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IoT Enabled Interactive Advanced Metering Infrastructure Technology in Smart Grids

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Abstract: ***In present scenario power quality issues and reliability are the challenges for the service providers and end users. The advancements in recent technologies like Internet of Things (IoT) provide good solutions for these challenges and strengthening the smart grid. Smart Meter Technology (SMT) and Advanced metering Infrastructure technology (AMIT) enables two way communication between service providers and end users there by exposing the power transactions between them in effective way. SMT and AMIT are discussed throughout this literature This paper discusses the role and feasibility of SMT in improving power quality and maintaining reliability in IoT enabled smart grid. At first we discuss in detail about SMT, wireless communication, routing algorithms enabling AMIT and then literature focusing on power quality and reliability in IoT enabling smart grid.***

Keywords: ***Smart grid, Smart Meter Technology (SMT), Advanced metering Infrastructure technology (AMIT), Internet of Things (IoT), power quality, reliability..***

I. INTRODUCTION

Electrical energy is the most essential factor for industrialization, social development and improving the quality of life. Day to day increasing of power demand creating more stress on conventional grid. Due to decrease in non-renewable resources and environmental issues motivate to produce power from renewable sources. Current area of research focuses on hybrid PV systems [1]-[3] along with high efficient converters [4]-[10] connected to grid.

The renewable sources are intermittent in nature and with their integration to the convention grid makes challenging to deliver quality power by maintaining reliability. Recent advancements in technologies like IoT provide two way communication between the service provider and end user enabling smart grid to know power truncations effectively.

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This feature provides best solutions for the challenges in smart grids. Smart city is one more demanding project for IoT enabled smart grid [11]. Compared to conventional grid more sensors are used for measuring data and SMT makes effective control and resolve power issues [12]. Smart meters functionalities will vary according to their applications such as control on power demand, power security, power quality assessment, outage and theft identification etc. [13],[14]. In power distribution system 80% electrical outages are due to component failures [15].

Hence considering the above this study focuses on SMT in smart grids on power quality improving and reliability monitoring. First we provide detailed review on AMIT for understanding the structure of smart grid consisting SMT, communication technology and routing algorithms.

This paper is organized as section 2: Surveys and outlines that contribute this paper and overview of technologies enable smart meters, communication technology and routing algorithms. Section 3: Comparing SMT literatures focusing power quality and reliability. Section 4: revealing the research gaps for providing future scope in SMT and IoT enabled smart grid.

II. SURVEY ON USAGE OF SMT IN SMART GRIDS

In this literature we have overviewed the usage of SMT and AMIT in smart grids. The authors in [16] has presented the challenges, limitations and the advantages on using the smart meters in smart grids. The authors in [17] reviewed on the smart meters applications comprising electric supply and domestic gas meters. The authors in [18] focused on reviewing smart meters application on load shedding and power outage management. They also presented the communication between suppliers and users at medium and low voltage distribution levels. H. Daki, A. El Hannani in [19] reviewed about smart grid framework including SMT, AMIT, routing algorithms and data processing for power quality monitoring and reliability management. In [20], the authors given an in depth review on the communication architecture for SMT considering Indian protocols. S. Pawar, B.F. Momin [21] mainly focused on smart meter data analysis confined to speed, complexity and data volume. They also focused on self-organizing maps, support vector machines and fuzzy logic as data mapping and analyzing techniques in SMT. In [22], communication network for identifying energy theft was designed. In addition to this, [23] mainly reviewed on AMIT and communication network aspects. This mainly focuses on transmission, distribution, user and operation domains.

However, all the above reviews haven't focused on routing algorithms, power quality and reliability management related to smart grid. The above mentioned references are compared in Table 1. It shows that routing algorithm, power quality and reliability aspects need further in depth knowledge. Thus we focused in these aspects for better understanding using available references. This literature was listed as follows

We focused on proving in depth knowledge on SMT and AMIT applications in smart grid considering routing algorithms and communication technology.

- We overviewed the design factors in wireless communication technology as well as routing algorithms for data processing in AMIT.
- We discussed available solutions and artificial intelligence techniques targeting power quality and reliability.
- The research gaps and future scope of research directions in smart grids.

Table- I: Name of the Table that justify the values

Year	SMT	AMIT	CTs	RA	PQ	PR
2017 [18]	Y	Y	Y	N	N	N
2017 [19]	Y	Y	Y	Y	N	N
2018 [20]	Y	Y	N	N	N	N
2018 [21]	Y	Y	Y	N	N	N
2018 [22]	Y	Y	Y	N	N	N

Y=Yes; N=No

III. ADVANCED METERING INFRASTRUCTURE TECHNOLOGY

In conventional grid due to one way communication it is difficult to examine the aspects of power quality, energy consumption, energy security and reliability at different load conditions. In this regard AMIT provides a solution with two way communication between utility and consumers as shown in fig. 1. The load demand curves consisting of voltage and current readings are collected using smart meters. This collected data was transferred to clouds and utilities using AMIT. The transmitted data was processed to manage power transmission and distribution side. This processed data was feedback to costumers for observing their power usage patterns and also to check power quality on receiving side.

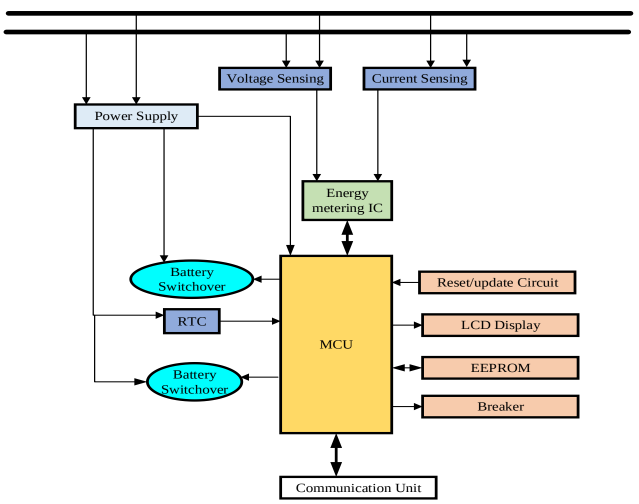

Fig. 1. AMIT internal structure.

A. Smart Meter Structure

Smart meter is the device enable AMIT which is installed at consumer side for collecting the data daily [24], monthly thorough communication network. The silent features of AMIT are list below.

- Energy billing based on power consumption.
- Net metering: Power delivered to grid and power consumed by load.
- Power consumption curves.
- Observing power quality: Presence of harmonics and Unbalanced voltages.
- Reliability: Interruptions in power supply.
- Power security: Unauthorized usage and power theft.
- Automatic remote controlling of consumers.
- Identification of appliances consuming more energy.
- Indirect reduction of greenhouse gases.

Power supply module: The power from supply AC lines is given to smart meter using DC converters. A back up power supply is provided using a battery charged from main AC lines. Solar panels can be used to power up the smart meter [25].

Microcontroller Unit: Microcontroller unit is the heart of AMIT used for processing the collected data. The major functions and operations controlled by microcontroller includes

- Communicating with energy meter integrated circuit.
- Process the received data from smart meter.
- Communicating with other interfacing devices.
- Theft detection.
- Power management and control
- Data storing and processing using EEPROM
- Interfacing display units.

Energy measuring module: The voltage and currents are measured by sensors used for calculating real and reactive powers. Further it performs signal conditioning. Energy measuring module can incorporated in microcontroller unit or as a single separate IC for energy management.

B. Artificial Intelligence (AI) for AMIT

Machine learning or artificial intelligence is the more effective tool used for optimizing large amount of data. These techniques enrich the implementation of AMIT in smart grids. We can provide best solutions for issues like predicting the power demand per particular area in a city, hybrid vehicle charging, load varying with respect to time. AI techniques have ability to learn from previous patterns as humans. This feature makes AMIT to predict about the upcoming events in future.

C. Communication structure in AMIT

We discussed earlier in this literature that AMIT provide two way communication for data collection from measuring sensors then to transfer the processed data from cloud to utility. This communication is classified into clusters [26] with respect to regions for ensuring quality of data transfer. The first cluster is on consumer side termed as Local Area Network (LAN).

LAN provides the communication between users and smart meters. Second cluster is Neighborhood Area Network (NAN) which contains flow gates to process aggression and encoding on the data coming from smart meters before transmitting it to the cloud. The third cluster is Wide Area Network (WAN) communication medium between the cloud and the service provider or utility.

The communication architecture in AMIT enable smart grid is shown in fig. 2. The other specific areas such as data security, data transmission and economic effectiveness needs more attention [27].The IEEE standards on communication networks such as ISO 1802, IEC 61970 and IEEE 802.15.4 insure secure and reliable power distribution to the consumers.

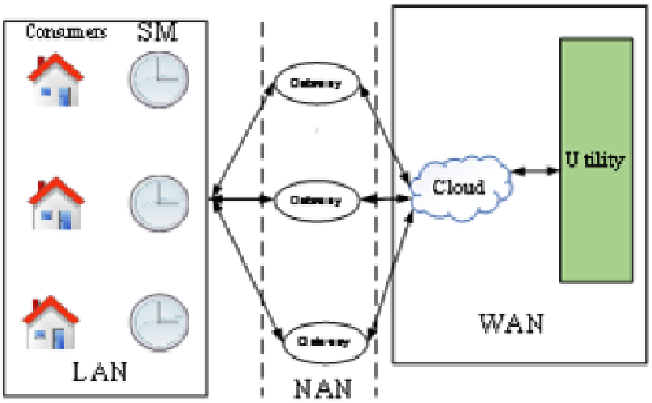

Fig 2. Communication architecture in AMIT

Bluetooth: Bluetooth is the technology which can perform communication within a short range of 0-100m in a smart grid. This is developed according to IEEE 802.15.1 standards which can transfer the data with a speed of 721kbps at 2.4 GHz frequency [28]. It consumes less power for transferring vast data. The widespread of smart mobile technology make more advantage to integrate the smart meters with Bluetooth among users.

ZigBee: ZigBee is another technology which can transfer data within low range of 0-100m. Its transfer speed is 250kbps at a frequency of 2.4GHz. This is developed according to IEEE 802.15.4 standards. It consumes less energy and cost effective data transmission rate. Hence it can give good performance in LAN cluster of a smart grid.

Wireless Fidelity (Wi-Fi): Wireless fidelity well known as Wi-Fi is another communication technology widely used now days in home, educational institutions, business and commercial areas. This is developed according to IEEE 802.11 standards which can communicate in 0-250m range with 54Mbps at 2.4-5GHz frequency. It has authentication and access protocol which makes Wi-Fi more advantage than Bluetooth and ZigBee in providing data security [29].

Other communication networks: There are other networks whose communication range is larger than Bluetooth, ZigBee and Wi-Fi technologies. Z-wave communication has 40kbps data transfer rate at 900MHz for 0-40m range [30]. The frequency of operation lower the risk of interruption compared to above technologies. Near field communication (NFC) is another technology used for short range communication of 20m. This targets smart cards and smart tags used for smart meters. NFC is based on peer-peer communication access through verification there by providing good service to the consumers [31]. Sigfox communication network overcomes the limitation of Bluetooth and Wi-Fi which are confined to lower ranges. This technology can communicate for 30-50km in rural and 10-20km range in urban areas with 100bps data transfer speed [32].

D. Routing algorithms in smart grid communication network

The main objectives to be considered when developing a routing algorithm are delay, data security, connectivity, firmware, cost and communication reliability.

Delay: When an undesirable event occurs in the system then the data transmitting and receiving has to done without any delay to take necessary remedial action. To minimize end to end delay in communication network can be done by choosing the correct path or route in the NAN region of smart grid [33]. Dijkstra based Dynamic Neighborhood Routing Path Selection (DNRPS) is superior among other algorithms with 19% of reduction in delay gain percentage [34].

Data security: Smart meters collect large amount of data from different sensors and transmit to control centers, service providers and other inter connected consumers. Smart grid was equipped with many AI devices for managing the power supply and load demand.This data consisting of consumer's private information is used for observing consumers activities such as the appliances being used, a vacant home, etc. Unlike conventional grid, smart grid components are not in utility control. This increases the risk of insecure or unauthorized data access. Hence the algorithms are developed accordingly to overcome the data security issues.

Connectivity: The main factors that influence the connectivity of smart grid are transmitting radio frequency power, transmitter and receiver antenna gain, frequency band width, receiving sensitivity and route loss effect.

Firmware: As discussed in data security IoT enabled smart grid can be easily hacked if the firewalls are not defendable. Hence the IoT enabled devices and appliances must able to upgrade time to time. Upgrading AMIT in smart grid is easy if it has high speed wireless communication network connection. This upgrading is the challenge in smart grid because the algorithms are not designed to send the update to all large number of smart meters at the same instant.

Cost: Another important aspect is routing cost. The authors [35] has proposed Open Shortest Path First (OSPF) relaying techniques for selecting cost effective routing path. In [36] reviewed DNRPS algorithm provides the shortest and low cost routing path among network nodes considering grid security.

Communication Reliability: Reliability is to deal with continuity and failure of transmitting the data from utility to end users and vice versa. Packet Delivery (PD) ratio is the amount of packet data transmitted to receive data which is the parameter indicates communication reliability. The PD ratio can be increased with Energy efficient and quality of service routing protocol [37].Packet Loss Rate (PLR) is another factor can be used to calculate the reliability. The authors in [38] has made an attempt to improve reliability using PLR by applying Ant Colony Optimization (AI technique). The summary of related studies were given in Table II and Table III.

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E. Power Quality and Reliability Assessment using SMT and AMIT

Power Quality: The IEEE standards of Power quality indices [37] are used to assess the quality of power delivered to the consumers. The power electronic converters and nonlinear loads inject harmonics into the system.

IEEE 519–1992 standards has recommended the practices to control the harmonics in steady state operation [40]. In this regard, SMT and AMIT were developed to assess the power quality parameters such as voltage sags and swells, power factor, power interruptions or faults and Total Harmonic Distortion (THD). Authors in [41] voltage profiles, imbalances and disturbances are used for evaluating power quality. All the above studies are classified according to the parameters considered for power quality assessment. The multi-tasking and smartness can be achieved by introducing smart meters embedded with power quality analyzing techniques such as net energy billing, detection of faults and outages, load demand profiles. The mathematical and signal processing techniques like wavelet transforms [42] and Fast Fourier transforms [43] are used for power quality assessment in time-frequency domain.

Table- II: Summary of design objectives

Technolog y	Data rate	Coverag e	Frequency	Standard
Zigbee	200-250 kbps	0–120m	2.2 GHz	IEEE 802.15.4
Wi-Fi	50-100 Mbps	0–300 m	2.2 and 5.6 GHz	IEEE 802.11b/g/n
Bluetooth	10-1000 kbps	0–50 m	2.2 GHz	IEEE 802.15.1
Z-wave	50 kbps	0–20 m	1000 MHz	ITU-T G. 9959
	100 Mbps (4G)		2000 MHz	UMTS/HSPA (3G), LTE (4G)
Sigfox	100 bps	20–60 km (Rural) 4–12 km (Urban) 2–6 km (Urban)	900 MHz	Sigfox

Table- III: Objectives of routing algorithms for IoT enabled SMT and AMIT in smart grids.

Ref.	Delay	Cost	Reliability	Coverage	Security
[31],[32]	Y	N	N	Y	N
[35]	Y	N	N	Y	N
[36]	Y	N	N	Y	N
[33]	N	Y	N	Y	N
[37]	N	N	N	N	Y

Y=Yes; N=No

Power Reliability: Power reliability refers to delivering power to the consumers without any interruptions all the time. It reflects as economic loss for the service providers and users. In [44] it is reviewed that 80% of reliability issues are due to failures and malfunctions in hardware equipment. The standards of IEEE1366-2012 are used to for power reliability assessment [45]. A power reliability indexing model was proposed by considering power quality data tracked by SMT or AMIT [46]. The literature available in this area is limited in evaluating power reliability using smart meters. Hence more focus is required to develop power reliability assessment for the wireless sensor networks.

IV. RESULTS AND DISCUSSION

The internal structure of advanced metering infrastructure technology shown in fig.1 is modeled to analyze its performance to improve power quality and power supply reliability. AMIT provides two way wireless communication, routing algorithms enables to expose the power transactions between provider and end user effectively. The comparison of different design objectives were presented in table 2 and communication technologies related to power quality and reliability were presented in table 1. It is observed that the 80% of the reliability issues are due to failure of hardware equipment's are traced effectively by AMIT. The voltage sags, power interruptions and THD have been reduced to 0.4pu according to IEEE 519–1992 standards. The artificial intelligence technique improves the performance of AMIT achieving the power quality 0.1 PU. Further DNRPS algorithm provides the shortest and low cost routing path among network nodes considering grid security.

V. CONCLUSION

The prominence of power quality and reliability in smart grids has gained our attention to develop new techniques and methodologies for assessment. IoT enabled SMT or AMIT in smart grids will give better solutions for such issues. In this context, we have deeply discussed the architecture of SMT and AMIT and their effectiveness. The essential factors to be considered in wireless communication and routing algorithms for power quality and power reliability assessment were reviewed and the future investigations for research were included in this literature.

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