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Smart metering and big data analytics in smart grid

Smart metering (SM) provides value added features such as automated billing, customer relationship management when compared to existing metering system. In this paper, capabilities, features, benefits and performance factors of SM are discussed. Various cyber attacks on smart meters and implementation of big data analytics on smart meters are also detailed.

Keywords: Smart grid, smart metering, cyber attacks, big data analytics

1.0 Introduction

A smart metering infrastructure (SMI) is an electronic system that is capable of measuring energy consumption, which provides more information than a conventional meter, to transmit and receive data through electronic communication [1]. Smart electricity meter data analytics can assist the distribution network operators in assessment and network management. A common process for data collection, communication and analysis leading to decision support for smart metering is discussed [2].

Advanced Metering Infrastructure (AMI) attempts to reduce cost and increase electricity reliability through the deployment of smart meters at consumer locations. These meters provide the customer with control over consumption and the ability to selectively use electricity when prices are low. Utilities benefit from being able to remotely detect outages, perform remote meter readings and offer prepaid options to customers. AMI also enables demand side management (DSM) which exercises direct/indirect control over consumer power consumption. This allows the increased integration of green technologies due to their inconsistent production [3].

AMI creates a two way communication network between smart meters and utility systems, as well as the integration of advanced sensors, monitoring nodes, and data management systems. AMI enables the collection and distribution of metering data information. AMI framework lay down the foundation for a two way communication between a meter and a central head end system (HES). AMI system is expected to support the broad features such as: (i) Automated meter reading of the energy, load survey data, instantaneous parameters and event data from meter to HES, (ii) Demand response facility to disconnect load on predefined variable load settings, (iii) Remote configuration as well as remote firmware upgrade without affecting metrology of the meter, (iv) Enable the consumer to read energy consumption, real time energy prices and control of load in their home display and other home area network (HAN) devices.

Two way communication between meter and HES can be achieved in following two ways: (i) Meter to HES directly over GSM/GPRS etc, (ii) Meter to data concentrator unit (DCU) over RF mesh/PLCC and from DCU to HES over GSM/GPRS etc. Table 1 shows comparison of communication technologies/protocols for AMI of smart grid.

The current metering environment is expected to have the following capabilities to be categorized as smart meter [2] as mentioned below:

- Real time capture of electricity usage and possible distributed generation.
- Providing the possibility of remote and local reading of the meter.
- Remote controllability of the meter, enabling control and even cut off of the supply.
- Possibility of linking to other commodity supply. (gas, water).
- Ability to capture events such as device status and power quality.
- Be interoperable within a smart grid environment.

2.0 Components and building blocks of smart metering infrastructure

AMI consists of hardware and software system having the main components as: (i) The meter, (ii) A communication

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Table 1: Comparison of communication technologies/protocols for AMI

Technology/Protocol	Last Mile/NAN	HAN	Backhaul/WAN and Backbone
Wireless	6LoWPAN-based RF mesh, ZigBee, Wi-Fi, Millimeter Wave Technology	6LoWPAN-based RFmesh, ZigBee, Wi-Fi, Blue tooth, Z-Wave, NFC, ECHONET	Cellular, Satellite, LPWA, LongWave Radio, TVWS, Private Microwave Radio links (P2P and P2MP)
Wired	PLC, Ethernet,Serial interfaces (RS-232, RS-422,RS-485), DSL	PLC, Ethernet, Serial interfaces (RS-232, RS-422, RS 485)	Optical Fiber, Ethernet, PLC, DSL

device (AMCD), housed either under meter‘s glass or outside meter, that transmits meter reads from meter directly or indirectly to control computer; (iii) A control computer (AMCC) is used to retrieve or receive and temporarily store meter reads before or as they are being transmitted to company‘s servers. The information stored in AMCC is available to log maintenance and transmission faults and issue reports on the overall operational condition of AMI system; (iv) A regional collector (AMRC) collects meter reads from AMCD and transmits them to AMCC. (v) A local area communications network (LAN) that transmits meter reads from AMCD to AMRC/AMCCs, (vi) A wide area network (WAN), communication network that transmits meters reads from AMCD/AMRC to AMCC and from AMCC to company‘s servers for processing and use.

Building blocks of AMI consist of components as described below and typical architecture of AMI is shown in Fig.1.

2.1 Smart meters

Advanced meter devices having the capacity to collect information about energy usage at various intervals and transmitting the data through fixed communication networks to utility, as well as receiving information like pricing signals from utility and conveying it to the consumer.

2.2 Communication network

Advanced communication networks which supports two way communication enables information from smart meters to utility companies and vice-versa. Networks such as Broadband over Power Line (BPL), power line communications, fiber optic communication, fixed radio frequency or public networks are used.

2.3 Meter data acquisition system

Software applications on the control centre hardware and DCUs are used to acquire data from meters via communication network and send it to MDMS.

2.4 Meter data management system (MDMS)

Host system which receives stores and analyzes the metering information.

Smart meters have basic elements such as accurate energy measurement, robust communication features, and integrated security. The details of SM building blocks are as follows: (i) Metrology integrated circuit (IC): It provides highly accurate, cost-effective solutions for advanced power measurements, equipped with suitable metrological solutions such as metrology analog front end (AFE), metrology system on-chip (SoC), metrology smart application on chip (SaoC), (ii) Host interface: smart meter (SM) has an optical port compliant with ANSIC12.18/ANSIC12.19 specifications, (iii) Communication media: SM has a varied choice of communication modes such as ZigBee protocols, RF mesh and radio frequency identification (RFID) for home area networks (HANs) and building area networks (BANs) applications, (iv) User privacy and security: Secure point-to-point communication based on strong authentication mechanisms and a robust and scalable key management schemes are crucial for assuring the confidentiality and the integrity of the data.[4]

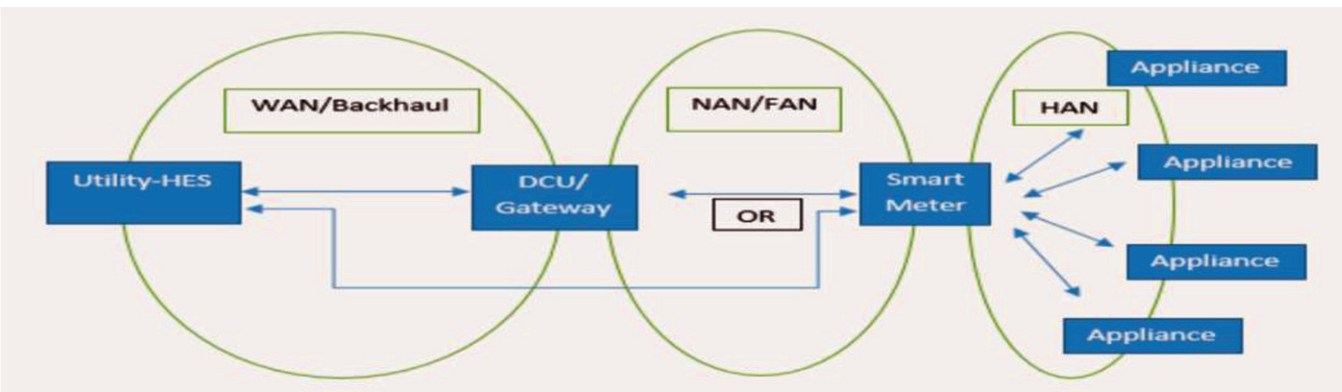

Fig.1: Typical architecture of AMI

3.0 Components and building blocks of smart metering infrastructure

The most common features of AMI infrastructure [5, 6] being implemented globally are:

- Collection of meter events.
- Daily collection of consumption data.
- Detection of illegal tie-in or unauthorized access to the meter (tampering).
- Elimination of estimated billing.
- Energy balance per MV/LV distribution transformer for network planning and to detect fraud areas.
- Meter service switch/valve with remote disconnect/ reconnect functionality.
- Fraud detection and prevention.
- Meter security services which support device authentication, encryption of data, role based access and validation of digital signatures prior to execution of remote commands or firmware upgrades.
- Multi-tariff structure programmability with possibility of daily, weekly, monthly and seasonal modulation.
- Monitoring of service quality (frequency and duration of interruptions in electricity supply) for each individual customer.
- Load profiles for active and reactive energy with 1 to 60 minutes sampling time; storage capability of 38 days at 15 minute sampling time for selected customers.
- Remote meter configuration/firmware upgrade.
- Remote reading of energy consumption and power demand.
- Remote change of contractual parameters.
- Remote disconnection and reconnection.

The performance of an AMI system and its adequacy is measured by the following factors [5]:

- Architecture and technological infrastructure.
- Adaptability to field topography of the served area.
- Adaptability to operational condition of customers' connections.
- Adaptability to environmental conditions.
- Adaptability to operational condition of the electricity network.
- Adaptability to network length.
- Adaptability to type of distribution transformers (low or high capacity).
- Information transmission capacity and operational reliability.
- Maintenance complexity.
- Information security/recovery systems.
- Ability to identify faults in the communication system.
- Installation.
- Compatibility with most meters in the market.
- Ability to operate equipment in the distribution network.
- Cost per installed unit.
- Maintenance costs.
- Experience in application of the technology.

4.0 Benefits and challenges of smart metering infrastructure in India

The benefits of AMI [7] are explained below and development/expectations of AMR/AMI/smart grid to provide return on investments as shown in Fig.2:

- Reduced meter reading and data entry cost.
- Reduced human errors and time consumption.
- Reduction of AT&C losses.
- Reduction in peak power purchase cost.
- Enabling faster restoration of electricity service after fault.
- Reduction in other meter services.
- Power quality enhancement.
- Asset optimization.

The following are the challenges for AMI rollout in India [8]

- Limitations in various last mile connectivity solutions.
- Availability of limited RF spectrum.
- End-to-End interoperability standards to integrate AMI systems.
- System security – need for standards and regulations.
- Latency in the reception of signals.
- Coverage of the communications network.
- Industry readiness for manufacturing of smart meters.
- Utilities lack clarity on functional requirements and business models.

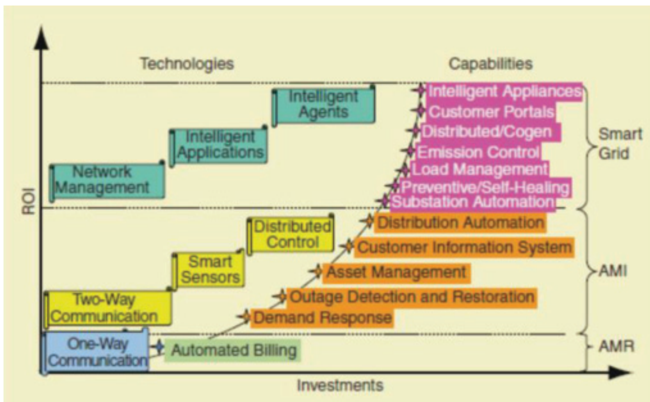

Fig.2: Smart grid return on investments

- Security concerns especially balancing firmware upgradability with usability.
- Manpower limitations for deployment, usage, and management.

The deployment of AMI in India has the following benefits and challenges [9]-[11] as mentioned in Table 2

TABLE 2: BENEFITS AND CHALLENGES FOR AMI DEPLOYMENT IN INDIA

Benefits	Challenges
Economic benefits:	
• Reduced metering reading and data entry cost	• Financial strength
• Loss reduction	• Absence of skilled manpower
• Reduction in peak power purchase cost	• Limited awareness
Operational benefits:	• Weak procurement framework
• Enabling faster service restoration after faults	• Lack of universal standards
• Reduction in errors	• Customer engagement
• Power quality measurement	• Implementation of AMI
• Asset optimization	
• Remote functionality	

5.0 Cyber attacks on smart meters

Smart meter should have necessary security requirements like network availability, data authenticity, confidentiality, integrity and information/consumer privacy and security to overcome different type of attacks. Smart meter attacks can be classified in two major categories: 1. Physical attacks: SMs are at higher risk of a physical security breach, where illegal user/attacker tries to modify SM records individually or through its interfaces in different ways, such as replacement of dedicated metrology IC with fake IC, Steal software to clone a meter and abusing host interface. Other attacks of this types are meter breaking, reversing and disconnection, using magnets, by passing neutral wire, abusing host interface and extracting the passwords. 2. Cyber-physical system (CPS) attacks: CPS consists of different types of hardware, communication devices and MDMS, to summarize the collected data into software application platform.

CPS attacks can be sub classified in three categories: (i) Denial-of-services (DOS) attacks: These attacks are related with temporary or permanently connect/disconnect AMI messages and communication link (wire-line or wire-less) flooding/jamming by spoofing packets. (ii) Man-in-the-middle (MITM) attacks: Here a malicious intruder inserts him/herself as a relay/proxy into a communication session between consumer or systems. After making independent connections with the victims and relays messages, it makes them to believe that they are directly connected with each other. (iii) Data integrity attacks: These attacks are related with data timings, data analysis, false-data injection, data replay and data modifications. During AMI applications sparse attacks, and churning attacks, are difficult to detect since they can be performed by an honest and curious adversary [12].

6.0 Cyber attacks on smart meters

Data analytics is the process of examining large amounts of data of different types to uncover hidden patterns, unknown correlations and other useful information. Data analytics is used to obtain value from such data captured and information derived such that stakeholder applications could be satisfied. The volume of data collected has increased massively due to collection of data in shorter intervals and the ability to store large volumes. The data capture at frequent intervals by smart meters and the infrastructure to transfer such data at high speeds results in streams of data. Due to the new technological capabilities of the smart meters as well as the increased demand from stakeholders including competition among utilities, different types of data are being collected to provide more value for stakeholders. Many factors such as weather, consumer profiles, seasons, geographic regions, infrastructure, type of homes and fittings all contribute to the complexity. The combination of volume, velocity and variability as well as different granularities, issues in integrating various types of data results in much more complexities need to be addressed by suitable analytics techniques. [2], [13] – [16].

Benefits from big data analytics in smart grid are: (i) increasing system stability & reliability, (ii) increasing asset utilization and efficiency and (iii) better customer experience and satisfaction. Table 3 gives the smart grid applications empowered by big data and various data analysis algorithms applied for the applications in smart grid.

TABLE 3: SMART GRID APPLICATIONS EMPOWERED BY BIG DATA

Applications	Software
Situational awareness system	FNET/GridEye
Wide area situational awareness	SMDA (ver5.0)
Event detection and alarm management	e-terra3.0
Power plant models validation	CERTS
Oscillation detection and mitigation	GRID-3P platform
Renewable resource Integration	DEMS
Transient stability and intrude detection	WARMAP5000

Challenges and future prospects of big data utilization in smart grid are listed as:

- Multisource data integration and storage.
- Real-time data processing technology.
- Data compression.
- Big data visualization technology.
- Data privacy and security.
- Information technology (IT) infrastructure.
- Data collection and governance.

- Data integration and sharing.
- Data processing and analysis.
- Security and privacy.
- Limited professionals of big data analytics and smart energy management.

7.0 Conclusions

Smart grid leads to harness the deployment and integration of information and communication technologies (ICT), smart metering to enhance grid reliability. It employs innovative products and services together like AMI, AMR, big data analytics to have intelligent monitoring and control of smart grid. It offers a sustainable option to deliver efficient and reliable power despite some controllable actions to be taken to overcome the threats like cyber penetration in communication protocols and attacks on the smart meter.

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References

1. Javier Leiva Alfonso Palacios, José A. Aguado (2016): "Smart metering trends, implications and necessities: A policy review". *Renewable and Sustainable Energy Reviews* 55:227–233.
2. Damminda Alahakoon, Xinghuo Yu (2016): "Smart Electricity Meter Data Intelligence for Future Energy Systems: A Survey." *IEEE Transactions on Industrial Informatics*, 12(1): 425-436.
3. Adam Hahn, Manimaran Govindarasu (2011): "Cyber Attack Exposure Evaluation Framework for the Smart Grid, *IEEE Transactions on Smart Grid*, 2(4): 835-843.
4. Konark Sharma, Lalit Mohan Saini (2015) "Performance analysis of smart metering for smart grid: An overview" *Renewable and Sustainable Energy Reviews,* 49:720–735.
5. www.globalsmartgridfederation.org/GSGF report/ smart meter security survey/August 2016.
6. Applications of Advanced Metering Infrastructure in Electricity Distribution, https://openknowledge.worldbank.org/handle/10986/12948.Washington, DC, 2011.
7. Hassan Farhangi (2010): "The path of the Smart grid". *IEEE Power & Energy Magazine*, (Jan/Feb)18-28.
8. http://www.tec.gov.in/Technical report on M2M enablement in power sector/TR-S&D-M2M-002- 001, released on 12.05.2015.
9. www.indiasmartgrid.org/ ISGF-BNEF Knowledge Paper on AMI Rollout Planfor India published at ISGW 2017.
10. Soma Shekara Sreenadh Reddy Depuru, Lingfeng Wang, Vijay Devabhaktuni. (2011): "Smart meters for power grid: Challenges, issues, advantages and status". *Renewable and Sustainable Energy Reviews* 15: 2736–2742.
11. Yeliz Yoldaº, Ahmet Önena, S.M. Muyeen, Athanasios V. Vasilakos, Ýrfan Alan (2017): "Enhancing smart grid with microgrids: Challenges and opportunities *Renewable and Sustainable Energy Reviews* 72:205–214.
12. Haibo He, Jun Yan (2016): "Cyber-physical attacks and defences in the smart grid: a survey", *IET Cyber-Phys. Syst., Theory Appl.*, 1(1):13–27
13. Kaile Zhou, Chao Fub, Shanlin Yang (2016): "Big data driven smart energy management: From big data to big insights. *Renewable and Sustainable Energy Reviews* 56(2016) 215–225
14. Chunming Tua,b, Xi He, Zhikang Shuai, Fei Jiang (2017): "Big data issues in smart grid– A review" *Renewable and Sustainable Energy Reviews* 79: 1099–1107.
15. Discussions and deliberations by V. Saravanan and M. Aravindan at 1st Power Utility Conference for Collaborative Growth, Distribution Utility Meet, DUM 2017, organized by Technology Innovation Centre, Bangalore Electricity Supply Company Ltd (BESCOM) in association with India Smart Grid Forum(ISGF) and Institute of Electrical & Electronics Engineers (IEEE) at The Sheraton Grand, Bengaluru, India on 29-30 December 2017.
16. Discussions and deliberations by V. Saravanan at ISGAN Knowledge Exchange on Distributed Generation, Microgrids and Smart Metering organized by the International Smart Grid Action Network (ISGAN), in partnership with National Smart Grid Mission, Ministry of Power, Government of India at Central Power Research Institute, Bengaluru, India on 14 November 2017.