure communications network across utility service territory are anticipated to significantly alter the nature of future power supply and power system operations, as well as consumer behavior [1].

Role of DR/DER under Markets and Smart Grid: DR is an important ingredient of the emerging smart grid paradigm and an important element in market design to keep the potential supply market power in check. Experience with energy markets has shown that the lack of DR has been a major contributing factor to occurrences of energy market meltdown. For example,

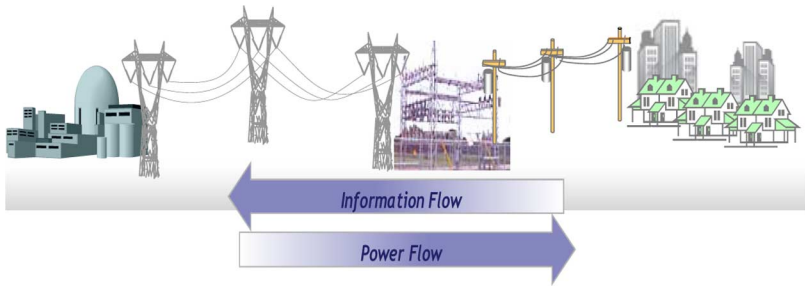

Fig. 2. Power and information flow in traditional utility environment.

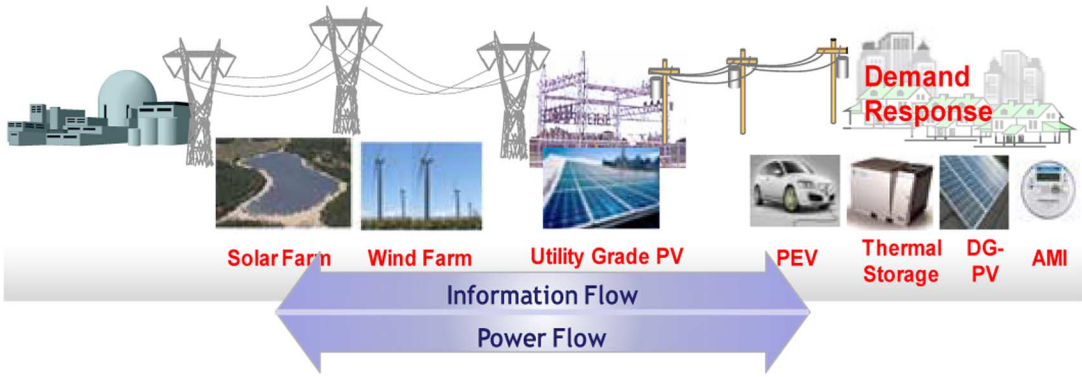

Fig. 3. Power and information flow under smart grid.

California's energy crisis at the turn of the millennium could, to a large extent, have been mitigated if sufficient DR was in place.

Several initiatives are helping promote the role of DR and more generally DER under the smart grid and energy market paradigms. Notable among these are Federal Energy Regulatory Commission (FERC) Order 719 and the American Recovery and Reinvestment Act (ARRA).

FERC Order 719: FERC Order 719 was issued 17 October 2008 [2]. The main directive in this order is comparable treatment of generation sources and DR in the wholesale markets. The order aims to improve wholesale markets by establishing a more forceful role for DR. It directs independent system operators (ISOs)/regional transmission organizations (RTOs) to:

- accept bids/offers from DR resources for ancillary services (A/S) comparable to any other A/S-capable resources (currently mostly generation resources);
- allow DR resources to specify limits on frequency, duration, and the amount of their service in bids/offers to provide A/S;
- where the ISO/RTO currently imposes charges to buyers for taking less electric energy in real time than scheduled, eliminate such charges during system emergencies;
- permit aggregators to bid DR on behalf of retail customers directly into the market;
- study and report on reforms needed to eliminate barriers to DR in energy markets.
- assess, through pilot projects, the technical feasibility and value to the market of using A/S from small DR units.

These provisions are being implemented at different ISOs/RTOs by modifying or expanding the existing market rules. Specific telemetry and/or control requirements may apply to DR resources for participation in some of these product markets. Also, different ISOs/RTOs are adopting different rules for monitoring DR performance in relation to different products and for settlement with DR resource owners, operators, and aggregators.

American Recovery and Reinvestment Act: The U.S. Energy Independence and Security Act (EISA) and the ARRA of 2009 [3] both include smart grid requirements. ARRA allocated significant levels of funding for smart grid activities. The U.S. Department of Energy issued two Funding Opportunity Announcements (FOA) in February 2009, namely, one (DOE-FOA-0000036) for smart grid demonstration projects, and another (DOE-FOA-0000058) for Infrastructure Development investments. The former included two main program areas, namely:

- Program Area 1: Regional smart grid demonstrations, which includes a number of projects such as DR and DER including generation, storage, and PEVs and plug-in electric hybrid vehicles (PHEVs).
- Program Area 2: Utility-scale energy storage demonstrations.

The total level of ARRA funding is US$4.5 billion, matched by an equal level of cost sharing by the entities that submitted proposals and were awarded DOA FOA funding under these programs.

II. Summary of U.S. ISO/RTO DR/DER Programs and Rules

Depending on retail tariffs, DR, and DER may be physically provided at commercial and industrial (C&I) customers sites or also by residential customers. Often DR and DER at the residential level must be "aggregated" to be eligible as wholesale market products. In the context of energy and A/S markets facilitated by the ISOs/RTOs, depending on the ISO/RTO market design and operational standards, the market products DR (and

more generally DER) can offer may include some or all of the following:

- capacity (installed capacity or unit commitment availability in some markets);
- energy (day-ahead, real-time balancing);
- reserve A/S, which may include some or all of the following:
  - — regulating reserve;
  - — spinning reserve/responsive reserve;
  - — supplemental reserve/nonspinning reserve.

Additionally, out-of-market (or out of merit order) deployment of DR may occur under emergency conditions.

Depending on the specific ISO/RTO design, the DR/DER products may be offered into the ISO/RTO markets by one or more classes of market participants, including load-serving entities (LSEs), utility distribution companies (UDCs), electricity service providers (ESPs), end-use consumers, load aggregators, and curtailment service providers (CSPs), who may or may not own any electrical load, generation, or storage assets.

In the following, we first briefly summarize the different product markets facilitated by the existing ISOs/RTOs in the United States, namely, New York ISO (NYISO), Pennsylvania–Jersey–Maryland (PJM), ISO New England (ISO-NE), Midwest ISO (MISO), California ISO (CAISO), Electric Reliability Council of Texas (ERCOT), and Southwest Power Pool (SPP). We then indicate which of the product markets are currently available to DR resources, and identify the corresponding infrastructural requirements, attributes, limitations, and performance requirements for participation of DR in these markets.

Summary of Product Markets at U.S. TSO/RTOs: Currently, NYISO, PJM, and ISO-NE facilitate centralized capacity markets. MISO does not have centralized capacity markets, but facilitates a residual voluntary capacity auction (VCA) process. CAISO, ERCOT, and SPP do not have capacity markets. CAISO has a resource adequacy (RA) obligation in place for LSEs, which they must generally satisfy through self-supply or bilateral arrangements. CAISO has an administrative mechanism in place to compensate resources that are not under an RA contract, but are called upon (committed) in CAISO's residual unit commitment (RUC) process.

All U.S. ISO/RTOs conduct an offer-based real-time balancing energy market. Except for ERCOT and SPP, all U.S. ISO/RTOs facilitate a day-ahead energy and A/S market. ERCOT plans to implement a day-ahead energy and A/S market as part of the ERCOT nodal market slated to start operation in December 2010, and SPP plans one for the 2012–2013 timeframe.

All ISO/RTOs have regulation and 10-min contingency reserve (spinning and supplemental/nonspinning reserves) requirements. Currently SPP does not have a centralized market for these services. The regulation service is a single symmetrical product in PJM, NYISO, ISO-NE, and MISO, but CAISO, ERCOT nodal, and SPP future markets distinguish upward regulation (Reg Up) and downward regulation (Reg Down) as separate products. A/S in PJM, NYISO, and ISO-NE also include a 30-min Supplemental (Nonspinning) service. At present CAISO and MISO do not have a 30-min A/S. ERCOT intends to include such a service under the ERCOT nodal market and drop its current 10-min nonspinning reserve service.

Summary of DR Products and Rules at NYISO: New York ISO accommodates four generic types of DR.

- Emergency Demand Response Program (EDRP). This program involves demand reduction under emergency conditions declared by NYISO. A demand-side resource participating in this program cannot subscribe the same metered load with more than one CSP. Participation in this program does not require telemetry, interval metering is adequate. When asked to curtail, and verified to have performed, the resource is paid the higher of $500/MWh or the zonal real-time locational—based marginal price (LBMP).
- Day-Ahead Demand Response Program (DADRP). The underlying product associated with and offered by this program is energy (negawatts). The price is established in the day-ahead market-clearing process. Although participation in this program is voluntary, for participating loads DR to dispatch instructions are mandatory. Participation in this program does not require telemetry; interval metering is adequate. Demand reduction is measured compared to a predetermined base line. If the participant fails to reduce demand from the baseline as scheduled, its consumption during the scheduled curtailment period is charged the higher of the day-ahead and the real-time price.
- Installed Capacity (ICAP) Special Case Resources (SCR). Similar to EDRP, this program involves load reduction under NYISO instruction under emergency conditions (i.e., the demand-side resources under this program are not dispatched just for economic reasons to displace a more expensive resource). The demand-side resources are compensated as ICAP resources and must perform when asked to curtail by NYISO. An individual demand-side resource can participate in either the EDRP program or the SCR program, but not both during the same period.
- Demand-Side Ancillary Service Program (DSASP). The underlying products offered by demand-side resources under this program are regulation, spinning, and supplemental (nonspinning) reserves. In addition to interval metering, real-time telemetry is also required to enable NYISO to monitor availability and performance of the resource.

Summary of DR Products and Rules at PJM: The DR products accommodated in the PJM market include energy, capacity, synchronized reserve, and regulation.

DR participation in PJM's energy markets includes the following.

- *Economic load response*, which may be provided by agent PJM members or CSPs. It is an economic program that uses the LMP as a trigger. Consumption under this program is curtailed when LMP $\geq$ $75 MWh.
- *Energy dispatched out of DR sold as capacity or A/S*. The energy dispatched out of capacity or A/S DR is paid the real-time LMP. The compensation is split between the CSP and the LSE as follows:
  - — compensation to CSP: zonal LMP minus retail rate (generation and transmission portion)
  - — compensation to LSE: retail rate

DR carticipation in PJM's capacity market enables LSEs and CSPs to offer DR as a capacity product and receive capacity credit for the MW quantity of DR that clears the capacity market.

For DR to participate in PJM's A/S markets, the following rules apply.

- For DR participation in PJM's synchronized reserve (spinning reserve) market:
  - *DR must be able to provide metering data at no less than a 1-min scan rate.*
  - *DR participation in synchronized reserve market is limited to 25% of the synchronized reserve requirement in each zone.*
  - *Mandatory training requirements exist for CSPs bidding DR in the synchronized reserve market.*
- For DR participation in PJM's regulation market:
  - *DR bidding regulation must meet all real-time telemetry requirements like a generator.*
  - *DR participation in the regulation market is limited to 25% of the regulation requirement.*
  - *There are mandatory training requirements for CSPs bidding DR in the regulation market.*

Summary of DR Products and Rules at ISONE: The DR programs facilitated in the ISO New England markets include the following.

- Real-Time Demand Response (RDR) Program: Participation in this program is voluntary. However, for participating loads, following the dispatch instructions is mandatory. Other characteristics of this program are as follows.
  - *Trigger: extreme emergency operating conditions (Operating Procedure #4).*
  - *Minimum reduction: 100 kW.*
  - *Subprograms based on notification time:*
    - 30-min DR program.
    - 2-h DR program.
  - *Compensation:*
    - Maximum of real-time load zone LMP or $500/MWh for the MWh amount curtailed.
    - Capacity credit for the MW amount committed.
  - Real-Time Price Response (RPR) Program: This is a voluntary Energy reduction program during periods of high real-time prices. The compensation is the greater of real-time zonal LMP or $100/MWh. No capacity credit is given for this program.
  - Day-Ahead Load Response Program: This is an optional program available to resources participating in RDR and RPR programs (see above). The main characteristics are as follows:
    - *Minimum Reduction: 100 kW.*
    - *Bid Price: min ($50/MWh); max ($1000/MWh).*
    - *Cleared as part of day-ahead market.*
    - *Compensation: greater of day-ahead zonal price or bid price (no capacity credit).*
  - DR eligible to participate in the forward capacity market (FCM): The following programs are eligible to participate in ISONE's FCM:
    - *real-time DR programs (RDR) mentioned above;*
    - *energy efficiency programs;*
    - *load management programs;*
    - *distributed generation programs.*

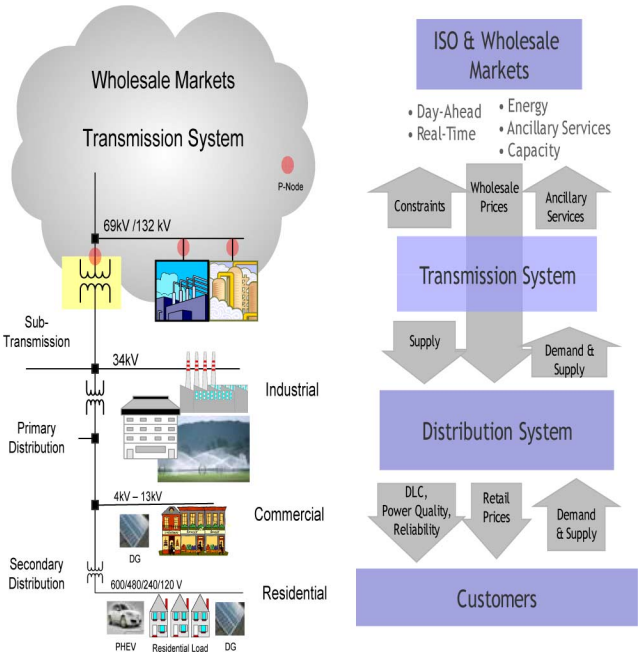

Fig. 4. DR connectivity and information flow.

Summary of DR Products and Rules at Midwest ISO: The DR programs accommodated under Midwest ISO's ASM market that started operation as of 6 January 2009 include two categories:

- *Demand Response Resource Type I (DDR Type I):* This program is available to physical interruptible load under Midwest ISO command. The following are the main characteristics of DRR Type I resources.
  - They may supply energy or contingency reserve (i.e., spinning or supplemental reserves), but not regulation.
  - They can be committed (ON or OFF), but not dispatched.
  - They can be committed for energy or cleared for contingency reserve, but not both at the same time (for the same hour).
  - Their energy offer may include the following components: a) targeted demand reduction (MW); b) shut down cost ($); and c) hourly curtailment cost ($/hr), but no energy ($/MWh) curve.
  - They can offer contingency reserve ($/MW/hr).
  - They can offer in day-ahead, reliability assessment commitment (RAC), and real-time markets.
  - They cannot set energy LMP, but can set A/S MCP.
  - They are eligible for revenue sufficiency guarantee (RSG) make-whole payment subject to performance.
- *Demand Response Resource Type II (DRR Type II):* These include behind the meter generation or controllable load under Midwest ISO command. Their market participation requirements and opportunities are comparable to generators. They are committable and dispatchable. They may supply energy, contingency reserve, and/or regulation.

Summary of DR Products and Rules at California ISO: CAISO started its new (nodal) market under the name Market Redesign and Technology Upgrade (MRTU) as of operating

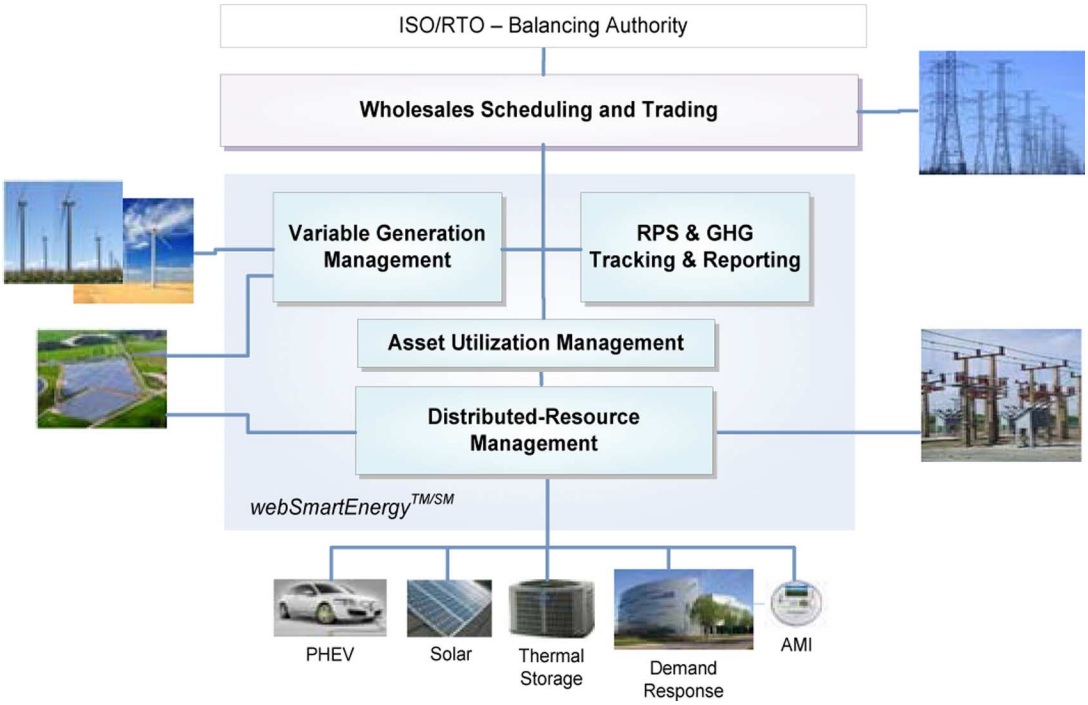

Fig. 5. Interaction of DR, variable generation, and storage.

day 1 April 2009. The MRTU program is expected to be further enhanced in the future. The current version is called MRTU Release 1 to be followed by another release called MAP (for Markets and Performance) a year or so later.

The DR programs accommodated under MRTU Release 1 include the following.

- Emergency demand response (EDR). This is a reliability-based DR program with the following characteristics.
  - Geographical granularity: load aggregation point (LAP), i.e., the entire service territory of a UDC or LSE. These include primarily the service territories of Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric Company (SDG&E).
  - Timing: intention to curtail must be announced to CAISO before close of the day-ahead market.
  - Trigger: The intention to curtail is triggered by the UDC/LSE based on out-of-market conditions (primarily temperature forecast).
  - Action by CAISO: CAISO reduces its residual unit commitment (RUC) procurement target based on the stated amount of planned load curtailment by the UDCs.
  - EDR may not provide A/S.
  - EDR may not bid in to be curtailed in the real-time market.
- Participating Load Program (PLP): This is an economic (market-based) program available to loads that register as participating loads (PL) with CAISO.
  - The following PL Types are accommodated in MRTU Release 1:
    - Pumping load associated with pump storage.
    - Single pumping or nonpumping load.
    - Aggregated pumping and nonpumping load.

    The PL program of main interest to the broad CAISO market is the aggregated PL. In fact, in the following paragraphs when we refer to CAISO's participating loads, we mean the aggregated PL.
  - PL may participate in energy and nonspinning reserve markets.
  - Settlement interval revenue metering is adequate for participation in the energy market.
  - Telemetry is required additionally for participation in nonspinning reserve market.
  - To register, an LSE must:
    - execute a participating load agreement (PLA) with CAISO;
    - request (subject to CAISO approval) a custom load aggregation point (custom LAP or CLAP), which must be entirely with a local capacity area (LCA);
    - request a pair of resources IDs; one for the custom load (to participate in the Energy market), the other for a pseudogenerator (to participate in nonspinning reserve market).
  - The PL must respond to CAISO dispatch instructions or incur penalties.

An extension of MRTU Release 1 DR programs (more specifically, aggregated PL) is planned for implementation before MAP. It is called the proxy demand resource (PDR). This program is to be implemented shortly (a few months) after MRTU Release 1. It has the following characteristics:

- The PDR must be registered with CAISO.
- Geographical granularity:
  - The host load must be within a LAP, but need not be more granular than a LAP.

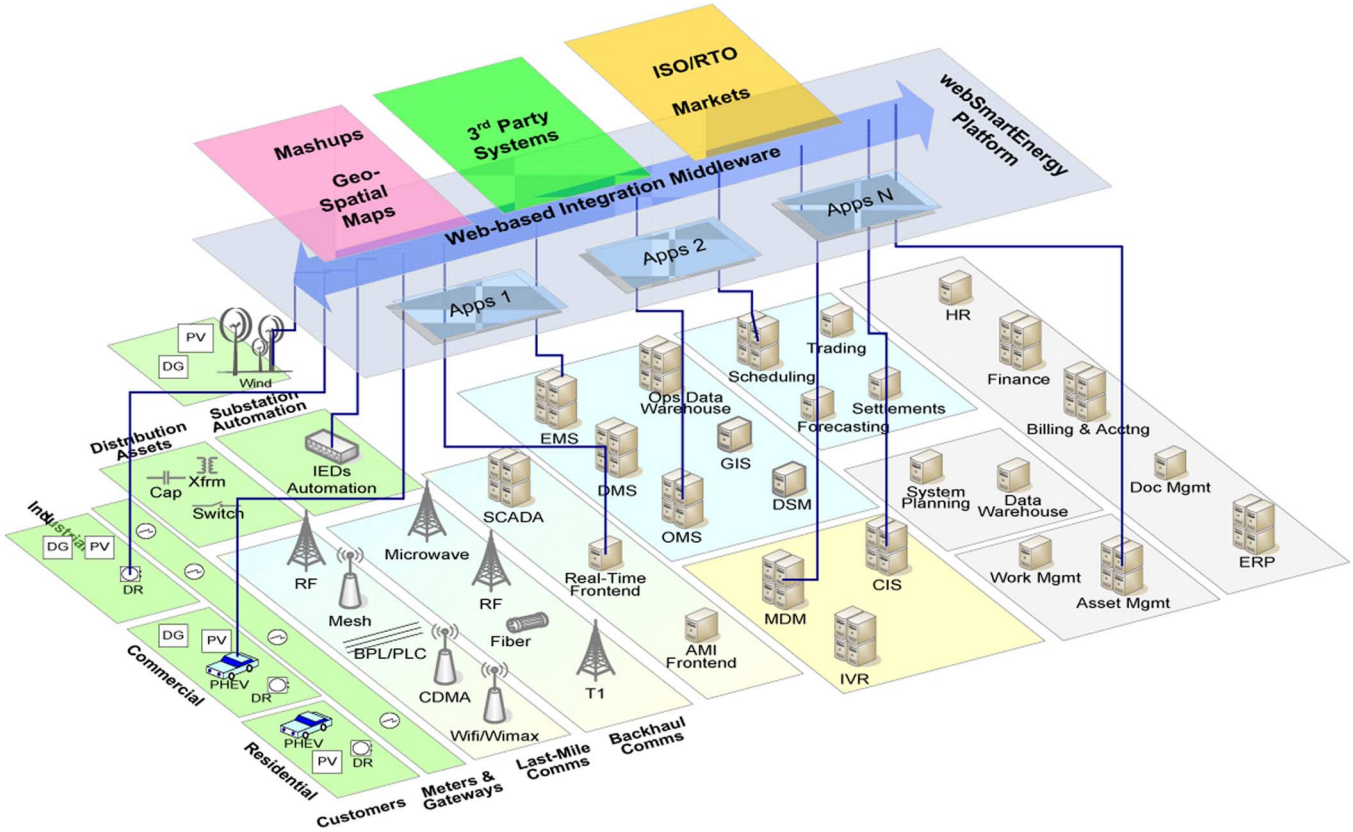

Fig. 6. Implementation of DR/DER on top of legacy systems.

- The PDR (proxy generator representing load curtailment) must be within an LCA (a CRR sub-LAP, a node, or a CLAP all qualify, since by definition they are within an LCA).

— Products offered: based on the current stakeholder discussions, the product markets PDR can participate in are:
- energy market (requires settlement interval revenue metering);
- nonspinning reserve market (requires telemetry);
- possibly spinning and regulation reserves (requires telemetry and direct load control).

Further enhancements under MAP include the Dispatchable Demand Resource (DDR) program. This is a market-based (economic) program. When implemented, the DDR will replace the Release 1 PL (single resource) program, as well as the Release 1 Aggregated PL (two-resource PL) program. However, DDR and PDR may coexist. DDR has the following characteristics and requirements:

— must execute a PLA with CAISO;
— must be within a CLAP, which in turn must be within an LCA;
— Must respond to CAISO dispatch instructions or incur penalties;
— may participate in all CAISO markets:
- energy market (requires settlement interval revenue metering);
- nonspinning reserve market (additionally requires telemetry);
- spinning and regulation reserves (additionally requires telemetry and direct load control).

Summary of DR Products and Rules at ERCOT: ERCOT's DR programs include the following.

- Voluntary Load Response: This program is self-directed in the sense that the decision to reduce consumption from scheduled or anticipated load by the LSE [or its qualified scheduling entity (QSE)] is in response to prices
- Qualified Balancing Energy Up Load (BUL): This program is directed by ERCOT, and has the following characteristics:
  — *Services provided:*
    - up-balancing energy service;
    - down-balancing energy service.
  — *Compensation:*
    - market-clearing price for ancillary service (MCPC);
    - market-clearing price for energy (MCPE) if dispatched.
- Load acting as a Resource (LaaR): This program pertains to controllable loads and has the following characteristics.
  — Telemetry and dispatchability requirements similar to that of a generator.
  — Services provided:
    - responsive reserve service;
    - nonspinning reserve service;
    - replacement reserve service.
  — Compensation:
    - market-clearing price for ancillary service (MCPC);
    - market-clearing price for energy (MCPE) if dispatched.

Summary of DR Products and Rules at SPP: SPP started its real-time energy imbalance service (EIS) market in Feb-

ruary 2007 and is considering implementation of additional markets (day-ahead energy, A/S, etc.) over the next few years (2012–2013 timeframe). SPP's DR programs may be summarized as follows:

EIS market enhancements to accommodate DR are underway and include provisions for "controllable demand resource, including behind-the-meter generation. This DR program has the following requirements and characteristics.

- Controllable load resources are offered and deployed like a generator (subject to 5–min dispatch).
- Real-time telemetry is required (similar to a generator).
- The compensation for deployment is the higher of the locational imbalance price (LIP) or the resource's offer price

The SPP future market design will include two types of DR resources, namely, variable dispatch demand response (VDDR), which is essentially the same as the "controllable load resource" under EIS, and block dispatch demand response (BDDR) program. Each DR resource must be completely within an existing load settlement point. The BDDR program is available to loads that may not be able to respond to real-time dispatch instructions, but may be predispatched (curtailed for the whole hour). It has the following characteristics.

- BDDR offer may include fixed MW blocks at a price.
- Dispatch interval is hourly.
- After-the-fact interval metering is required (no telemetry is required).

III. Challenges and Potential Solutions

The advent of smart grid brings along operational challenges for electric power system operators. Expected profusion of variable generation requires departure from traditional operations planning, scheduling, and dispatch practices to take into account erratic supply-demand mismatches that may occur because of supply intermittency. DR, storage technologies, and predictive real-time awareness (provided by synchrophasor technology) can provide potential solutions to address these new challenges.

Currently, the ISO/RTO operator has visibility into transmission substations, but may have visibility into large subtransmission substations where large C&I customer DRs are located, but generally does not have visibility into the distribution network where most of the small commercial and the main residential DR takes place. Other entities, such as UDCs, LSEs, ESPs, and CSPs interact directly with consumers on the one hand and the ISO/RTO operator on the other. They play an important role in bundling the DR from their subscribed customers into products used in the ISO/RTO markets. Fig. 4 demonstrates the physical location of DR (on the left) and the information flow among customers, distribution system operators, transmission system, and wholesale markets (on the right).

Fig. 5 schematically shows how the DR, variable generation, and storage technologies may be managed, bridging the gap between distribution/retail and transmission/wholesale domains.

Fig. 6 shows how DR/DER may be implemented in the context of smart grid as an incremental layer on top of existing/legacy systems. It illustrates an example (OATI's webSmartEnergy platform) whereby relevant data from existing/legacy applications are retrieved and merged with other relevant data using Web services. The user interface allows the users to analyze the data and run applications, the results of which may be summarized in reports, displayed graphically or in tabular, and fed back to the existing/legacy applications as relevant.

IV. Closing Remarks

The smart grid paradigm cuts across several disciplines and impacts different business units in the utility environment. DR is an important ingredient of smart grid, promoting both market efficiency and operational reliability. If implemented correctly, it helps curb supply market power vis-à-vis supply scarcity conditions, and improve operational reliability vis-à-vis profusion of variable generation.

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Farrokh A. Rahimi (M'66–SM'72) received the Ph.D. degree in electrical engineering from the Massachusetts Institute of Technology, Cambridge.

He has 38 years of experience in electric power systems analysis, planning, operations, and control. Before joining Open Access Technology International, Inc. (OATI), Minneapolis, MN, in 2006, he collaborated with California ISO, Folsom, CA for eight years, where he was engaged in market monitoring and design, Federal Energy Regulatory Commission (FERC) and California Public Utilities Commission filings, and FERC testimonies, as well as Califoria ISO Board and stakeholder processes. He is Vice President of Market Design and Consulting at OATI, where he is currently involved in analysis and design of power and energy markets, and smart grid solutions. He has provided consulting services to electric utilities in many countries in Europe, North America, Latin America, Africa, Asia, and the Middle East.

Ali Ipakchi received the Ph.D. degree from the University of California, Berkeley.

He has over 30 years of experience in the application of information technology to power systems and electric utility operations. He held various senior management positions at the leading T&D vendors working with power applications, control, and systems development and deployment. He was Vice President of Integration Services at KEMA, assisting utility clients with roadmaps, specifications, and implementation strategies for advanced metering infrastructure, smart grid, and system operations. He is Vice President of Smart Grid and Green Power at Open Access Technology International, Inc. (OATI), Minneapolis, MN, leading product activities and business development activities in the smart grid area. He is coholder of three U.S. patents on power systems applications and instrument diagnostics.