Overview of Demand Response under the Smart Grid and Market Paradigms

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Abstract **- Demand Response (DR) is an important ingredient of the emerging Smart Grid paradigm. Although much of the DR emerging under Smart Grid is targeted at the distribution level, DR programs are regarded as important elements for reliable and economic operation of the transmission system and the wholesale markets. In the context of Energy and Ancillary Service markets facilitated by the ISOs/RTOs, DR programs may be broadly classified as market-based or reliability-based depending on the conditions under which DR is deployed: The former provide for DR vis-à-vis economic signals, while the latter are generally triggered under emergency conditions. Depending on the ISO/RTO market design and applicable operational standards, the market products DR can offer may include Energy, Reserve Ancillary Services (i.e., Supplemental/Non-spinning Reserve, Spinning/Responsive Reserve, or Regulating Reserve), and Capacity.**

In this paper we first explore different facets of Demand Response under the Smart Grid paradigm. We then briefly summarize the existing and evolving Demand Response 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**-- Demand Response, Smart Grid, Energy and Ancillary Services for Demand Response Resources**

I. Introduction

The concept of Smart Grid was first introduced with the notion of "self healing" electrical networks vis-à-vis 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 variable generation (wind, solar, etc.), Demand Response, and Distributed Generation, (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. The following figure schematically depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the place of Demand Response in the new arena.

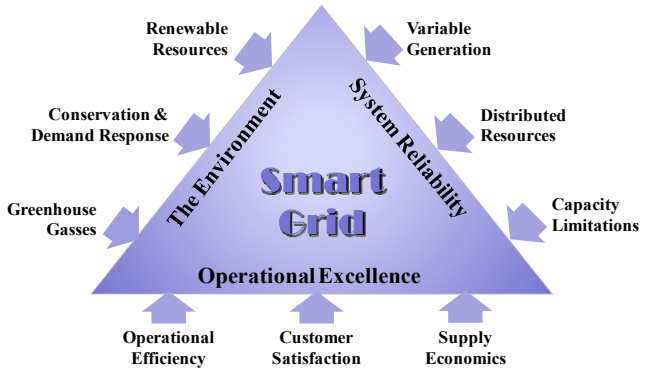

Fig. 1 – Industry Drivers of Smart Grid

Another emerging paradigm shift is the increased and bidirectional interaction between wholesale markets/transmission operation and retail markets/distribution operations. The expected profusion of Demand Response, Renewable Resources, and Distributed Generation at distribution/retail level has direct implications on the operation of the transmission system and the wholesale energy markets. Enabling technologies, such as enhancements in communication and information technologies, make it possible to turn the potentially adverse autonomous operational impacts of these new resources into useful controllable products for wholesale market and transmission system operators.

The following figure 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.

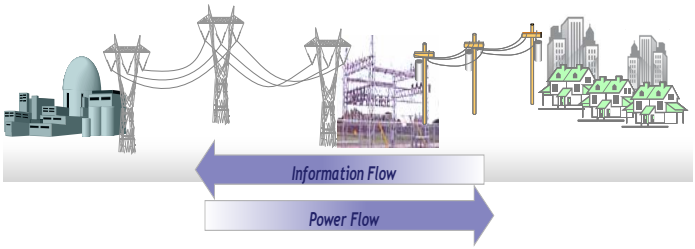

Fig. 2 – Power and Information Flow in Traditional Utility Environment

In contrast, in the emerging utility environment, both power and information flows are bidirectional.

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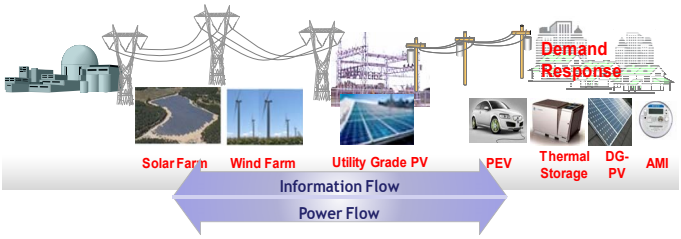

Fig. 3 – Power and Information Flow under Smart Grid

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

Role of Demand Response under Markets and Smart Grid

Demand Response (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 lack of Demand Response has been a major contributing factor to occurrences of energy market meltdown. For example, California's Energy crisis at the turn of the millennium could to a large extent have been mitigated if sufficient Demand Response were in place.

Several initiatives are helping promote the role of Demand Response under the Smart Grid and Energy Market paradigms. Notable among these are FERC Order 719 and the American Recovery and Reinvestment Act (ARRA).

FERC Order 719

FERC Order 719 was issued on October 17, 2008 [2]. The main directive in this order is comparable treatment of generation sources and Demand Response in the wholesale markets. The Order aims to improve wholesale markets by establishing a more forceful role for Demand Response (DR). It directs RTOs/ISOs 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 of DR performance in relation to different products and for settlement with DR resource owners, operators, and aggregators.

American Recovery and Reinvestment Act (ARRA)

The U.S. Energy Independence and Security Act (EISA) and the American Recovery and Reinvestment Act (ARRA) of 2009 [3] both include Smart Grid requirements. The ARRA allocates significant levels of funding for Smart Grid activities. The U.S. Department of Energy has recently issued two Funding Opportunity Announcements (FOA), namely one (DOE-FOA-0000036) for Smart Grid demonstration projects, and another (DOE-FOA-0000058) for Infrastructure Development investments. Demand response is included in both. More specifically, the former includes two main program areas, namely:

- Program Area 1 - Regional Smart Grid Demonstrations, which includes a number of projects including Demand Response (DR) and Distributed Energy Resources (DER) including generation, storage and Plug-in Electric Vehicles (PHEV/PEVs).
- Program Area 2: Utility-Scale Energy Storage Demonstrations

The total level of ARRA funding is 4.5 billion dollars to be matched by 4.5 billion dollars of cost sharing by the interested entities. Many U.S. organizations, including Investor Owned Utilities, Municipalities, Information Technology providers, Communication infrastructure firms, research labs, system vendors, and consultants are preparing proposals responding to these FOAs.

II. SUMMARY OF U.S. RTO/ISO DEMAND RESPONSE PROGRAMS AND RULES

In the context of Energy and Ancillary Service Markets facilitated by the ISOs/RTOs, DR programs may be broadly classified as Market-Based and Reliability-Based. The former provide for DR vis-à-vis economic signals, while the latter are generally triggered under emergency conditions. Depending on the ISO/RTO market design and operational standards, the market products DR 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 Ancillary Services, which may include some or all of the following:
    - Regulating Reserve
    - Spinning Reserve/Responsive Reserve
    - Supplemental Reserve/Non-spinning Reserve

Additionally, out-of-market (or out of merit order) reliability-based Demand Response may be provided for mostly under Emergency conditions.

Depending on the specific ISO/RTO design, the DR products may be offered into the ISO/RTO markets by one or more classes of Market Participant 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 load assets.

Below we briefly summarize DR products, their underlying infrastructural requirements, attributes, limitations, and performance requirements in different U.S. ISO/RTO markets including NYISO, PJM, ISO-NE, Midwest ISO, CAISO, ERCOT and SPP.

Summary of DR Products and Rules at NYISO

New York ISO accommodates four generic types of Demand Response, which include:

- 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 Curtailment Service Provider (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, response to dispatch instructions is mandatory for demand participating in this program. Participation in this program does not require telemetry; interval metering is adequate. Demand reduction is measured compared to pre-determined base line. If the Participant fails to reduce demand 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 Installed Capacity (ICAP) Resources and must perform when asked to curtail by NYISO. An individual Demand-side Resource can participate either in the EDRP program or the SCR program, but not both during the same time period.
- Demand Side Ancillary Service Program (DSASP). The underlying products offered by Demand-Side resources under this program are Regulation, Spinning and Supplemental (Non-spinning) 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:

- *Economic Load Response*, which may be provided by Agent PJM members, or Curtailment Service Providers (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 Ancillary Services*. 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 Participation in PJM's Capacity market enables LSEs and CSPs to offer DR as Capacity product and receive Capacity Credit for the MW quantity of Demand Response that clears the Capacity market.

For DR to participate in PJM's Ancillary Service markets, the following rules apply:

- For DR participation in PJM's Synchronized Reserve market:
  - *DR must be able to provide metering data at no less than 1 minute 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 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 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*
  - *Sub-programs based on Notification Time:*
    - 30-minute DR Program
    - 2-hour 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 ($1,000/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*

Summary of DR Products and Rules at Midwest ISO

The DR programs accommodated under Midwest ISO's ASM market that started operation as of January 6, 2009 include two categories:

  - *Demand Response Resource Type I (DRR Type I)*
  - *Demand Response Resource Type II (DRR Type II)*

- 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 ($/MWh) curve.*
  - *They can also offer Contingency Reserve ($/MW/hr)*
  - *They can offer in Day-ahead, Reliability Assessment Commitment (RAC) and Real-time markets*
  - *They cannot set Energy LMP, but can set Ancillary Service 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 MRTU (Market Redesign and Technology Upgrade) as of Operating Day April 1, 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 Utility Distribution Company or Load Serving Entity. 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 Ancillary Services
  - 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 Non-pumping Load*
    - *Aggregated Pumping and Non-pumping 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 Non-Spinning Reserve Markets
  - Settlement interval revenue metering is adequate for participation in the Energy market
  - Telemetry is required additionally for participation in Non-spinning Reserve market
  - To register a Load Serving Entity 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 Pseudo-generator (to participate in Non-Spinning Reserve market)
  - The PL must respond to CAISO dispatch instructions or incur penalties

An extension of MRTU Release 1 Demand Response 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.
    - The PDR (proxy generator representing load curtailment) must be within a Local Capacity Area (a CRR sub-LAP, a Node, or a CLAP all qualify since by definition they are within a LCA)
  - Products offered: Based on the current stakeholder discussions, the product markets PDR can participate in are:
    - *Energy market (requires Settlement Interval revenue metering)*
    - *Non-Spinning 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 Participating Load (single resource) program as well as the Release 1 Aggregated PL (two-resource PL) program. However, DDR and PDR may co-exist. DDR has the following characteristics and requirements:

  - Must execute a Participating Load Agreement with CAISO.
  - Must be within a Custom Load Aggregation Point (CLAP), which in turn must be within a Local Capacity Area.
  - Must respond to CAISO dispatch instructions or incur penalties
  - May participate in all CAISO markets
    - *Energy market (requires Settlement Interval revenue metering)*
    - *Non-Spinning 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 Load Serving Entity

(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
    - Non-Spinning 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 February 2007 and is considering implementation of additional markets (Day-ahead Energy, Ancillary Services, etc.) over the next few years. SPP's DR programs may be summarized as follows:

- Current (EIS) market enhancements to accommodate DR include provisions for two types of DR resources (VDDR and BDDR) explained below. Each DR resource must be completely within an existing Load Settlement Point.
  - Variable Dispatch Demand Response (VDDR). This DR program is available for controllable loads, including those with behind-the-meter distributed generation. It has the following requirements and characteristics:
    - VDDR resources are offered and deployed like a generator (subject to 5 minute 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 VDDR's offer price
  - Block Dispatch Demand Response (BDDR). This DR program is available to loads that may not be able to respond to real-time dispatch instructions, but may be pre-dispatched (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)
- Future Markets: DR program enhancements in the context of SPP's Future Markets provide for DR ability to participate in Day-Ahead, Reliability Unit Commitment, and Ancillary Services markets. No Capacity market is planned at this time.

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. Demand Response, 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 sub-transmission substations where large Industrial and Commercial (C&I) customer DR are located, but generally does not have visibility into distribution network where most of the small commercial and the main residential demand response takes place. Other entities, such as Utility Distribution Companies (UDCs), Load Serving Entities (LSEs), Energy Service Providers (ESPs), and Curtailment Service Providers (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. The following figure demonstrates the physical location of Demand Response (on the left) and the information flow among customers, distribution system operators, transmission system, and wholesale markets (on the right).

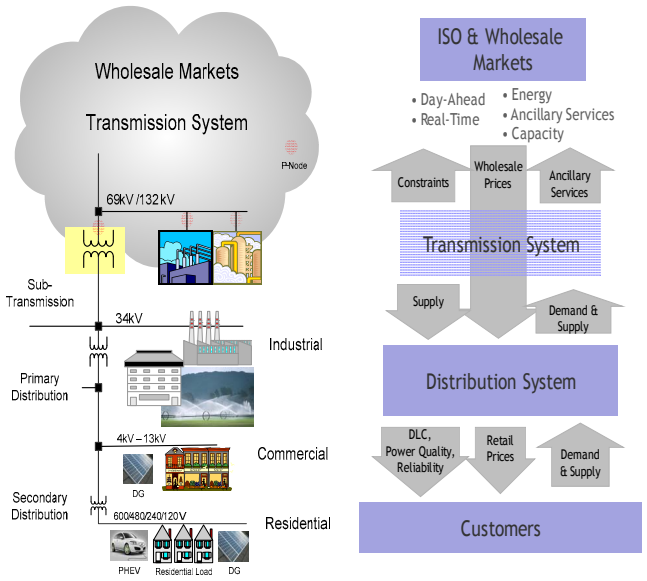

Fig. 4 – Demand Response Connectivity and Information Flow

The following figure shows schematically how Demand Response, Variable Generation, and Storage technologies may be managed vis-à-vis regulatory, environmental, and operational requirements bridging the gap between distribution/retail and transmission/wholesale domains.

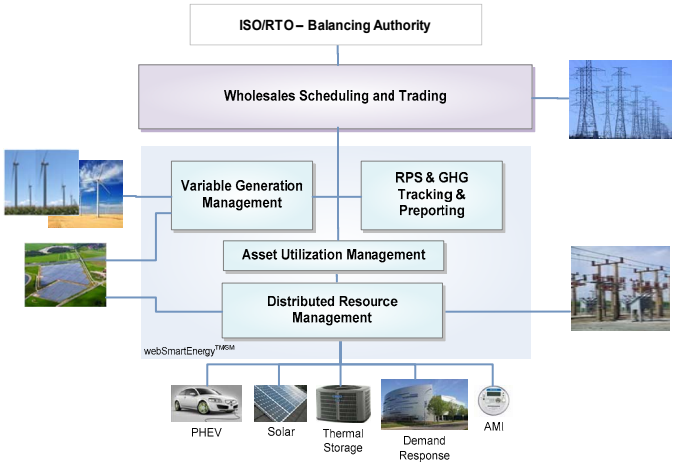

Fig. 5 – Interaction of Demand Response, Variable Generation, and Storage

The following figure 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 as an example, OATI's webSmartEnergy platform, whereby relevant data from existing/legacy applications are retrieved and merged with other relevant data using web services. webSmartEnergy applications and User Interface allow the users to analyze the data and run applications, the results of which may be summarized in reports, displayed graphically or in tabular forms as desired, and fed back to the existing/legacy applications as relevant.

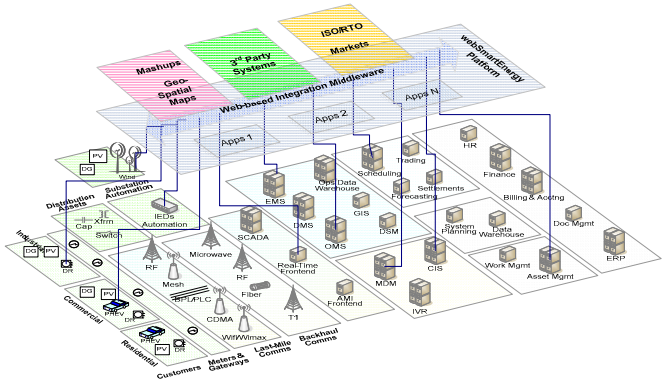

Fig. 6 - Implementation of DR/DER on top of Legacy Systems

IV. CLOSING REMARKS

The Smart Grid paradigm cuts across several disciplines and impacts different business units in the utility environment. Demand Response 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.

V. ACKNOWLEDGMENT

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