Technology Deployment Status of U.S. Smart Grid Projects - Electric Distribution Systems

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***Abstract*— Upgrade of electric distribution networks is vital for unified modernization of the grid. To fulfill this prerequisite and contribute to the overall development of the smart grid, the U.S. government awarded up to 50% federal grants to 57 Electric Distribution Systems (EDS) projects in the Smart Grid Investment Grant (SGIG) program under the 2009 American Recovery and Reinvestment Act (ARRA). This paper presents a quantitative study of the technology deployment status of these projects. In this paper, EDS projects are classified in four groups based on the number of substations in their respective service territories. Numeric comparison is provided depending on the portion of the distribution systems that has been modernized with distribution automation (DA), SCADA, and based on number of DA devices installed. Finally, projects with the highest progress (in 2009-2012) are identified based on these analyses.**

***Index Terms*-- Distribution automation, smart grid, deployment status and electric distribution systems.**

I. Introduction

Smart grid is a platform that embraces several multidisciplinary concepts towards computerization of electric power grids. While traditional grid operation refers to one-way flow of electricity from utilities to customers, smart grid, in contrast, generally emphasizes additional interaction between consumers and utilities via advanced devices, which gather consumption data and communicate with the utility's network operations centers [1]. Though the definition of smart grid takes different forms in different contexts, incorporation of intelligence and communication technologies along with deployment of automated control systems throughout the network can be used as basic characteristics to picture the growth of the smart grid irrespective of its starting point.

Smart grid implementation has evolved significantly in the 21st century, globally. Table I summarizes a survey research showing top ten federal investments in smart grid development for the year of 2010 [2]. The U.S., being one of the pioneers in smart grid research and development activities, appropriated $4.5 billion to the Department of Energy (DOE) and Office of Electricity Delivery and Energy Reliability (OE) for deployment of smart grid programs like the Smart Grid Investment Grant (SGIG) and Smart Grid Demonstration (SGDP) Program under The American Recovery and Reinvestment Act (ARRA) in 2009 [3]. Besides DOE, the Electric Power Research Institute (EPRI) launched the IntelliGrid Program which centers on researches on standards, interoperability and cyber security issues in the smart grid environment [4].

TABLE I.
Top Ten Countries for Federal Smart Grid Investment, 2010

Position	Country	Federal Investment in million USD
1	China	7320
2	U.S.	7090
3	Japan	849
4	South Korea	824
5	Spain	807
6	Germany	397
7	Australia	360
8	United Kingdom	290
9	France	265
10	Brazil	204

Powered by all the initiatives taken throughout the globe, smart grid is expected to revolutionize the grid infrastructure in the coming decades. This momentum is creating new challenges regarding increasing penetration of distributed energy resources, storage elements and plug-in vehicles. Also, in response to varying real-time price signal, the consumption pattern is changing [5]. Because the traditional distribution grid is not very capable of coping up with these changes, new technologies in the distribution tier must match the progress on consumer-centric activities in a smart grid environment.

The objective of this paper is to evaluate the technology deployment status of distribution system projects in the U.S. funded under ARRA. It utilizes the publicly accessible 'build metrics' data [6], which have been reported to DOE by various utilities deploying smart distribution equipment. This paper analyzes different aspects of EDS projects on the ground of numeric comparison and presents the findings in an intuitive and interpretable way. The organization of this paper is follows: Section II gives a general overview of the SGIG project categories. The project scale and type of customers served by EDS projects are discussed in Section III. Section IV describes technologies deployed by the EDS projects. In Section V, the program impact is evaluated.

This work was supported in part by the U.S. Department of Energy under Grant# DE-OE0000031.

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II. OVERVIEW OF SGIG PROJECT CATEGORIES

The Energy Independence and Security Act of 2007 charged the DOE with the establishment of the Smart Grid Investment Grants (SGIG) program. DOE awarded all of its grants ($3.5 billion) to 99 recipients under this program to expedite the installation of state-of-the-art information technologies for a more reliable grid and lower the effective energy consumption [7]. Projects under the SGIG program can be classified into five categories as follows:

1) Advanced Metering Infrastructure (AMI): AMI projects install electronic/digital hardware and software like smart meters, home/local area network, meter data management systems, operational gateways, for interval data measurement from customer sites and continuous or intermittent remote communication with a central system through wide area communications network [8,9].

2) Customer Systems (CS): Because of related interests in aiding distributed energy systems, demand response equipment, energy storage devices, plug-in electric vehicles, and microgrids, most of CS projects are coupled with AMI ones. Technology highlights of CS projects include in-home displays, home area networks, smart appliances, web portals and direct load control devices [10].

3) Electric Distribution Systems (EDS): EDS projects involve distribution monitoring, control, and optimization by setting up distribution automation (DA) through supervisory control and data acquisition (SCADA) systems and field DA devices working either autonomously or in linkage with the network center. Other devices highlighting these projects are equipment monitoring, smart relays, communications infrastructure, and distribution management systems [10].

4) Electric Transmission Systems (ETS): ETS projects involve installation of phasor measurement units, phasor data concentrators and visualization tools which are helpful in assessing system risk [11]. Projects in this area also aim at adding smart grid capabilities to the transmission grid through remote sensing, monitoring, data acquisition and retrieval equipment [10].

5) Equipment Manufacturing: Projects in this area produce or purchase equipment, devices, software and communications or control systems to modify the existing system into one with smart grid features.

Some of the participant projects (about 39%, total value-wise) merge the implementation of two or more types of projects as they involve equipment and/or software applications which include more than one topic areas. These projects are called integrated or cross-cutting projects. There is another subset of AMI and CS projects which study the consumers' response to variable time-based rates. DOE identifies this set of projects under the sub-category of 'consumer behavior studies'. Such an effort enriches the industry's understanding of consumer acceptance/ retention to imminent changes in the overall grid operation [12].

Around 57% of all SGIG projects belong to the EDS project area, which is the second largest topic, both according to number of recipients and amount of total fund. Apart from this specific statistical viewpoint of SGIG program, EDS projects are important for that they aim to add greater flexibility to the conventional distribution grid so that it can maintain reliable delivery by balancing between instantaneous demand and supply. These projects mainly address two imperative performance issues of distribution systems in a smart grid environment – outage management and Volt/VAR control. Grid operators also intend to employ other applications like fault detection, islanding and preventive maintenance of equipment through the EDS projects [3].

III. EDS PROJECT PROFILES

The SGIG program funds 57 EDS projects throughout the U.S. with total funding of $1.96 billion from DOE and the recipients. Based on the publicly accessible 'build metrics' data reported to DOE, the total number of customers served by utilities supported by these projects is nearly 34 million. Fig. 1 shows the number of residential customers served by selected utilities under the SGIG EDS projects. The figure reveals that, on average, 85% of the customers (totaling nearly 30 million) are accounted in the residential sector. According to U.S. Energy Information Administration, there were 125.7 million residential customers in 2010 [13]. Extrapolating 12-years of customer data from 1999-2010, it can be estimated that by 2012, the number of residential customers will be around 127 million. EDS projects, hence, supplies electricity to around 23% of residential customers over the U.S.

Another important parameter to identify the size of a utility, besides the customer number served, is the number of distribution circuits under the service territory of that utility. Most of these EDS projects are working on small-scale investments with the limited number of distribution circuits. However, in total, the projects cover around 32 thousands of distribution circuits which again represent 20% of the total distribution circuits in the U.S. [14].

For the numeric comparison presented in the next section, this study classifies EDS projects according to their number of substations at the distribution level in four different groups:

- *Very Small* (≤50 substations)
- *Small* (>50 but ≤100 substations*)*
- *Medium* (>100 but ≤500 substations)
- *Large* (>500 substations)

The size of a utility acts as a vital factor concerning automating the distribution system. Fig. 2 shows the distribution circuits in each utility along with corresponding substation numbers for four abovementioned groups. The slope of an individual line in this figure gives a rough idea of how branched the system is, as a typical residential grid is radial. This piece of information is handy when comparing the number of installed DA devices between two systems with similar number of distribution substations.

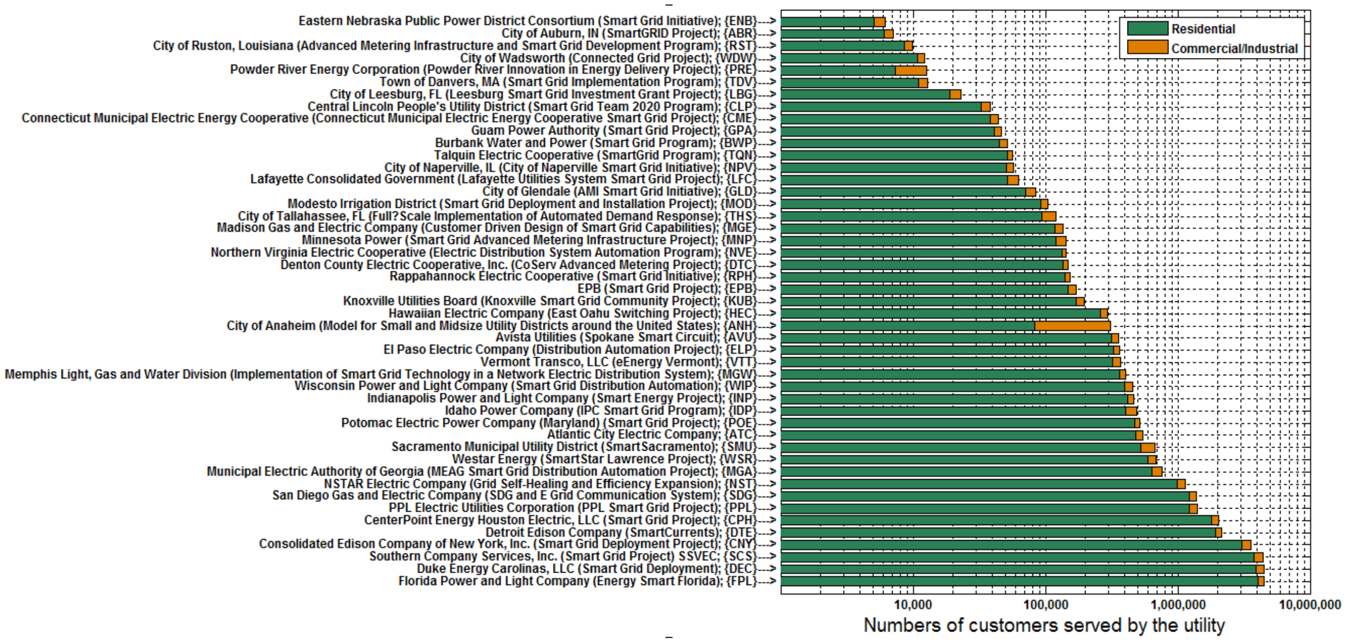

Fig. 1. Customer profile of EDS projects.

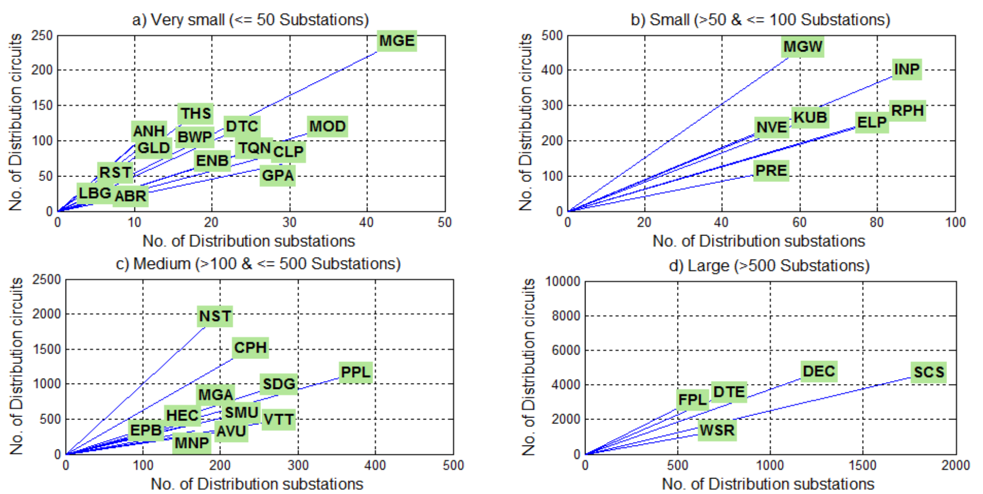

Fig. 2. Number of Substations and Distribution Circuits for: a) Very Small, b) Small, c) Medium and d) Large sized utilities.

IV. Technologies Deployed by EDS Projects

To enable a smarter and automated distribution system, several distribution-level technologies can be deployed. Such a system typically signifies monitoring and controlling the distribution grid automatically. Distribution automation (DA) is the utilization of SCADA systems through realization of field DA devices that integrates the information about real-time operation [15]. In the context of this work, DA generally refers to substation automation and/or feeder automation. This section reviews some of these specific technologies deployed by EDS projects throughout the U.S.

Distribution Automation (DA)

A broad definition of DA includes any automation which is used in the planning, engineering, construction, operation and maintenance procedure of electric power distribution system along with interaction with the generation and consumption networks [16]. Incorporating DA can result in significant cost savings through measurable improvements in operational efficiency, reliability, and service quality and energy conservation [17]. There are three fundamental components of DA that are identified in the literature: (a) distribution SCADA or distribution management systems (DMS), (b) data communications infrastructure and (c) various field DA devices implementing different DA functions, like Volt/VAR control, fault detection or minimizing harmonics.

SCADA

SCADA systems are highly distributed systems used to control geographically dispersed assets, often scattered over thousands of square kilometers. They are typically found in distribution systems where a control center monitors and controls field site devices over a long distance communications network. Field devices control local operations such as opening and closing breakers, collecting data from sensors and monitoring for alert conditions [18]. A smart grid requires that the distribution utility has SCADA that supervises all of its distribution substations to ensure uniform reliability through the entire distribution network.

DA devices

These devices are at the end of the SCADA system, which implement certain DA functions being centrally controlled or driven autonomously. Such DA functions are largely designed to either ‘monitor’ some regular or emergency situations or ‘execute an action’ being locally or centrally driven. DA devices can again be classified on whether they are located in the substation/feeder level (e.g., voltage regulators, feeder monitors, automated capacitors, etc.) or in the end-user level (e.g., smart meters, load control devices, remote connect/disconnect services, etc.). EDS projects are mostly concerned with substation and feeder automation devices. Table II summarizes some general features of DA devices popularly used by SGIG EDS projects.

TABLE II.
DA DEVICES DEPLOYED BY EDS PROJECTS

DA devices	Functions	Benefits
Automated Feeder Switches	Primarily locates a fault, isolates the faulted segment of the feeder and restores service if possible.	Reliability improvements, labor savings, optimal network configuration [19]
Automated Capacitors	Responds to the sagging voltage at its location and provides VAR by switching capacitor banks	Volt/VAR control, adjusting power factor [20]
Automated Regulators	Monitors the voltage at its location and changes the tap settings in the transformer secondary to adjust the voltage at the primary end.	Maintain voltage at a pre-programmed level [21]
Fault Current Limiters	Limits the amount of current flowing through the system during a fault by introducing a larger impedance by High-temperature Superconducting techniques or solid- state switching	Enhancement of system safety, reduced wide area blackouts [22]
Smart Relays	Monitors voltage, current, and frequency in the system, sends control signals to breakers and switches; also stores and processes data about system conditions.	Fault and overload protection for transformer, automatic load shedding, as PMU’s [23]
Remote Fault Indicators	Detects faults in the distribution network by measuring current threshold, zero/negative sequence transients using combined or synchronized methods and communicates to the control center	Increasing operational efficiency by reducing localization or sectionalization time in fault detection, save labor and time [24]
Monitoring System (Trans-former/line, feeder	Uses different sensing technologies to measure the voltage, current and loading condition at the sensor placement node.	Monitoring loads, regulating equipment health inspection, detecting faults which do not involve too high of current

V. PROGRAM IMPACT BASED ON TECHNOLOGY DEPLOYMENT STATUS

One way to assess the SGIG program impact on the recipient projects is to measure the headway they have made until now. This study analyzes and compares the projects’ impact or progress in a quantitative way.

A. *Project Progress by Percentage of DA Implementation*

A very simple way to quantify the EDS project progress is to examine the percentage of the system under DA. The closer it is to 100%, the more capable the utility is to fit in a smart grid system. Fig. 3 shows the percentage profile of the projects with DA after SGIG program was implemented. The percentage value denotes the ratio of the number of substations with DA to the total number of substations. From Fig. 3, DEC in *large* group, RPH in *medium* group, MGW and NVE in *small* group and BWP in *very small* group have made the most out of it until now, as long as setting up DA in substations is considered. Other projects which are worthy to be mentioned would be SMU, MNP and ELP. Please see the list of abbreviations in Fig. 1.

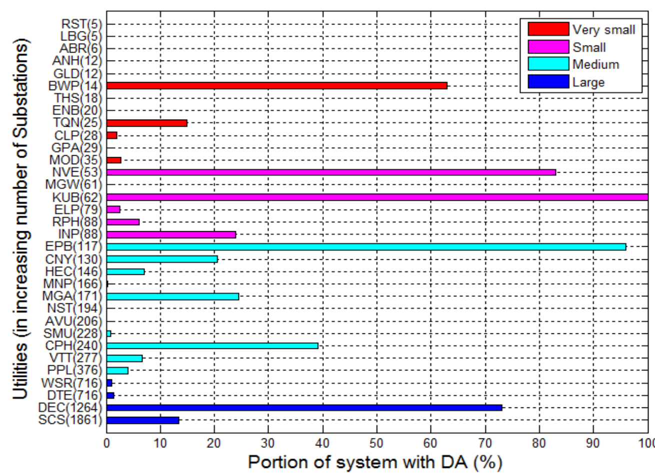

Fig. 3. Percentage of DA implementation in EDS projects.

B. *Project Progress by Percentage of SCADA Implementation*

Unlike the DA profile, the SCADA implementation profile has a higher number of long peaks, as depicted in Fig. 4. It implies that greater numbers of projects are successful in covering their substations with SCADA. In fact, there are only a few projects which lie under the 20% mark. In the *very small* group, among the 4 projects above 80% line, GLD and BWP have a slightly higher number of circuits corresponding to similar number of substations than ABR and LBG, according to Fig. 2. So GLD and BWP can be regarded as more fruitful than ABR and LBG. Similarly, in the *small* group KUB, PRE, NVE; in the *medium* group CPH, AVU, NST and in the *large* group WSR, SCS are the projects which have almost covered their entire distribution system with SCADA control.

C. *Project Progress by DA Devices Deployed*

The DA percentage profile can be elaborated if we observe the number of DA devices installed in the system. Fig. 5 shows the DA device distribution for the *very small* group.

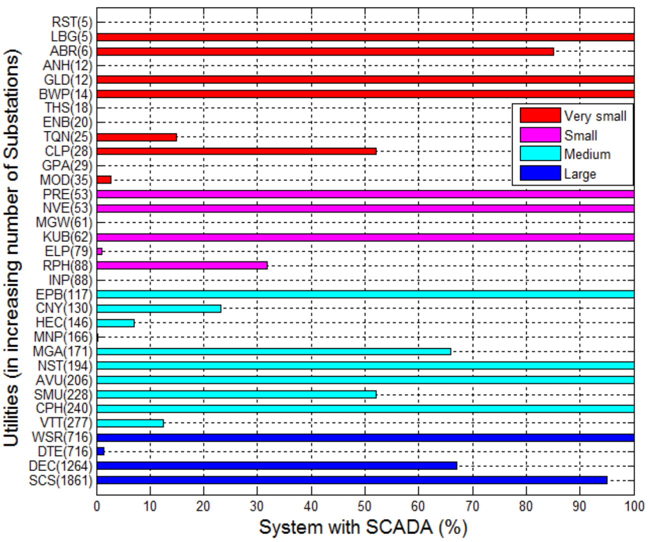

Fig. 4. Percentage of SCADA implementation in EDS projects.

ENB made good progress with about 150 devices for 68 distribution circuits. RST and BWP has less number of devices installed, but they also have achieved a high impact level as their distribution circuit number is low, 18 and 118, respectively (See Fig. 2). DTC has a good blend of devices unlike the ones discussed previously and therefore is expected to make their distribution network more reliable and secure.

In the *small* group, as shown in Fig. 6, obvious peak happens for INP which has 400 distribution circuits. NVE, on the other hand, is also on the high-impact level, i.e., highly effective, for it has 235 distribution circuits. KUB lies in the medium-impact level as it has about 100 transformer monitors for its system of 259 circuits.

The *medium* group shows a very high peak for CNY, with 14,206 of the listed devices. Apart from this project, EPB also lies in the high-impact level, as seen in Fig. 7. For installing around 800 devices, AVU qualifies for medium-impact level, while NST does not as it has 1,960 distribution circuits whereas AVU has 330 circuits.

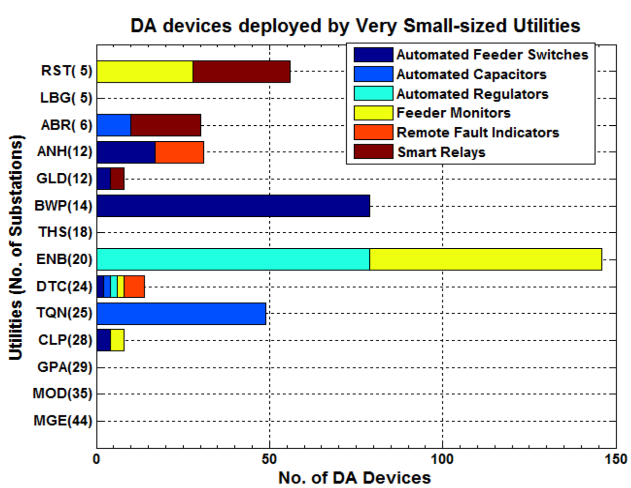

Fig. 5. Number of DA device deployed by very small-sized utilities.

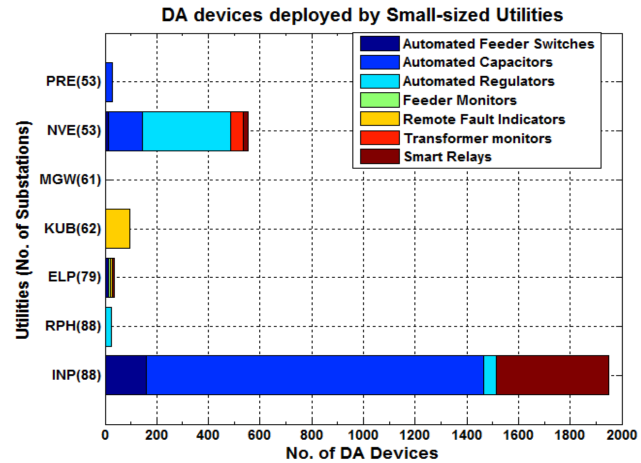

Fig. 6. Number of DA device deployed by small-sized utilities.

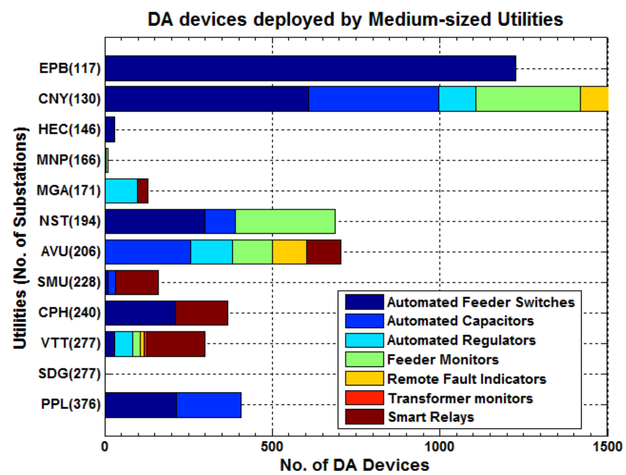

Fig. 7. Number of DA device deployed by medium-sized utilities.

Finally, in the *large* group, FPL and SCS are at high-impact level as they have quite ample amount of DA devices for their big systems as depicted in Fig. 8. DEC is considered in the medium level of impact not only because it has less amount of devices, but also because it has a similar number of circuits as in SCS.

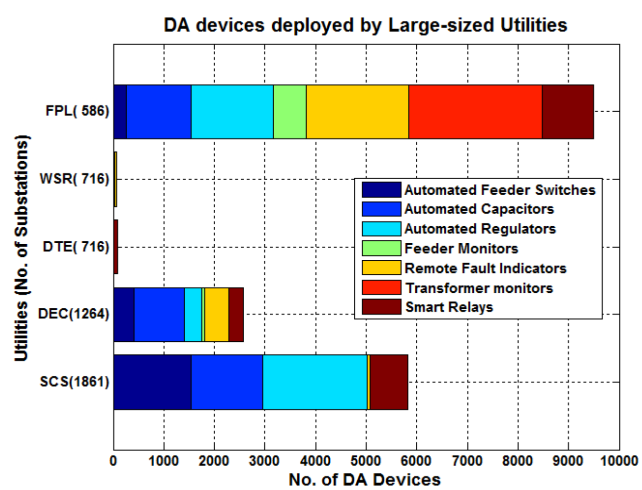

Fig. 8. Number of DA device deployed by large-sized utilities.

VI. Summary

This paper presents a quantitative assessment of the progress of SGIG EDS projects in the U.S. Progress of these DA projects are evaluated by the number of DA equipment adopted and in operation in the system. By analyzing project outcomes until the second quarter of 2012, DA and SCADA percentage profiles reveal that most projects have fully covered their respective distribution networks with SCADA but have yet to reach the same place with DA coverage. Overall, this paper is expected to give an insight into the EDS project progress through quantitative studies. While higher-level picture of overall SGIG program status is available, this study puts forth the data in a systemized method and showcases simple forms of project comparisons. The quantitative evaluations as presented here can be useful to identify the most impactful EDS projects in smartening the distribution grid. A similar kind of analysis can be applied to other SGIG projects and their assets which can produce even more constructive insight into the status of the federal smart grid investments in the U.S.

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Recommended Revisions:

Reviewer 1:

Thank you for your valuable suggestions. The paper has been revised according to your comments, as follows:

Comments & their answers:

The paper presents much information that is of interest, but it also presents information that is not relevant, and it presents information in a confusing way.

In the first section, the material that has to do with the expenditures in the rest of the world is not relevant to a paper about expenditures in the US. While it may be used as background, it should be considerably shortened. Perhaps much of it could be summarized in a table. The material I Section 2 that is not to do with EDS is not too long, and can remain.

The introduction was re-written according to the suggestions.

The size classification Very Small . . . Large does not allow for utilities with 50 or 100 or 500 substations.

It has been corrected.

The graphs in are in need of much work.

Fig 1 should be re-ordered so that they are in order of the number of customers served by the utility, or maybe by the number involved in the SGIG. It may be that in a large utility these may not be the same, but the paper has not informed us one way or the other. Also, since other figures have the display grouped by size, this figure should use the same grouping. That may possibly naturally fall out of organizing by number of customers.

This figure has been replaced and it's organized in increasing order of customer numbers in semilog scale. As this picture shows an overall picture of the outreach of EDS projects, no classification is done for this figure.

Fig 2 should be reorganized as follows. (1) The descriptions Very Small . . . Large should be placed where the letters a) . . . d) are presently placed. It will save the reader the trouble of following this trail. (2) the axes should be scaled so that a line slope in terms of circuits-per-substation has the same geometrical slope on each graph. At present this relationship holds for a) and b), where corner to corner the slope is 250/45 = 5.55 = 500/90. For c) the value is 3000/400 =7.5 and for d) it is 2.5. Making them all the same would allow the reader to see the similarities and differences. Having them different makes comparison impossible.

Min and max slopes in each graph are approximately as follows:

a) 2.3 – 10
b) 2.1 - 7.5
c) 1.9 – 20
d) 1.8 - 5.3

Evidently there is not much difference at the low end, and while CNY has a slope of 20 in c), it seems to be an outlier.

Fig 2 is corrected as per the suggestions.

Fig 3 and Fig 4 should be made to look more like Fig 1 (or vice versa) by changing the width of the bars in the bar chart. Fig 4 is a good candidate for a table instead of a figure.

Fig 3 and 4 are redrawn with increased bar width and are reordered according to number of substations.

Fig 5 through 8 should be redrawn, rotated 90 degrees clockwise, so the bars are horizontal and the graphs are more like the other figures.

The figures have been redrawn according to the suggestion.

Considering the amount of data presented, the conclusions seem weak. They can be strengthened.

Conclusion has been re-written.

The writing should be checked by someone with better language skills. The paper is patchy in its quality if English, and quite hard to read in places.

Sometimes the English seems illogical, as in this from the SCADA section: "Unlike the DA profile, the SCADA implementation profile has higher number of long peaks, as depicted in Fig. 4."

The paper has been revised to address this comment.