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Advanced Metering Infrastructure and Customer Side System

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Abstract Electricity Grid relies on relatively outdated technologies even after significant advancement into the Information Technology Age. The Smart Grid is a Comprehensive Plan to Computerize and Optimize the existing Electrical Grid. Smart Grid is a system that deals with the modernization of the Grid from Generation to End Customer. The research paper deals with two modules of the Smart Grid Network, i.e. Advanced Metering Infrastructure (AMI) and Energy Management of The Customer Side Systems (CS). Smart meters enable two-way communication between the meter and the Utility. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an Advanced Metering Infrastructure (AMI) differs from traditional Automatic Meter Reading (AMR) in that it enables two-way communication with the meter. The National Electric Regulatory Authority (NEPRA), Pakistan, has allowed consumers with surplus power to sell their electricity to the distribution companies according to the Net Metering Regulations, 2015. Keeping in view the growing market need in Pakistan and World Wide, the research paper focuses on providing Bi-Directional Metering and Remote Data Transfer to the Utility/Distribution Company, for Demand Response and Billing, along with billing on short time interval profile for On- and Off-Peak Billing.

Keywords: Smart Grid, Electrical Power System and Policies, Embedded Systems, Electronics and Applications, Information and Communication Technologies

I. INTRODUCTION

Power Grid Modernization is a global phenomenon and a requirement. In recent decades, advancement in Information Technology has led to the growth or demise of many industries. There is an ever growing demand in electricity, however, electric utility systems are still largely operating today as they were operating in the early 20th century. The basic method till today is the same that the central generating stations generate electric power that is transmitted via high voltage transmissions lines to local community substations. Onwards, several primary distribution lines extend from each substation, feeding a network called the grid.

Smart-Grid refers to the computerization and automation of the existing traditional distribution network. Until recently, there was no cost-effective manner in existence to computerize the grid, via introduction of communication and information technology into the grid. But the modern advancements in communication and information technology over the recent times, as well as the increasing demands society is placing on the grid requires steps to be taken requiring a cost-effective, reliable and permanent solution. The smart-grid fulfills these requirements to quite a large extent. The Smart Grid is a whole package that includes an upgrade and computerization plan for all stages from generation to consumption. The idea of Distributed Generation is a critical component of the Smart Grid Network and allows the Government, Utility and Consumers to play an important part towards the contributing in the Energy Mix for the Power Sector and reducing the stress on the Power Generation Sector by making even the end consumers stakeholders.

II. FEATURES OF SMART GRID TECHNOLOGY

The main focus areas of the Smart Grid Network are shown as follows

- Advanced Metering Infrastructure (AMI)
- Customer Side Systems (CS)
- Demand Response (DR)
- Distribution Management System/Distribution Automation (DMS)
- Transmission Enhancement Application (TEA/TA)
- Asset/ System Optimization (AO)
- Distributed Energy Resources (DER)
- Information and Communication Integration (ICT)

III. ENERGY MANAGEMENT SYSTEM AND SMART METER

Two of features of Smart Grid, i.e. Advanced Metering Infrastructure and Customer Side Systems are discussed. These mentioned modules have been focused upon for the specific reason that despite the fact that these are one of the most highly researched and implemented modules of the Smart Grid Network all over the world, unfortunately these projects are not being focused upon in Pakistan. We aim to present a cost-effective solution to design a technology that could achieve the basic motives of the aforementioned modules. The Distribution Network across Pakistan is relatively operating on outdated technologies of the mid-20th century. This presents us with the opportunity to explore and to provide a solution tailored for Pakistan with the aims of implementing Bi-Directional Metering and Residential/Commercial Energy Management System. This solution would provide benefits to both the Utility and the Consumers, providing consumers with a new tool of Energy Management and Short time interval Energy Consumption Profile view of the electricity consumed. The Utility Sector is benefited on multiple levels. The provision of the Smart Meter allows the Utility On- and Off-Peak Billing, which would allow the Utility systems to reduce On-Peak timing demand. The National Electric Power Regulatory Authority [NEPRA] Pakistan has already provided the tariff structure for Off and On-Peak Billing as well as for Bi-Directional Metering for the Distribution Companies according to the Net Metering Regulation, 2015.

The Short time interval Energy Consumption Profile billing information can provide the Utilities with comprehensive view of the consumption pattern of the consumers enabling the utility to note the highest and lowest peak demand patterns, that have been previously based on extrapolation, theoretical calculations and models. Such knowledge would allow the utilities to plan ahead as per the requirements and reduce their Outage Dollarization values. It allows the Bi-Directional Electricity Billing. Bi Directional billing is a relatively novel concept world-wide. It allows the consumer to upload the electricity generated by the Renewable Energy Sources (installed at the distribution side by the consumer), into the National Grid, or the electricity Distribution Grid, with the units uploaded into the grid at the predefined rates by the Regulatory Authority or the Distribution Company that would be buying the electricity being uploaded by the consumer. The incentive for provision of Bi-Directional Electricity Meters is enormous for the Utility and the Consumer as it benefits both parties in the long run, but would be a capital intensive solution in the short run.

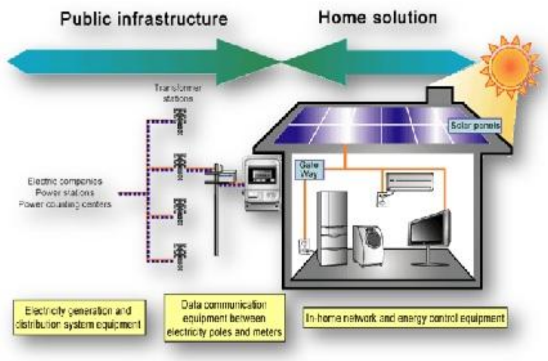

Figure-1: Division between the Public Infrastructure and our solution

IV. Advanced Metering Infrastructure Projects in Pakistan

To date there have been 3-Pilot Projects for AMI initiated in Pakistan.

1. Multan Electric Power Company (MEPCO), in-coordination with USAID, 200 Smart Head End System installation.
2. Peshawar Electricity Supply Company (PESCO), in-coordination with USAID, 200 Smart Head End System installation.
3. K-Electric (KE), itself is currently implementing two pilot projects for Advanced Metering Infrastructure [AMI] and Network Management System [NMS]

− North Karachi – Cluster 1 – Project Implementation on 9 Feeders

− Gulistan–e-Johar – Cluster 2 – Project Implementation on 3 Feeders

V. Project Models

The Smart Meter and Home Energy Management Modules are interconnected and sends the data to the Data Processing Unit.

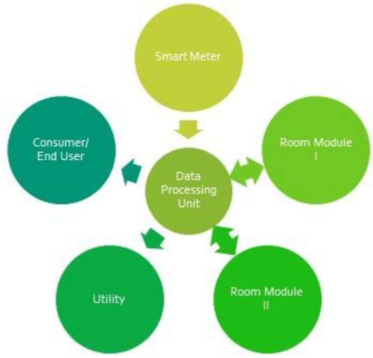

Figure-2: Connectivity of the different Modular Division of the Project

VI. Project Design

The research project design has been divided into two separate modules, i.e. Customer Side System and Advanced Metering Infrastructure.

The Project has been divided and defined as per its modular approach. The basic working principle of the project is that the Customer Side Systems would consist of two modules, i.e. Room Module and Data Processing Unit and a separate Advanced Metering Infrastructure Module, linked with the Data Concentrator.

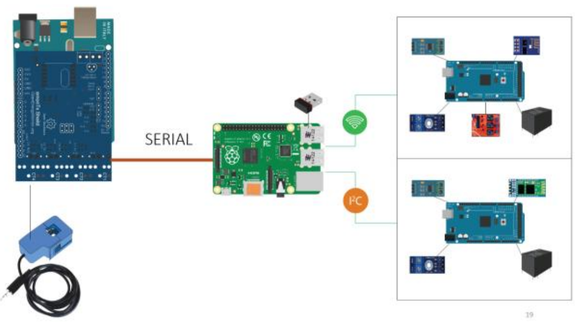

Figure-3: Complete profile view of the connectivity of Smart Meter and Room Modules with Data processing Unit

A. Room Module

The Room Module would be designed as non-intrusive module not requiring alteration of Residential/Commercial Electrical Wiring Network. The purpose of its design would be to provide Remote Switching application for the loads inside the room, i.e. ACs, lights, fans. The aforementioned module would be a complete packaged solution that would be installed at a specific point in the room and all the electrical network of the room would be plugged into the module. It would have built in Communication Modules that would be interfaced with the Data Processing Unit installed at a central location across the house. The Data Processing Unit would be the Controlling Base for all the installed Room Modules and both the Internal and External Communication Network.

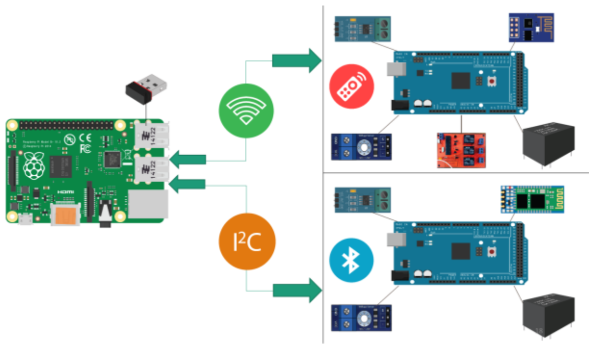

Figure-4: 2 different Room Module Designs with different communication Protocols

The module design would require the live wire to be extended from the already installed switch board in the room and be extended to the module. The Module is being designed with the approach that it could be installed at a certain height away from the reach of children and from the risk of water contact. The switches installed in the switch board would work as the backup hard switches that would also allow us direct manual control in case of any emergency.

The Design of the Room Module is being kept simple and less complicated to reduce the cost. The relays are being used to control the on and off circuitry via wireless remote device. After research and detailed analysis based on features and our requirement for communication which includes Infra-red, Bluetooth, Xbee Pro Modules, RF, Wi-Fi and GSM, the use of Wi-Fi modules was selected for the reason of ability to create a LAN network and allows easy one-to-many and many-to-one connection. The use of free band and standard encryption protocols reduces the implementation cost and prototyping cost of the project.

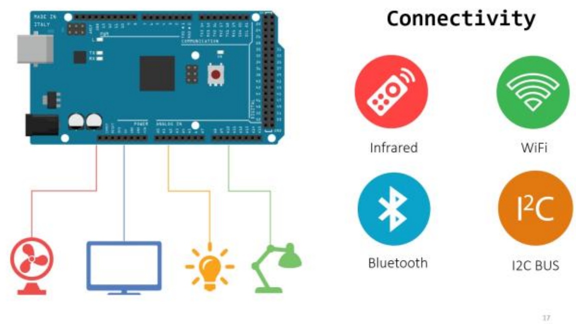

Figure-5: Room Module Communication Protocols

B. Data Processing Unit

The Data Processing Unit is designed as the Command and Control System. It would be communicating and controlling all the Room Modules as well as Data logging and running the Data Analytics. The Data Processing Unit would also handle the Communication of the Consumer to the Devices along with notification of the Power Consumption by the consumer to both the Utility and the Consumer.

The Data Processing Unit module is designed with a Micro-Processor for data logging and running of the data analytics to provide a complete analysis of the Energy Consumption and Losses in the Home Network. The information would be uploaded in an open source cloud management system using a Wi-Fi module connected to a Wi-Fi router providing access to internet based Cloud Management System, accessible to both the consumer and the Utility. Online storage of the data accessible to both the consumer and utility caters the task of two way communication required as a part of Smart Meter and Energy Management System. A single Data Processing Unit is being designed to cater for the Smart Meter and the Energy Management System to make the equipment cost-effective and affordable as well as reducing the prototyping cost.

C. Advanced Metering Infrastructure

The Advanced Metering Infrastructure major features include Remote Energy Consumption Record Transfer to Utility/ Distribution Company for billing purposes, followed by Energy Consumption Data Logging for Data Analytics and includes Bi-Directional Energy Meter. It allows the consumers and Utility to utilize the feature of Bi-Directional Energy allowing the user to both Upload and Download Energy to and from the National Grid respectively. The Advanced Metering Infrastructure also provides the consumer with the Energy Units consumed so as to allow the consumer to successfully manage the energy consumption. The meter would store the Data in the Data Processing Unit.

The AMI includes Smart Meters as the major component. The basic features that need to be encompassed into smart meter are two way communication, bi-directional metering, on and off peak billing, data logging, remote communication and data storage. The Smart Meter Design includes current sensing clip and a metering shield for the calculation of Real Power, Reactive Power and Power Factor the base values that are required for all the calculation and running of the data analytics formula. The Data from the Meter would be transmitted to the Data Processing Unit and from there onwards, it would be uploaded onto the cloud management system for access to both the consumer and utility.

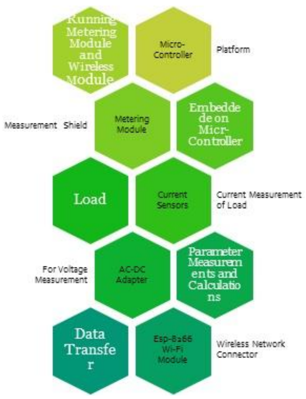

Figure-6: View of Smart Meter Components and their functionality

VII. DATA ANALYTICS

Applicable in case of application of AMI modules throughout a specific region connected to the Pole Mounted Transformer (PMT) and the Residential/Commercial Units under analysis.

Phase balancing: If power factor of all the three phases are same that indicates the phases are balanced as power factor is the cosine of phase difference.

Voltage analysis: If load voltages of all the three phases are same that indicates the voltages are balanced.

Load Balancing: If the line currents of the three phases are not same that means the load unbalancing has occurred and thus some current must be flowing through the neutral otherwise the neutral current must be zero.

Ideally,

$I_1<0 + I_2<120 + I_3<240 = I_N = 0$

Line loss analysis: knowing the conductor material (resistivity), its length to which it is extended and its cross sectional area the total resistance of the conductor can be known. Multiplying this resistance with square of current, line loss can be calculated.

Line loss= I^2R where R=PL/A

Transformer load management: If the customers connected to a particular PMT are continuously facing tripping or explosions of PMT it means that the transformer is running on overload. Thus by summing up the maximum demands of the consumers a PMT should be installed of such rating that it does not trip.

Customers Max Demand < PMT Rating

Unit Difference Analysis: The difference of power provided by the PMT to a particular area and the sum of total power consumed by the customers connected to that PMT. If an enormous difference is observed in these two measurements then that means the company is facing loss.

KW PMT - KW Consumer = Unit Difference

Short circuit KVA: The magnitude of short circuit fault current multiplied by voltage of the line before occurrence of fault can be used to calculate the short circuit KVA of the asset. And thus we can know the capacity of the instrument

Short Circuit KVA= Post fault current * pre fault voltage

Power factor analysis: Lesser power factor causes burden to the utility company and also to the consumer as consumer always pays for active power consumption lesser power factor indicates that it is using more reactive power. The data indicates the different values of power factors, it is thus easy for the company to impose penalty on the consumer if its power factor is less than 0.85.

Outage minutes validation: The data can provide us with the duration of outage, formula for outage duration can be expressed as,

Duration= Power Up (time/min) - Power Down (time/min)

Outage Dollarization: The amount of revenue lost by the utility due to outage. For example, 4000 customers are affected due to outage of 4 hours with 15 Rs per unit cost and an average of 1.5kWh per house. The revenue lost by the company in that 4 hours will be 3lac 60thousand rupees.

Outage Dollarization (Rs) = No. of outage hours*no of consumers under outage*per unit cost*average energy consumption rate

Load profile analysis: Load profile analysis can be performed by the voltage, active and reactive power consumed by the system by constructing the graph of present values and indicating the Max Demand, Utilization factor etc. concerning the system.

Demand Factor: Consumers do not use all the devices at full load simultaneously. Maximum demand for each consumer is therefore less than total connected load.

Demand Factor= Max Demand/ Total connected load

Demand Factor is usually less than 1.

Average Load or Average Demand: From the data average demand can be calculated in a particular time interval. As it is the ratio of energy consumed in a given time period

%Av. Load= Energy Consumed in a given period/Hours in that time period

Diversity Factor: Maximum demands of individual consumers are not likely to occur simultaneously, so there is diversity in occurrence of load. Large diversity factor has the effect of reducing the maximum demand, consequently lesser plant capacity is required, thus capital cost is reduced and the cost of generation is also reduced.

Diversity Factor= Sum of individual maximum demand/coincident max demand of whole system

%Utilization Factor\ = Maximum Demand/Rated System capacity

VIII. RISK ANALYSIS AND MITIGATION

Every project has some risks associated with the construction of the project hardware, software and communication procedure. The analysis of the project design has some evident risks associated in the hardware and communication of the project. Since the project is directly dealing with the Distribution Grid Network having 220V in both the Metering and the Customer Side Energy Management System. Moreover, the short-circuiting, current surges, voltage fluctuations and overheating issues, usually associated with the extreme weather conditions, sharp demand fluctuations, especially in the summer season and high losses in the transmission and distribution network. The high load-shedding usually in the summers is also deemed as the risk to the System Modules.

Several system health and safety protection precautions are planned to be included into the system, for risk mitigation, such as inclusion of circuit breakers, fuses and voltage regulators to protect against the current surges, voltage fluctuations and short-circuiting.

To protect the module against the extreme weather conditions the Smart Meter, Room Module and the Data Processing Unit would be packed inside proper casing with a cooling fan installed to avoid overheating condition.

The usage of cheaper and free band commercially available communication modules poses a huge risk of the services provided by the module to cyber-attacks and hacking which could in return pose a severe risk to the user for falling of personal data into wrong hands and could be misused.

IX. MATERIAL AND METHODS

The Smart Meter is a micro-controller based prototype which consists of metering module and current transformers. The Smart Meter sends the data to the Data Processing Unit (DPU) via a serial link in order to maintain data security and a dedicated link. In the HEMS Room Modules are designed on a micro-controller with Multi-Protocol System allowing remote control to the user and wireless/ wired data transfer to the DPU so as to ensure future extendibility of the system and compatibility with multiple systems. The DPU, based upon a micro-processor, acts as the central Hub allowing both the data storage and uploading of the data to the cloud storage providing access to the utility and consumer.

X. ADVANTAGES

1. High Untapped Potential in Pakistan
2. Cost-Effective
3. Reliable
4. Reduces the Chances of Power Theft on the Distribution Side upon the implementation of the Module completely in the Residential/Commercial Unit in full capacity
5. Reduction in Cost incurred in the Manual Billing Procedure and Man hours Employed
6. Provides Insight to Customer and Utility regarding Energy Consumption
7. Remote Data Communication of Energy Consumption to Utility and Consumer
8. Inexpensive
9. Non-Intrusive in Residential/ Commercial Electrical Wiring Network
10. Allows Previous Demand Pattern and Consumption value Retrieval
11. Remote Communication of Billing Information to Utility and Consumer
12. Provides Remote Control of Appliances connected on the Energy Management System
13. Allows for Bi-Directional Energy Transfer. Recently approved in Pakistan by NEPRA in the Net Metering Regulation, 2015, issued on September 3, 2015
14. Enables On-Peak and Off-Peak Billing
15. Promotion of Renewable Energy Resource Implementation on Distribution Side by Consumers
16. Profitable for Long-term Implementation. Low Total Ownership Cost (TOC).

XI. CONSTRAINTS

The limitations and constraints faced in the project and its implementation are as follows

17. High Initial Investment Cost to benefit from complete range of features
18. Long-term Payback Period
19. Heavy Dependency on Wireless Communication Systems and disruption can adversely affect the Chain of Communication between the Internal Systems and External Systems
20. Long Duration Power Outage can cause the system to shut down.
21. Security of Wireless Data Communication can compromised due to usage of commercially available Free Band Communication Modules
22. Vulnerable to extreme Power Surges and Voltage Fluctuation.
23. Lack of Pilot Projects Implementation and Testing across Pakistan.

XII. RESULTS

1. Design of a Three-Phase Bi-Directional Smart Meter, which allows both the Uploading and Downloading of the Electricity to and from the National Grid in accordance to the NEPRA Policy.

2. Establishing Multi-Protocol Link which includes Wi-Fi, I2C, Serial, Bluetooth and Infra-red

3. Data Storage on SQL Database and Uploading to cloud storage for billing and study Energy Consumption Profiles

4. Enabling Remote Switching of Appliances by the user to fully utilize On- and Off-Peaking Billing Hours.

The Proposed System is an indigenously developed Market Solution for Pakistan enabling the utilization of two of the most highly implemented features of the Smart Grid Technology in Pakistan. This system allows Pakistan to compete in the spheres of Smart Grid implementation along with the Developed and developing nations of the world who have focused the efforts towards the implementation of the Smart Grid Features.

Smart meter results:

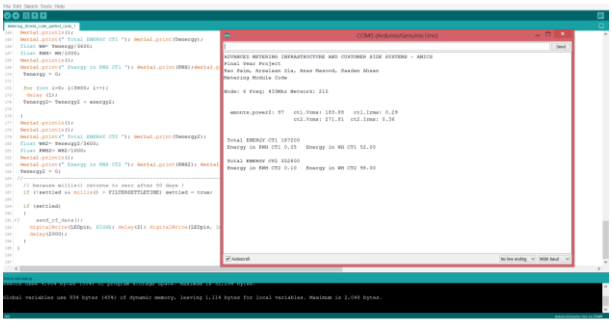

Figure-7: View of Coding and Results

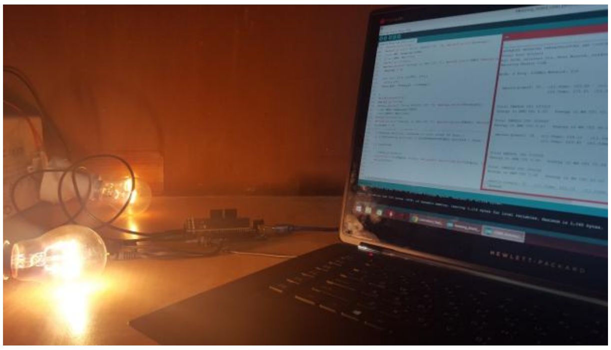

Figure-8: View of Load Connected to the Metering module and display of readings

←T→	Date	Time	Power	PowerFactor	Voltage	Current
Edit Copy Delete	2016-01-01	2016-01-01 09:00:00	3.5	70	240	14.5
Edit Copy Delete	2016-01-01	2016-01-01 09:30:00	3.5	70	240	14.5
Edit Copy Delete	2016-01-01	2016-02-01 05:16:00	2	70	240	10.4
Edit Copy Delete	2016-01-01	2016-02-01 05:16:14	2	70	240	10.49

Table	Action	Rows	Type	Collation	Size	Overhead
Meter_D	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	16 KiB	-
Meter_U	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	16 KiB	-
room_module_1	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	32 KiB	-
room_module_2	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	32 KiB	-
4 tables	Sum	16	InnoDB	latin1_swedish_ci	96 KiB	0 B

Figure-9: SQL Database of Data Processing Unit

XIII. CONCLUSION

The Project has tremendous potential not only in Pakistan, but also world-wide with heavy investments in the field of Smart Grid Technology especially on the Distribution Side by the Developed Nations, i.e. UK, USA, European Union and the Developing nations, i.e. India, Bangladesh, China, Philippines, etc.

The Europe's 2020 Vision of converting the traditional Electricity Grid to Smart Grid is also in-line with the proposed design. The magnanimity of the idea can be imagined by the fact that United Kingdom has alone invested £ 11 Bn. in implementation of the Smart Meters [ref. E&T Journal June 2015 issue vol1.]. It is believed that Pakistan with a population of 180 million and an estimated average of 2o million Residential/Commercial consumers has a vast untapped potential for the implementation of such a state-of the-art technology with numerous benefits in both short and long term. The low long-term cost of the project can be lucrative for both the Utility and Consumers to invest in this sector and to cater for the growing disparity between the Electricity Demand and Consumption in Pakistan that has been adversely affecting our growth and development for the past few decades.

The Proposed System is an indigenously developed Market Solution for Pakistan enabling the utilization of two of the most highly implemented features of the Smart Grid Technology in Pakistan. This system allows Pakistan to compete in the spheres of Smart Grid implementation along with the Developed and developing nations of the world who have focused the efforts towards the implementation of the Smart Grid Features.

XIV. REFERENCES

[1] Office of Electrical Delivery and Energy Reliability, http://energy.gov/oe/services/technology-development/smart-grid

[2] National Energy Technology Laboratory, http://www.netl.doe.gov/research/energy-efficiency/energy-delivery/smart-grid

[3] US Department of Energy, https://www.smartgrid.gov/

[4] Department of Energy & Climate Control, UK https://www.gov.uk/government/publications/smart-grid-forums-smart-grid-vision-and-routemap

[5] Ofgem, UK https://www.ofgem.gov.uk/electricity/distribution-networks/forums-seminars-and-working-groups/decc-and-ofgem-smart-grid-forum