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Some Characteristics of Emerging Distribution Systems Considering the Smart Grid Initiative

Modernization of the electric power system in the United States is driven by the Smart Grid Initiative. Many changes are planned in the coming years to the distribution side of the U.S. electricity delivery infrastructure to embody the idea of ''smart distribution systems.'' However, no functional or technical definition of a smart distribution system has yet been accepted by all.

Hilary E. Brown, Siddharth Suryanarayanan and Gerald T. Heydt

I. The Smart Grid Initiative and Its impact

Title XIII of the Energy Independence and Security Act of 2007 (EISA07), passed by the 110th United States Congress and signed into law by the 43rd U.S. President, includes the official policy of modernization of the electricity delivery infrastructure in the U.S.[1] Popularly known as the Smart Grid Initiative, this legislation calls for: an increase in use of digital control and information technology with real-time availability; dynamic optimization and cyber-security relating to grid operability; inclusion of demand-side response (DSR) and demand-side management (DSM) technologies; integration of distributed energy resources (DER) including renewables and energy storage; and deployment of smart

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metering, automated metering infrastructure, distribution automation, smart appliances, and customer devices.[1,2] Following the EISA07 in 2008, the U.S. Department of Energy (DOE) announced a specialized initiative intended to modernize the national electric power grid and all its attendant components with the objectives of increasing supply reliability, transmission security, and energy efficiency.[3] The DOE modernization policy vis-à-vis the performance of the modernized electric power system in the U.S., also known as the Smart Grid, taken directly from the U.S. Office of Electricity Delivery and Energy Reliability is listed below:

- Self-healing from power disturbance events;
- Enabling active participation by consumers in demand response;
- Operating resiliency against physical and cyber attack;
- Providing power quality for 21st century needs;
- Accommodating all generation and storage options;
- Enabling new products, services, and markets, and
- Optimizing assets and operating efficiently.[3]

Following this announcement, a number of additional stakeholders from governmental, professional, commercial, and international sectors added, aligned, or accentuated their respective philosophies to the DOE announcement.[4] The proliferation of attention and descriptions of the Smart Grid have led to a lack of unanimity of exactly what the Smart Grid might be and what it should contain.[5]

Grid 2030, the DOE's long-term vision for the 21st century electric infrastructure, also calls for the introduction of smart controls and appliances to the existing grid.[6] It is expected that most of the attempts to modernize the grid apropos enhanced performance and incorporating intelligence will affect the distribution side of the electricity delivery infrastructure.[7] This is substantiated by plans from utilities nationwide for several innovative additions to the existing distribution systems including the deployment of smart devices, meters, appliances, controls, communication pathways and sensors.[8,9,10,11,12,13,14] The importance of reengineering the distribution system is emphasized by noting that the first generation distribution system, which has been in place for about 80 years, is still being used.

Grid 2030 calls for the introduction of smart controls and appliances to the existing grid.

In order to achieve significant levels of intelligence and to reliably supply the demands of 21st century loads, an imperative requirement is a unique framework for the smart distribution system that takes into account the following: levels and locations of increasing intelligence in distribution systems; reconfiguration of distribution system architecture from a radial topology to a partially meshed (networked) structure; placement and utilization of sensors in distribution systems that will aid both supervised and fully automated controls; and enabling strategies and configurations for interconnecting renewable energy sources to distribution systems. However, there exists no single repository of technical perspectives for achieving the proposed metamorphosis of the existing distribution system into a *smart distribution system*. In that regard, in order to help elucidate expectations of the Smart Grid from the perspective of emerging distribution systems, an online survey of stakeholders in the power distribution area was designed and disseminated by academic researchers associated with the Power Systems Engineering Research Center (PSerc) in 2009. A comprehensive account of the design of the survey, sans results, exists in archival form.[15] In this article, a detailed description of the results of that survey is summarized.

The article is organized as follows: Section II describes the motivation and framework of the survey; Section III describes the results of the survey based on the responses; Section IV presents some main conclusion which served to describe the characteristics of emerging smart distribution systems.

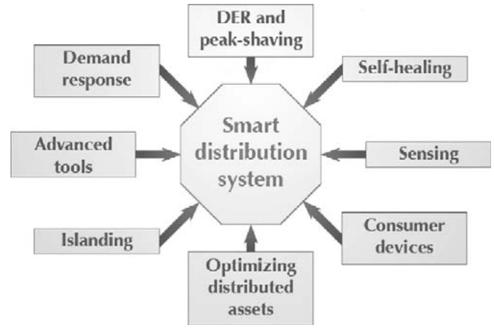

Figure 1: Eight Attributes of a Smart Distribution System[15]

II. Motivation and Framework of a Survey to Define Smart Distribution Systems

Despite the significant volume of work on policy-based definitions of the Smart Grid, a functional and technical definition of a smart distribution system has not yet emerged.[16,17,18,19,20] However, many of the benefits of the Smart Grid Initiative will be realized at distribution voltages – 120 V, 240 V, 5 kV class, 15 kV class, and 35 kV class (in the U.S.). In order to avail oneself of the proposed modernization, it is imperative that some baseline characteristics of a smart distribution system are defined in the perspective of the power industry.

Presently, several utilities are retrofitting their metering infrastructures with ''smart meters''; however, the smart meter is only an enabling technology which will further the Smart Grid Initiative. What further changes must be made to the distribution system to fully realize ''smart'' operation? With the goal of answering the above question, the authors designed an online survey aimed at stakeholders in distribution system engineering.

Using the 10 points of the Smart Grid Initiative, as described in Title XIII of *EISA07*,[1] eight basic attributes of a smart distribution system were identified, viz.: DER and peak-shaving; self-healing; sensing; consumer devices; optimizing distributed assets; islanding; advanced tools; and demand response, as shown in **Figure 1**.[15] The eight attributes of a smart distribution system were used to design and organize the survey questions related to the detailed functionality and technological applications envisioned by the participants.[15]

The cited survey consisted of 67 questions, with two introductory questions.[15] As a result of early feedback from survey participants, the survey was split into four sub-surveys with approximately 15 questions apiece and separate Web links to each sub-survey. The reason for the split was two-fold: (1) to limit the total number of questions in each survey links, and (2) to encourage partial participation. It was not expected that all participants would have views on all of the eight attributes behind the survey design. The only ''required'' questions were the affiliation of respondents (e.g., industry, academe, national laboratories) and the ranking of the eight attributes of smart distribution relative to one another. By ranking the eight attributes, the participants were able to assert their personal view of the relative importance of the eight attributes, which could guide further development of a smart distribution system.

The survey was hosted in the public domain by an Internet service[21] intended to maintain the anonymity of participants. The survey links were disseminated using popular Internet listservs related to power engineering[22] and via a power industry consortium soliciting respondents from North America. For ease of responding, all the survey questions were designed to be one of the following three types: (1) single-select, using radio buttons, (2) multi-select, using check boxes, and (3) ranking, using

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moveable arrows. The respondent also had the option of providing input that was not listed a choice in the survey by using a free response text box for each question.

III. The Results from the Survey on Defining a Smart Distribution System

Participation in the survey was opened for seven months and the participant count reached 31 respondents, based on the introductory questions. Approximately 75 percent of participants identified their affiliation as ''Industry,'' with job titles of Manager of Smart Grid Technology Planning, Consulting Engineer, and Business Manager. Less than 15 percent of respondents identified their affiliation as ''Academia.'' A recent Pacific Crest Mosaic survey on the smart grid completed in July 2009 had 20 participants.[23]

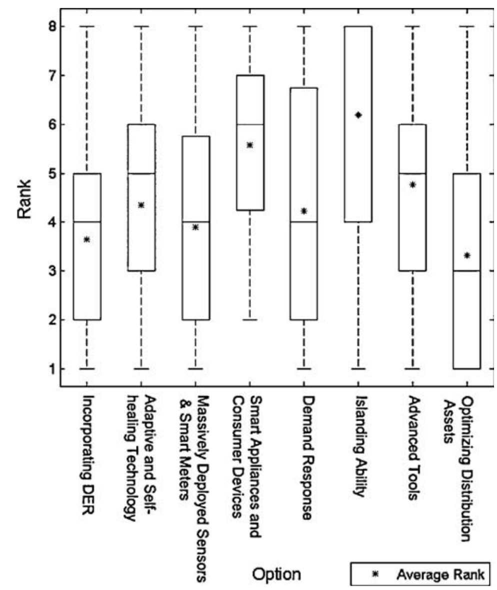

Figure 2: Box Plot of the Rankings of the Options Presented in **Table 1**

When asked to rank the eight attributes of a smart distribution system relative to one another, the average ranks given by participants to the options are shown in **Table 1**. There were 31 responses to this question. A rank of 1 is interpreted as ''most important'' and a rank of 8 is interpreted as ''least important.'' From Table 1 it is observed that, according to the respondents, optimizing distributed assets and incorporating DER are considered central aspects of a smart distribution system, while the ability to island ranks as least important. The remaining survey results will be presented in order of relative importance given by the results in Table 1.

A box plot of the results in Table 1 is shown in **Figure 2**, which depicts the spread of the choice of rankings among the individual choices. The box plot may be interpreted as follows: the least rank forms the lower end of the whisker; the lower edge of the box indicates the first quartile; the line contained within the box represents the median; the asterisk in the box represents the mean; the top edge of the box indicates the third quartile; and the upper whisker forms the highest rank of each option. The plot may also include information on outliers that can occur at a distance greater than 1.5

Table 1: Relative Rankings of the Attributes of a Smart Distribution System.

Attribute of a Smart Distribution System	Rank: Average	Rank: Std. Deviation
Optimizing distributed assets	3.32	2.29
Incorporating DER	3.65	1.92
Integration of massively deployed sensors and smart meters	3.90	2.20
Active participation by consumers in demand response	4.23	2.19
Adaptive and self-healing technologies	4.35	2.12
Advanced tools	4.77	2.09
Integration of smart appliances and consumer devices	5.58	1.82
Islanding ability	6.19	2.40
Sample size = number of respondents = 31		

A rank of 1 is the most important, while a rank of 8 is the least important.

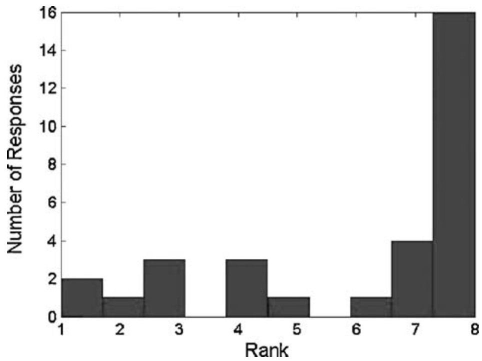

Figure 3: Histogram of the Actual Responses for the Importance of the Ability to Island, from Table 1. Rank 1 = Most Important, Rank 8 = Least Important

interquartile ranges from the edge of the box and are represented as '+' in the box plots.[24]

Figure 2 provides a visualization of the spread or variance in rankings of the options and also indicates the absence of outliers in the individual rankings of the attributes of a smart distribution system. **Figure 3** provides a histogram of the responses for ''islanding ability.'' From the histogram, it is seen that 16 respondents ranked the ability to island as the least important (rank 8), while the remaining 15 respondents ranked the ability to island as increasingly important. This distribution of rankings causes the median line to overlap with the line for the third quartile in the box plot of Figure 2. The purpose of the in-depth analysis of the response statistics of islanding ability is to explain the statistical implications of the box plot and highlight the fact that most participants thought that the ability to island is the least important aspect of a smart distribution system.

A. Optimizing distributed assets

New products, services, and markets could be used to ease incorporation of the Smart Grid paradigm into the distribution system. For example, survey participants identified plug-and-play methodology (or interoperability), standardized services, and easy upgrades as three product philosophies that would enable adoption of a smart distribution system. Smart distribution is expected to open markets for smart grid-tailored devices, planning services, and software tools for advanced energy management such as local energy management systems (LEMS).[15] A LEMS corresponds to load-level management software and is operated by the consumer; a LEMS may be contrasted with a commercially operated distribution management system (CDMS), which corresponds to feeder-level management software and may be operated by a commercial entity.

Participants identified several new markets opened by a smart distribution system – ancillary services, managing energy for the consumer, power quality on demand, and (again) smart grid-tailored devices. The top three ''smart'' technologies to enable new products, services, and markets were real-time pricing or time-of-use pricing, smart metering infrastructure, and demand response/load management programs. Other changes to enable the optimization of distributed assets include DER developments, custom power devices, and networked/meshed distribution topology.

Two areas needing further optimization include two-way communicating devices and networked connections between feeders. Respondents expected that condition-based monitoring and maintenance, advanced outage avoidance and management, and transformer load management would help to optimize asset utilization and efficient operation.

B. Incorporating distributed energy resources

Almost 40 percent of the survey questions dealt with incorporating DER while enabling peak-shaving technologies. DER includes distributed storage (DS) and renewable energy sources (RES). Respondents expressed that DER integration should be allowed at all distribution voltages (from 120 V to the 35 kV class). Some 72 percent of question respondents

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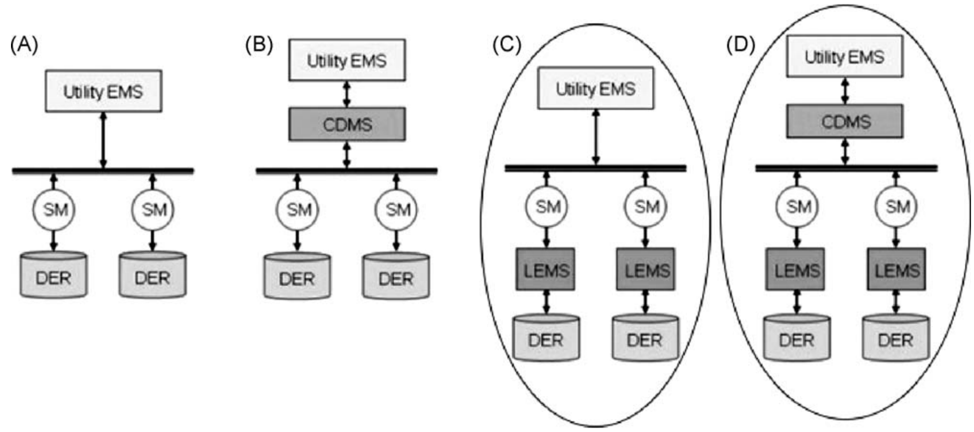

Figure 4: DER Management (Sample Size = 21). The Favored Two Options are Circled

identified the most important *smart* quality for DER as two-way communication capabilities.

Regarding the management of DER, participants selected options that had large degrees of local control. **Figure 4** depicts the top management selections identified by 21 respondents, which were options C and D shown in Figure 4. These options both had the LEMS controlling local DER. Option D included the feeder level CDMS before connecting to the utility's energy management system (EMS). Local communication options were ''all'' or ''nothing'' comparatively; the top two options were: (1) two-way communications between the smart meter and the DER, and (2) a combination including two-way communications between the smart meter and the LEMS, two-way communications between the smart meter and the two-way communications between the DER and the LEMS, and two-way communications between individual DER units. These options are shown in **Figure 5**. ''SM'' indicates smart meter in Figures 4 and 5.

A question asking participants to identify the percentage of total generation expected to be met via RES was prefaced by the fact that most state renewable portfolio standards (RPS) range from 15 to 20 percent of electricity sales from renewable energy by 2030 and include hydroelectric generation. The overall response to this question was that participants expected 10–19 percent of generation to be met via a combination of dispatchable and non-dispatchable RES. However, some participants responded ''none, RPS causes uneconomic investment'' and ''I don't think that there should be a mandate, such as is implied in the wording of the question.'' In general, participants expected no more than 50 percent of new DER to be comprised of RES. To deal with the non-dispatchability of some RES, respondents gave the ranks in **Table 2**, which shows that the top response was to combine non-dispatchable RES with a combination of fast-starting dispatchable generation sources.

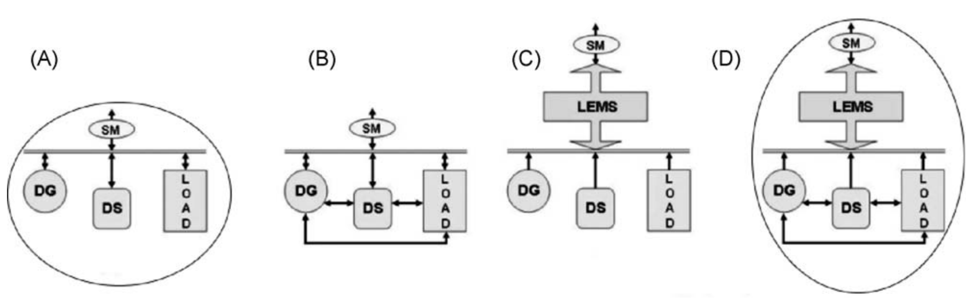

Figure 5: DER Communications (Sample Size = 21). The Favored Two Options are Circled

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Table 2: Relative Rankings of the Possible Ways to Deal with Non-Dispatchable RES.

	Rank	
Dealing with Non-Dispatchable RES	Average	Std. Deviation
Combine non-dispatchable RES with fast-starting generation sources	2.19	1.51
Incorporate different types of DS	2.38	1.02
Monitor and predict conditions which cause intermittency to efficiently plan system usage	2.89	1.36
Incorporate bulk storage at the transmission level	2.94	0.68
Other		
✓ Provide concurrent prices to RES and DS to allow them to make their own economic decisions to produce, consumer, store	4.6250	1.02
✓ Storage at the distribution substation level (15 kV)		
Sample size = number of respondents = 16		

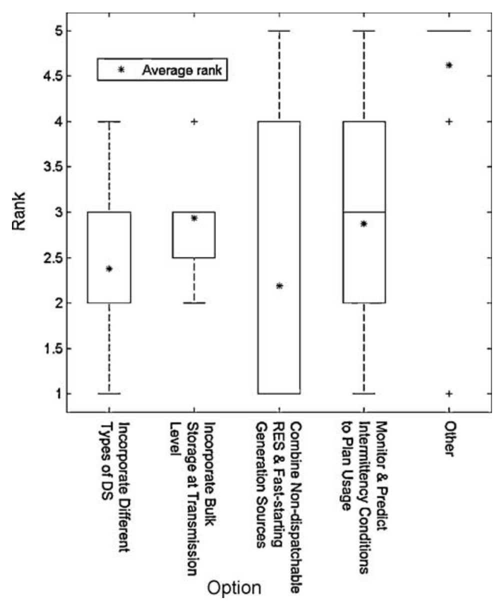

Figure 6: Box Plot of the Ranks for the Possible Ways to Deal with Non-Dispatchable RES

The same information is represented using a box plot in Figure 6, to present the previously outlined statistical measures of the ranking. The first quartile lines overlap the median lines of ''Incorporate Different Types of DS'' and ''Combine Non-Dispatchable RES with Fast-Starting Generation,'' respectively; the third quartile of ''Incorporate Bulk Storage at Transmission Level'' overlaps its own median line. The top-rated renewable energy technologies were photovoltaics, biofuels and biomass, combined heat and power (CHP), and wind. The ''smart'' functionality necessary to achieve the desired level of RES penetration was the ability to store non-dispatchable energy for later use.

Participants were divided on the location of DS between the following choices: (1) on the consumer-side of the smart meter or (2) the utility-side of the smart meter. The useful amount of DS in percentage of rated load for at least four hours was identified as

Table 3: Relative Rankings of DS Technologies.

	Rank	
DS Technology	Average	Std. Deviation
Battery storage	1.4444	0.70
Flow batteries	2.9444	1.30
Flywheels	4.1111	0.83
PHEVs	4.1667	2.48
UPS	4.2778	1.64
Super-capacitors/ultra-capacitors	5.3889	1.29
Compressed air energy storage (CAES)	5.6667	1.75
Sample size = number of respondents = 18		

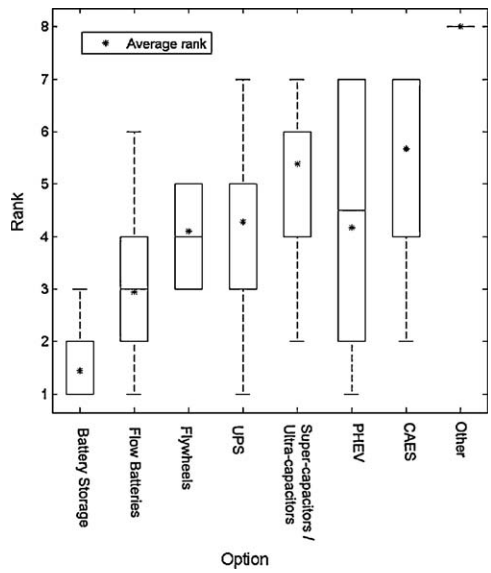

Figure 7: Box Plot of the Relative Rankings of Different DS Technologies

less than 50 percent. Similarly, the amount of non-dispatchable DER expected to be supported by DS was up to 50 percent of the device rating. The relative rankings of the different type of storage devices are shown in **Table 3** and **Figure 7** (box plot). The most popular form of storage was batteries; surprisingly, respondents ranked plug-in hybrid electric vehicles (PHEVs) less favorably to flywheels as possible technologies for distributed storage although the responses were widely spread compared to other storage technologies. It is interesting to conjecture as to the broad future of energy storage: it appears that distributed energy storage (e.g., at substations, in the distribution primaries, at customers in their distribution secondaries) may hold a significant portion of energy storage in the U.S. Note, however, that technologies such as pumped hydro storage offer literally thousands of megawatt-hours as a central-system alternative. When calculated on an energy density basis, batteries and technologies such as super-capacitors offer an enticing alternative.

The ''smart'' functionality required to enable the penetration of DS into the system was identified as ''automatic charge and discharge using frequency sensors.'' The most important benefit of DS is expected to be constant power output from distributed generation. However, respondents also expected the following benefits: (1) ride-through capability during faults and outages, (2) energy reserves, (3) countering momentary power disturbances, and (4) damping price spikes in market caused by unmet electricity demand.

Aspects of feeder and distribution automation considered the most important to the integration of DER were identified as microprocessor-based feeder automation with communication capability and feeder condition monitoring to improve reliability. Smart grid technologies to enable DER usages are real-time pricing and utility-initiated demand response programs. Respondents said that DER should be scheduled one day in advance and in real-time; almost 40 percent of respondents said that the utility should schedule DERs. However, there was no consensus as to the limits on DER scheduling: unrestricted, conditionally, or contractually. Conditional scheduling means that utilities may approve/deny short-term DER scheduling changes. Contractual scheduling consists of penalties levied against the controlling entity if the schedule is not maintained.

Most participants thought that DER should be communicating with the utility EMS at least once per minute, whether it was communicating directly or indirectly through the LEMS or CDMS. When asked about communications technologies within the smart distribution system, there was no clear consensus on the preferred method from options including: cellular, Wi-Fi, wireless mesh networks, Internet, broadband over power line, and fiber optic cables. The authors feel that the area of communications technologies vis-à-vis electric distribution systems is one that could clearly use more exploration, since communications is a central principle of the Smart Grid Initiative.

Peak-shaving was grouped with DER integration as a potential application; demand response in the survey was focused on changing demand to reduce consumption, whereas peak-shaving was assumed to be an application of DER. However, the authors acknowledge that peak-shaving is also an application of demand response. Participants did not reach a consensus on the voltage level most suitable for performing peak-shaving: 35 percent said all distribution voltage levels, and 24 percent said 120 V. Respondents did not agree on the method of deciding when peak-shaving should occur – based on dynamic pricing or based on time of use. The types of peak-shaving that were considered the most important, excluding DER, were residential load control and widespread use of smart appliances. When asked about the time period of activation from the onset of the need for peak-shaving technologies, ''within 5 minutes'' was the most popular.

C. Integration of massively deployed sensors and smart meters

Participants said that massively deployed sensors, excluding smart meters, should be located in the 15 kV class. The information that participants desired from massively deployed sensors is (1) monitor the direction and amount of power flow, (2) monitor locations and usage patterns of DER, and (3) notification of when and how much DER are energizing the system. Respondents defined ''real-time'' as once per minute with respect to sensors and smart metering. The desired type of sensing technology is ''digital sensors with incorporated intelligence.'' Participants saw alarm-processing algorithms as the most important application for massively deployed sensors.

Overwhelmingly, respondents said that the smart meter should act as both a communications link and local control system. The desired functionality of the smart meter is shown in **Table 4**. It is pertinent to note that in Table 4, current and voltage profiling, as well as to store and download time-of-use schedules both had more that 70 percent of the response.

D. Active participation by consumers in demand response

Participants identified ''dynamic pricing'' as the most important smart function to enable consumer participation in demand response. Within dynamic pricing, ''real-time'' pricing was considered the preferred type of pricing. With respect to the point of common coupling (PCC), utilities can give consumers no control, very limited control, limited control, or total control of utility-approved installations. No control at the meter implies that the customer controls small loads (less than 3 kVA) and the utility controls everything else, including ''smart'' appliances. If a consumer receives very limited control at the meter, then the customer controls loads, including smart appliances, and the utility controls DER. Limited control at the meter means that the customer controls real power supplied by the DER, loads, energy demand, automated controls for smart appliances, DER, demand response, and market participation through supply of ancillary services. Total control at the meter means that the customer has control of all utility-approved installations, the ability to island, and everything in the ''limited'' control class.

Given these options, 35.7 percent were inclined to give the consumer ''limited'' control and another 35.7 percent gave ''total'' control. When asked if the utility should have override capability, 40 percent answered ''No'' and 33.3 percent answered ''Yes, for all cases.''

Three technologies were identified as enabling demand response: (1) programmable, communicating consumer devices (smart appliances), (2) advanced metering infrastructure, and (3) building/facility EMS interfaced with market pricing signals. The ''useful time frame'' for automated demand response was

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Table 4: Smart Meter Functionality.

Function	Percentage of Responses
Communication	
✓ Two-way communication with utility	58.8
✓ Two-way communication with other devices, such as DER or LEMS or CDMS	58.8
Reads	
✓ Real-time	58.8
✓ On demand	47.1
✓ Scheduled	47.1
Automation	
✓ Automatic registration	35.3
✓ Time synchronization	58.8
Alarms	
✓ Tamper detection	64.7
✓ Power quality monitoring and alarms	52.9
✓ Outage and restoration alarms	52.9
Profiling	
✓ Current and voltage	70.6
✓ Demand, load, and generation	47.1
Scheduling	
✓ Schedule and bid for system activity	29.4
✓ Store and download time-of-use schedules	70.6
Control	
✓ DER	35.3
✓ Interpret system economic activity	29.4
Miscellaneous	
✓ Event logging	52.9
✓ Ability to measure bi-directional power flow	47.1
✓ Other	0

Sample size = number of respondents = 17.

''within minutes'' by a majority of the survey participants.

E. Adaptive and self-healing technologies

Most respondents thought that adaptive and self-healing technologies would be incorporated into the distribution system at the 15 kV class and 35 kV class. There was no consensus on the desired philosophy of self-healing: preventative, corrective, emergency, or restorative.[25] Most participants thought that self-healing would be accomplished through a combination of automated processes and utility-supervised actions. When asked how effective self-healing at the distribution level should be with respect to a variation of the average system availability index (ASAI),[26] most participants cited a goal of 0.9999 (4 nines) or 0.99999 (5 nines).

The activation timeframe for self-healing actions was the ''several cycles range'' and the restoration timeframe, once action had been initiated, was ''within minutes.'' Participants thought that smart feeders and smart substations should hold the responsibility for self-healing functions.

F. Integration of smart appliances

Respondents were asked to identify the most useful types of smart appliances – thermal devices, programmable devices, or smart circuit devices – of which over 50 percent chose smart circuit devices. Some 70 percent believed that smart appliances should be equipped with two-way communication and just over 50 percent believed smart appliances should also have control algorithms. There was no consensus over where the control system for the smart appliances should be located: on the device, LEMS, smart meter, or a demand response/load management program.

IV. Conclusions

Based on the results of the survey of respondents from the industry and academia, some baseline characteristics of emerging distribution systems under the Smart Grid Initiative are defined. Also, on the basis of responses of experts in the field, one may conjecture as to the future of the smart distribution system. **A smart distribution system**:

- **Optimizes distributed assets** through the use of real-time pricing, smart metering infrastructure, two-way communicating devices, and networked connections between feeders. New market and product opportunities are enabled by plug-and-play methodologies, expected supply of ancillary services, and smart-grid tailored devices.
- **Incorporates DER at all distribution voltage levels** enabled with two-way communications. DER usage will be scheduled in advance and in real-time by the utility. Local management of the DER will incorporate the LEMS at a minimum, but may also incorporate both the LEMS and the CDMS. DER will communicate with the smart meter, LEMS, and one another at least once per minute. Approximately 10–19 percent of total generation will be met via RES, such as photovoltaics, biogas/biomass, CHP, and wind. Less than 50 percent of new DER are expected to comprise RES, which will be supported by battery storage and fast-starting dispatchable generation sources. DS (primarily batteries) will comprise less than 50 percent of rated load for up to four hours, and is expected to support up to 50 percent of non-dispatchable DER. Peak-shaving techniques employed primarily in the 120 V class, such as residential load control, will engage within approximately 15 minutes.
- **Integrates massively deployed sensors and smart meters**. Digital sensors with incorporated intelligence are used to monitor the directions and amounts of power flow and the locations and

usage patterns of DER. The sensors are expected to be located at the 15 kV class and will communicate at least once per minute. The sensors will be able to engage in two-way meshed communications and be enabled with control algorithms to automatically react to measurements. The smart meter acts as a communications link and a local control system and its functionality includes (i) two-way communications with the utility, as well as other devices, (ii) real-time reads, (iii) automatic time synchronization, (iv) tamper detection alarms, (v) current and voltage profiling, and (vi) the capability to download and store time-of-use schedules.
- **Enables consumer participation in demand response** through the widespread use of dynamic pricing and real-time signals. The utility is willing to give the consumer ''limited'' and ''total'' control of load and generation with respect to the point of common coupling. Demand response will engage within minutes.
- **Uses adaptive and self-healing technologies** primarily integrated at the 15 kV class. The technologies should be able to engage in all types of self-healing: restorative, emergency, corrective, and preventative. Self-healing will be achieved through a combination of automatic restoration and utility-supervised actions. Distribution-level self-healing actions should enable the system reliability to reach between 4 nines and 5 nines. Technologies will activate within several cycles and will restore the system within minutes, once activated. Smart feeders will carry the responsibility for self-healing actions and will be enabled by microprocessor-based with communications capability.
- **Possesses the ability to operate in either islanded or grid-connected mode**. A system with islanding potential should have control systems for local regulation of voltage, real power balance, and reactive power balance. The utility should be able to identify islands. The ability to

  doi:/10.1016/j.tej.2010.05.005

island would be facilitated by the implementation of controls for grid-like behavior. ■

Endnotes:

1. *See* Energy Independence and Security Act of 2007, 42 U.S.C. 17381§1301–1309 (2007).

2. *See* Richard E. Brown, *Impact of Smart Grid on Distribution System Design*, PROC. 2008 IEEE POWER & ENERGY SOCIETY GENERAL MEETING, Pittsburgh, at 1–4 (2008).

3. An outline of the U.S. Dept. of Energy's approach to the Smart Grid is available at *Smart Grid*, Office of Electricity Delivery & Energy Reliability, at http://www.oe.energy.gov/smartgrid.htm.

4. A brief listing of such entities is given by *A Smart Grid: Realizing a Smart Grid*, GridWise Alliance, at http://www.gridwise.org/smartgrid_realizing.asp.

5. *See* M. Granger Morgan, Jay Apt, Lester B. Lave, Marija D. Ilic, Marvin Sirbu and Jon M. Peha, *The Many Meanings of 'Smart Grid,'* Power Systems Engineering Research Center (PSerc) (2009) at http://www.pserc.wisc.edu/ecow/get/publicatio/2009public/morgan_smart_grid_july_09.pdf.

6. *See GRID 2030: A National Vision for Electricity's Second 100 Years*, U.S. Dept. of Energy (2003) at http://climatevision.gov/sectors/electricpower/pdfs/electric_vision.pdf.

7. *See* David Moore and Don McDonnell, *Smart Grid Vision Meets Distribution Level Reality*, McDonnell Group, Inc. (2007).

8. *See SmartGridCity*, Xcel Energy at http://smartgridcity.xcelenergy.com/index.asp.

9. *See* Electric Reliability Council of Texas (ERCOT) at http://www.ercot.com/.

10. *See Edison SmartConnect*, Southern California Edison at http://www.sce.com/PowerandEnvironment/smartconnect/.

11. *See PG&E SmartMeter Leads the Nation*, Pacific Gas & Electric Co. at http://www.pge.com/mybusiness/customerservice/meter/smartmeter/.

12. *See The Future Smart Grid: Smart Meters Are Just the Beginning*, CenterPoint Energy at http://www.centerpointenergy.com/services/electricity/competitiveretailers/smartmeters/thefuturesmartgrid/.

13. *See Smart Texas: Rethinking Energy*, Oncor, at http://www.txuelectricdelivery.com/tech_reliable/smarttexas/.

14. *See Automated Meters: Austin Energy and the Smart Grid*, Austin Energy at http://www.austinenergy. com/Customer%20Care/Billing/AM/index.htm.

15. The framework, motivation, and detailed description of questions is available in Hilary E. Brown and Siddharth Suryanarayanan, *A Survey Seeking a Definition of a Smart Distribution System*, PROC. 41ST NORTH AMERICAN POWER SYMPOSIUM, Starkville, MS, at 1–7 (2009).

16. *See Smart Grid: Enabler of the New Energy Economy*, Electricity Advisory Committee, U.S. Dept. of Energy (2008) at http://www.oe.energy.gov/DocumentsandMedia/final-smart-grid-report.pdf.

17. *See The Modern Grid Strategy*, National Energy Technology Laboratory, U.S. Dept. of Energy (2007) at http://www.netl.doe.gov/moderngrid/.

18. *See National Electric Deliveries Technology Roadmap*, Office of Electric Transmission & Distribution, U.S. Dept. of Energy (2004) at http://www.oe.energy.gov/DocumentsandMedia/ER_2-9-4.pdf.

19. *See Xcel/NREL Study: With a Smart Grid, Plug-In Hybrid Electric Vehicles Could Have System Benefits*, National Renewable Energy Laboratory, U.S. Dept. of Energy (2007) at http://www.nrel.gov/news/press/2007/499.html.

20. *See* American Recovery and Reinvestment Act of 2009, Pub. L. No. 111-5 § 405 (2009).

21. Survey Gizmo at http://www.surveygizmo.com/.

22. Power Globe at http://listserv.nodak.edu/archives/power-globe.html.

23. Douglas C. Montgomery and George C. Runger, APPLIED STATISTICS AND PROBABILITY FOR ENGINEERS (John Wiley & Sons, 4nd Ed., 2007) § 6–4 at 215.

24. Survey information was given at SmartGridNews, *Pacific Crest Survey Tracks Smart Grid Progress* (2009) at http://www.smartgridnews.com/artman/publish/Key_Players_Utilities_News/Pacific-Crest-Survey-Tracks-Smart-Grid-Progress-1227.html.

25. Note that the choices for the desired philosophy of self-healing were adapted from Jay Giri, David Sun, and Rene Avila-Rosales, *Wanted: A More Intelligent Grid*, IEEE POWER & ENERGY MAGAZINE, Vol. 7, No. 2 at 34–40 (2009).

26. Gerald. T. Heydt, *Improving Distribution Reliability (the ''N 9 Problem'') by the Addition of Primary Feeders*, IEEE TRANS. ON POWER DELIVERY, Vol. 19, No. 1 at 434–435 (2004).