Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

A Brief Review on Ancillary Services from Advanced Metering Infrastructure (ASAMI) for Distributed Renewable Energy Network

Chen Chai Phing[1,*], Tiong Sieh Kiong[2], Siaw Paw Koh[2], Tarek Abedin[2], Yaw Chong Tak[2], Wanbalyan[3], Talal Yusaf[4,5], Mei Wyin Yaw[2]

[1] Department of Electrical and Electronics Engineering, Universiti Tenaga Nasional (The Energy University), Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
[2] Institute of Sustainable Energy, Universiti Tenaga Nasional (The Energy University), Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
[3] Engineering Services, Distribution Network, Aras 11, Wisma TNB, No. 19, Jalan Timur, 46200, Petaling Jaya, Selangor, Malaysia
[4] School of Engineering and Technology, Central Queensland University, Brisbane, QLD 4009, Australia
[5] College of Engineering, Almaaqal University, Basra 61003, Iraq

ARTICLE INFO

Article history:
Received 24 September 2023
Received in revised form 7 November 2023
Accepted 12 December 2023
Available online 20 March 2024

Keywords:
Advanced metering infrastructure; Ancillary service; Distribution network

ABSTRACT

Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enable the secure, effective, and dependable distribution of power while also delivering enhanced capabilities to energy consumers. The system also can measure power usage, connect, and disconnect service, detect tampering, identify and isolate outages, and monitor voltage automatically and remotely, which were previously unavailable or required user intervention. This article focuses on AMI and effectively integrating renewable energy sources (RES). However, the study also recommends smart metering for renewables such as solar photovoltaic (PV), hydropower, anaerobic digestion (ad) metering, and renewable energy storage, in which AIM thoroughly supervises the energy utilized by users' appliances. With the prediction of new ancillary services connected with contestability, related regulation, the sufficiency of consumer protection, and safety issues, the magnitude of renewable energy sources in the AMI is an almost unprecedented problem for consumers. The present energy management problems include reducing the power supply-demand gap and boosting power supply dependability. Implementing AMI with distributed renewable energy resources might be a viable strategy for lowering power consumption, improving power supply management, and maximizing management resource use.

1. Introduction

Many governments [1-6] are currently promoting an increase in the amount of renewable energy (RE) in their national resource variability and single-phase nature of specific Distributed Energy Resources (DERs), as well as the last mile networks to which the DERs are linked, were never meant to bear such loads. They may have several detrimental consequences in the previous mile networks.

* *Corresponding author.*
E-mail address: chencp@uniten.edu.my

https://doi.org/10.37934/araset.41.2.4361

The fundamental goal of this study is to discover strategies for using the potential afforded by DER to permit additional renewable energy connections while maintaining statutory restrictions, network stability, and power quality. Given the wide variety of last-mile network factors (network capacity, length, loading, number of users, etc.), generic network models and a set of tools must be established to conduct this study.

Shortly, Malaysia's electrical utility company wants to implement advanced metering infrastructure (AMI) in 8.3 million residences throughout the nation. The main goal of this smart meter implementation is to supply users with more current information, enabling demand side control through customer interaction [7]. The operation of the electricity system will become more complex with significant penetration of renewables. Renewable energy's intermittency makes it challenging to maintain a second-by-second balance between supply and demand unless a sufficient reserve is kept on hand. Creating a flexible market that follows generation [8] answers these difficulties.

Meters and home area networks (HANs) bring with them a slew of additional advantages, including but not limited to:

i. Monitoring of Power Quality.
Voltage excursion events, such as the quantity and timing of voltage sags, voltage surges, and so on, maybe tracked. This may assist network operators in determining the severity of a power quality issue, locating the cause of voltage difficulties, and devising mitigation strategies. The power factor may also be examined.
ii. RE Profiling.
Visualization of the spatial-temporal profile of renewable energy gathered to investigate solar irradiance and energy harvesting efficiency.
iii. Analysis of Energy Density and Profile.
For distribution network design and improvement, visualization of energy and load density may be developed [7,9,10]. This will allow network designers to describe equipment more precisely, eliminate oversizing/under sizing on new equipment, and postpone or cancel asset replacement spending.
iv. Outage Reporting
AMI data may be used to analyse outages to determine the accurate outage time and length for low-voltage (LV) networks [11].
v. Energy Loss Mapping
AMI meters aggregate electricity from the substation and DER and deliver it to each consumer. This helps identify both technical and non-technical distribution network losses.

Because AMI offers a variety of services/functionalities and provides information to customers, it's critical to know what other services/functionalities are appropriate for Malaysia, investigate business cases for such services/functionalities, and develop tools/applications for such services/functionalities. As a result, the feasibility, business cases, and tools necessary for the following services/functionalities will be thoroughly investigated in this study.

2. The Advanced Metering Infrastructure System

The advanced metering infrastructure (AMI) is usually divided into many networks and consists of several components. Upper System (MDMS: Metering Data Management System), Intermediate

System (HES: Head End System), and Lower System (Figure 1) offer an overview of AMI [12]. The primary components of the AMI will be briefly introduced in the following sections.

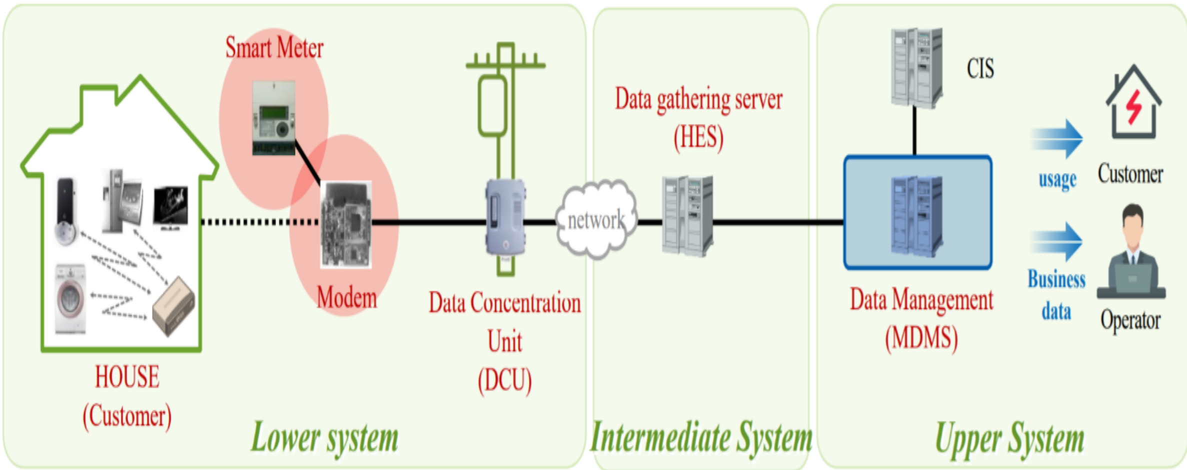

Fig. 1. Advanced Metering Infrastructure Networks and Components [12]

2.1 Upper System (MDMS: Metering Data Management System)

The data centre houses the metering data management system responsible for storing, analysing, and managing the user's metering and billing data. MDMS offers fundamental data to assist smart grid decision-making as an interface with other systems [13]. MDMS provides analytical tools that allow various operation and management systems to interface and gather whatever required data. Outage management systems (OMS), Consumer information systems (CIS), Geographic information systems (GIS), and distribution management systems are the most common operation and management systems (DMS). Figure 2 depicts the interaction of several parts of a smart grid with an MDMS [14].

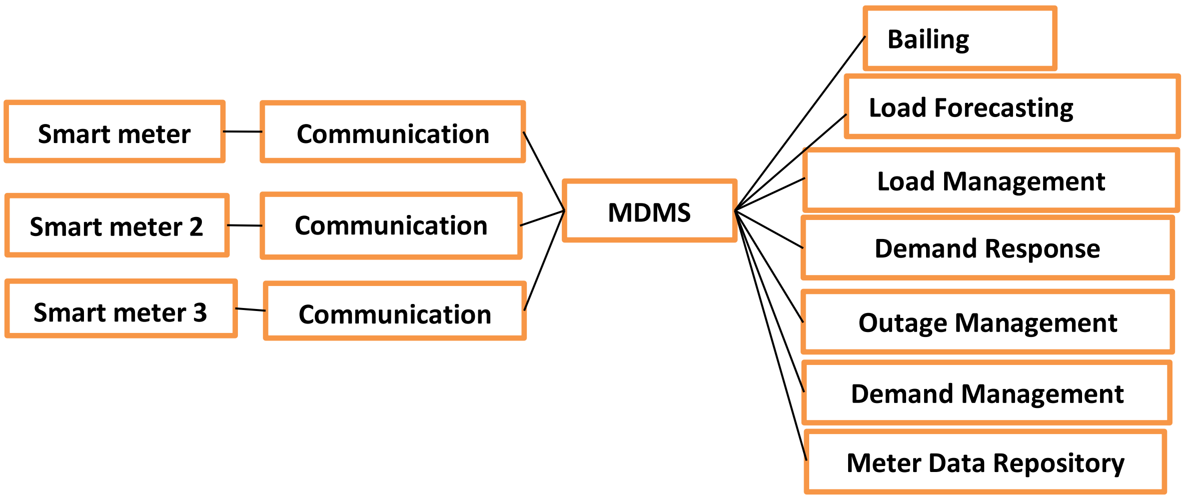

Fig. 2. Meter Data Management System (MDMS) [14]

2.2 Intermediate System (HES: Head-End System)

A metering company's HES, often known as a meter control system, is placed inside its network. The metering business is the distribution system's responsible party in most circumstances. The HES communicates with the meters directly. This is because services and functionality will be offered to the outside, the HES is situated in a demilitarised zone (DMZ). There is a lot more infrastructure on the distribution system operator (DSO) or metering firm side. The data will be maintained by a MDMS which will also map the data to the appropriate customer. Metering data will impact DSO operations to balance the grid, depending on the automation level [15].

2.3 Lower System

Smart meter, communication modem, and DCU are all part of the lower system (Data Concentration Unit).

2.3.1 Smart meter

A smart meter is a digital meter that may be used to track electric, water, or gas use and send that information to a utility. A utility may also utilise it to provide instructions or price indications [16].

2.3.2 Communication

AMI relies heavily on standard communication. A highly dependable communication network is necessary for transmitting a massive amount of data due to the number of users and smart meters at each centre [17]. The infrastructure consists of multiple networks, each of which may use various media and protocols. When it comes to AMI, three networks are often mentioned. The wide area network (WAN), neighbourhood area network (NAN), and Home Area Network (HAN) are three types of networks (HAN). The three communication networks are shown in Figure 3.

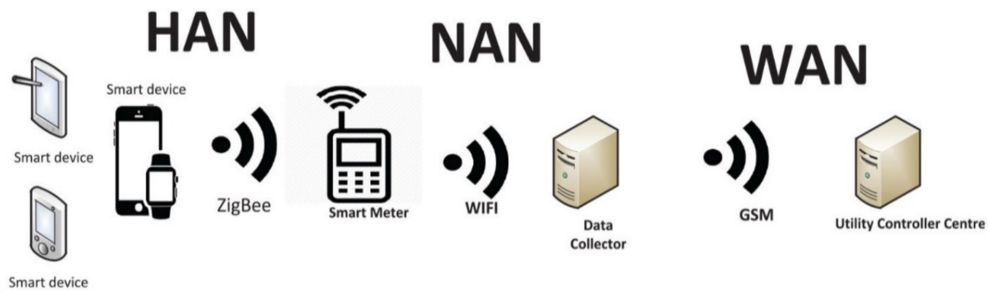

Fig. 3. Communication Network Connection o AMI [18]

2.3.3 DCU (Data concentration unit)

The HES's communication node is the DCU, sometimes a concentrator or gateway. The collector might be a meter depending on the infrastructure. Its principal role is connecting the HES to the meters and other collectors in its vicinity - the NAN. Threats are exposed not just at the head-end but also at the collector. Opponents physically confront the collector. It also has a trust relationship with both the HES and the NAN, allowing it to communicate with either end [15].

3. Services, Features and the Functionalities

A literature analysis was conducted to understand better the many services, features, and functions given by AMI, and the following is the summary of the findings:

3.1 Distribution Voluntary Demand Reduction

Customers are anticipated to voluntarily turn off appliances based on utility needs by supplying time-varying pricing information and energy use. Customers would turn off appliances willingly to save money on their power bills [19].

3.2 Direct Load Control (DLC)

Demand-side management schemes that remotely turn off or adjust the thermostat settings of customers' electrical equipment (e.g., air conditioners and water heaters) are becoming more popular (DSM). With 5.13 million participants in 2011, direct load control (DLC) is the most popular DSM program in the United States (US) [20]. When an incident occurs, that necessitates a reduction in demand, the DSM administrator sends out a signal to reduce the customer's loads. Use Home Energy Management Systems (HEMS) for load shifting and valley filling.

HEMS (through smart meters and a Home Area Network (HAN)) can operate smart devices automatically. To achieve flexible demand, the control unit connected with the HEMS controls the operation of each device depending on pricing signals received from the utility. Peak demand is reduced, which minimizes the need for high-cost generators. For instance, consider Roscoe [8]. Because peak prices are greater than off-peak pricing, appliances are more likely to be turned off during peak hours.

3.3 Reconnection Scheduling

Network operators will be able to forecast future demand for specific sections of their networks using historical smart meter data. This feature may be used to arrange phased reconnection schedules before re-energizing after a blackout [21]. Increased distributed generating penetration might result in voltage spikes that exceed distribution feeder constraints ➔ data from smart meter ➔ With intermittent renewable energy sources, voltage regulation of the distribution network is possible [22]. Smart meters provide knowledge about peak current magnitudes and durations, paired with historical data to minimize expenditure without jeopardizing supply dependability or cable life span [9]. Distribution network voltages can be reliably estimated using previous-day smart meter data to supplement relatively few upstream measurements [23]. The other options are as below:

i. Condition monitoring.
ii. Voltage monitoring and control.
iii. Frequency response.
iv. Smart meters can detect and coordinate loads to offer primary frequency response [24].

3.4 Net Energy Metering (NEM) [25]

NEM is one of the ways for you to offset or lower your power expenses by generating electricity from solar PV systems. NEM is designed to give credit for any solar energy you generate in excess. It is then applied to the next power payment as a credit. This manner may save money on power bills while also protecting from potential increases in electricity expenses. A bi-directional meter will be placed for these sorts of connections, and an appropriate communication signal will be required since meter reading will be done remotely.

3.5 Privacy Preserving Techniques

Encryption is how smart meter users utilize public and private keys to safeguard personal data from intruders. Mohammed *et al.,* suggested an effective symmetric-key-cryptography-based privacy protection strategy for AMI networks [26]. Using the Optimized Network Engineering Tools (OPNET) 14.5 simulator, the authors of [27] suggested a data aggregation technique based on the principle of homomorphic encryption. In a smart metering network, the proposed approach decreases latency, delay, and network traffic while protecting private smart meter data from intruders.

Abdallah and Shen [28] offer a homomorphic encryption-based privacy preservation approach that takes data aggregation into account. To decrease network processing costs and protect user privacy, the authors adopted the notion of lattice-based homomorphic encryption. The creators of [29] employed the notion of a battery controller to switch between grid and battery power and then worked on adding noise to maintain further privacy. The authors focused on lowering additional costs while also improving reciprocal information exchange. A scenario is shown is Figure 4. The suggested [30] technique developers calculated the noise using a gamma distribution and then tweaked smart meter data before sending it to the utility.

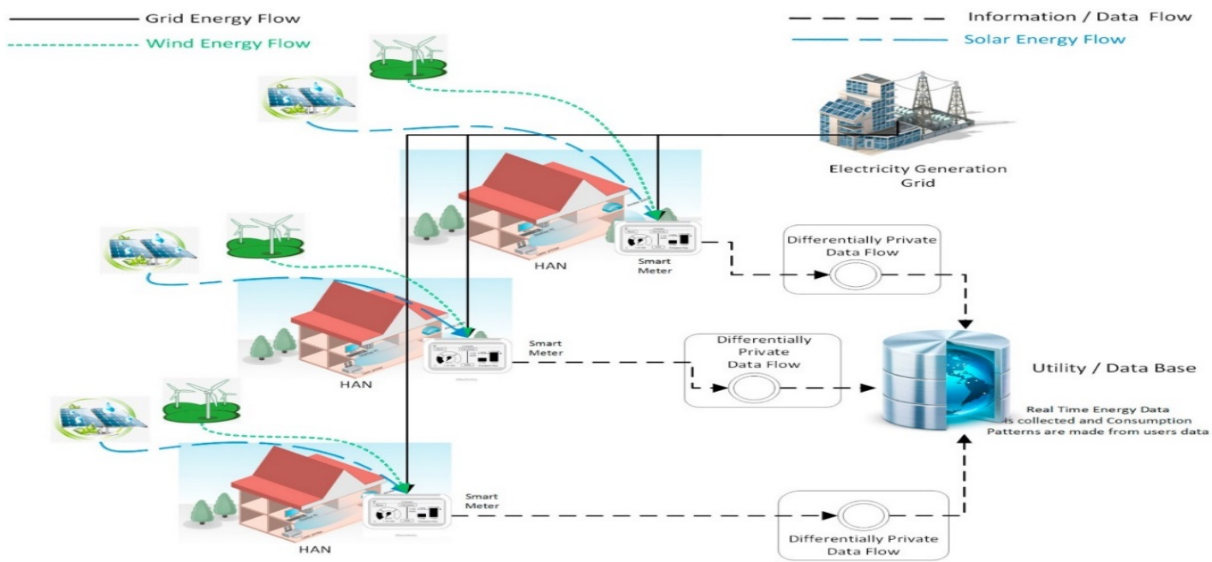

Fig. 4. A smart meter utility application scenario demonstrating the operation of differential privacy in Renewable Energy Resources (RERs). In this scenario, every smart house has a smart meter that talks with the utility and send real-time data every 10 minutes [35]

3.6 Online Bill Payments and Pre-Pay Billing Plans

In the electric power market, online bill payment is standard, but using web portals in conjunction with AMI installations has improved consumer understanding. Customers that utilize this service more often save money on paper bills and have fewer errors when processing payment slips and cheques [31]. By communicating consumption at regular intervals, pre-pay billing schemes prevent billing volatility, unexpectedly large power bills and service interruptions for consumers on pre-pay programmes. In addition, outstanding utility bill write-offs were limited [32].

3.7 Security Model in AMI

The security system is the most difficult to implement in a smart meter system. Many occurrences of power theft arise due to meters failing to detect physical and system changes [33]. Extraordinary security measures are required to secure the integration, availability, and privacy of meter reading data and management communications [34]. Given its significance, the study illustrates the security problem as a chart (Figure 5) with three significant aspects: safeguarding user privacy, system resilience against cyber or external assaults, and power theft.

Additional literature review is shown in Table 1.

Table 1
Additional of Literature Review

Articles	**Findings**	**Research Gaps**	**Remarks**
Smart Meters as a Sensor Network for Low-Voltage Grid Monitoring [36].	To address the problem of power management, improved data management is required.	~ Doesn't take into account the difficulty of transmission. ~ No comparative analysis	A smart meter network is being investigated as a sensor network.
Smart Metering Design in Developing Countries: A Retrofit Design Science Methodology [37].	Use a smart meter to save billing costs and implementation costs.	~ No comparative analysis. ~ When 5G is going to arrive, GPRS use is rather rudimentary.	GPRS, PLC, experimental, design science research approach.
Smart Metering Data Cluster Analysis [38]. Load estimate using K-means for household smart meter observations [39].	Customer consumption behaviour may be predicted using cluster analysis on smart meter data.	~ No comparative analysis. ~ Accuracy not determined.	Business analytics may be easily incorporated.
Assessment of power quality in LV networks using a novel Smart Meter design [40].	Experimenting with power quality, statistical analysis, and ARM processors.	~ No comparative analysis. ~ No complexity analysis.	Power quality can be assessed more easily.

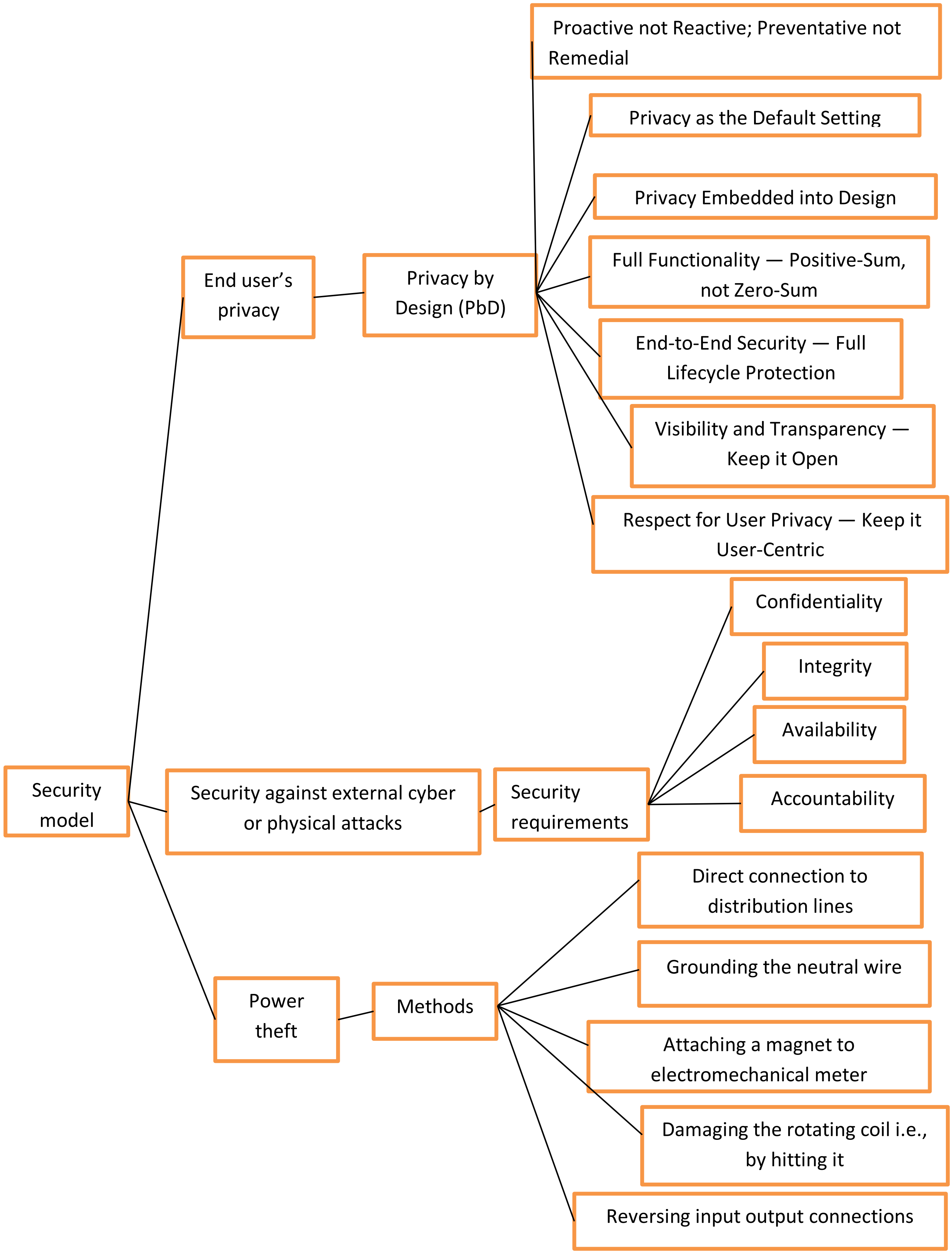

Fig. 5. Security Model in AMI

4. AMI and Energy Transition

Smart meters will play a critical part in this decarbonization effort. Smart meter data analytics will benefit grid optimization, consumer experience, and distributed energy resource integration. According to [41], worldwide smart meter adoption will increase from around 44% by the end of 2020 to 56% by 2028, resulting in over 1.2 billion devices. The first generation of AMI meters, announced in 2020 and currently on the market, utilizes high-resolution waveform data to deliver significantly more comprehensive insights both behind the meter and at the grid edge. The previous generation of AMI meters, which used 15-minute interval data and may take up to 24 hours for customers to view, didn't provide the kind of real-time, comprehensive experience required for consumer involvement. However, a new generation of AMI meters can handle apps like Sense without requiring extra hardware in the house. Meters need three additional features to provide detailed real-time applications [42]:

i. High-Resolution Waveform Data: Employ a load disaggregation technique to enable a comprehensive picture of activity in homes and detect various failure types in devices and the grid. For real-time load disaggregation, even one-second Interval data is insufficient. Instead, tens of thousands of times per second must be sampled from a continuous voltage and current waveforms stream.
ii. Edge Computing: Because of the high data rates necessary, most of the work must be completed inside the meter. Several meter-based edge computing solutions that can execute apps are currently available. The key is to have adequate edge computing power with raw data stream access.
iii. Low-latency Networking: In most cases, meters employ a mesh network built for dependability rather than speed. Meters need an extra networking channel for consumer apps, Wi-Fi or cellular, to allow a real-time customer experience with one- or two-seconds delays.

5. AMI and the Generation of Renewable Energy Sources

As the shortage of fossil fuels increases, renewable energy generation, such as wind and solar, is gaining favour due to its clean and ecologically friendly attributes. Renewable energy production may be distributed or centralised, and it can be linked to the grid. The formation of AMI would provide a platform for renewable energy generation in enterprises and families and technical help. Renewable energy production is becoming more expensive than traditional thermal power generation. The government must provide power price subsidies to renewable energy providers to encourage fossil energy conservation and achieve sustainable development. Due to continual advancements in manufacturing and technological innovation, the cost of renewable energy generation will drop in the future. The impact of adding a renewable energy source to the power grid would be reduced if the power system had adequate reserve capacity [13].

5.1 Smart Metering for Renewables

When combined with Meter Online, approved Smart generation meters are perfect for remote monitoring of solar photovoltaic (PV), wind turbines, and other renewable energy sources. Customers that need to monitor several locations, such as councils, housing associations, maintenance, and investment firms, benefit significantly from remote monitoring. Meter Online delivers revenue-generating data and condition monitoring and proactive maintenance warnings. The inherent scalability of Meter Online allows for a fully managed metering system that can handle any number of meters from practically any location. The online meter management pages make it simple to add to a metering account at any time. Some of the most intriguing smart metering for renewables is described below:

5.1.1 Solar PV monitoring

The new smart meters, above all, are compatible with solar panels and other photovoltaic installations. They enable customers to monitor how much energy they use from their solar panels and how much electricity they are importing from the grid. The same is true for solar energy exported back to the grid. Smart meters may display actual and real-time power use so that customers are aware of their solar energy usage and can take steps to reduce it. EDF Energy, British Gas, First Utility, Ovo Energy, Utilita, Bulb, and Octopus are among the energy companies that offer smart meters compatible with solar panels [43].

5.1.1.1 Smart meter reading with solar power

It's easy to read your solar meter: It flips between positive and negative numbers on display. The positive figure is the amount of power you've imported from the grid, and it's what you'd see on a regular electricity meter if you didn't have solar. The negative figure is the quantity of power you've exported to the grid from your solar system; this is the amount of electricity your solar system produced more than what your home required at the time [44].

5.1.1.2 AI meter with PV integration

Artificial Intelligent Meter (AIM) or AI meter will be the smart meter of choice in the future because it manages consumer energy consumption independently, communicates with households and providers and improves power supply quality under the supervision of artificial-intelligent power quality diagnosis in the AIM device [45]. Photovoltaic (PV) installations on every rooftop might be a reality within the next decade. The AI meter will be a management mechanism between PV-generated energy and grid-supplied electricity [46]. Because PV may give some electricity to lights and medium loads like fluorescent bulbs and motors, the system may minimise grid energy use. Furthermore, the energy produced by PV will be stored in home batteries and used as "backup" energy during power shortages. The AI meter will operate an extra switch situated in the house's distribution board to switch between grid power and batteries during a power outage. The ability of an AI meter to detect instantaneous over-current conditions before the circuit breaker trips and switches to batteries will be a solution for protecting household equipment from damage.

Furthermore, surplus PV energy will be sold to the grid, with the AI meter measuring the energy transferred to the grid. Because the energy bought from the utility may be deducted, this condition can lower the power cost. Figure 6 shows how the AI meter interacts with the PV system.

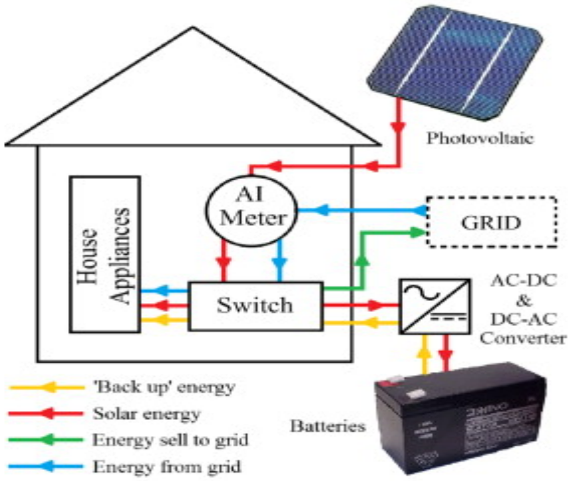

Fig. 6. Security Model in AI Meter with PV Integration [33]

5.1.2 Wind turbine monitoring

Smart meters are appropriate for wind turbines located in distant and spread areas where complex collecting meter readings. The smart meter provides a cost-effective technique of remotely monitoring performance and providing alarms in the event of faults for smaller systems without local telemetry. When the MID-approved smart meter is used as the primary generating meter, it may deliver the kWh values required for generation incentive programmes and power purchase agreements without a site visit [47].

5.1.3 Hydro power metering

When a small hydro scheme operator has their check meters, and generation meters on-site, smart meters or retrofitting communications to existing meters like the Honeywell Elster A1700 allows for remote generation monitoring and collection of the needed kWh measurements. Meter online can collect and store readings and half-hour profiles from MID authorised meters at both low voltage (LV) and high voltage (HV) for study [47].

5.1.4 Anaerobic digestion (AD) metering

Using the operator's smart meters, the generation and parasitic load of an AD plant may be monitored remotely. Meters may be read at low and high voltages, and communications equipment can be retrofitted to existing meters. Meter online records kWh readings and half-hour kW profiles using MID-approved smart meters, establishing a data archive that verifies plant functioning and provides kWh readings off-site [47].

5.2 AMI and Distributed Renewable Energy Storage

Although its utility as a complement to renewable generating is one of its key benefits, energy storage is still far from becoming a ubiquitous and pervasive feature, owing to its high cost. Meanwhile, due to technological maturity and resulting price reductions, distributed generation is becoming more prevalent in low voltage networks and the form of small power plants, to the point where grid parity for solar photovoltaic systems has already been achieved in countries such as

Germany and Italy [48,49]. Furthermore, the concept of the prosumer, i.e., an agent capable of both generating and consuming energy, which consumes the electricity generated for their purposes but can also feed it into the grid, will gradually evolve for consumers and generators, increasing the need for bidirectional information and control to optimise integration [50]; this model still requires legal development in countries such as Spain [51].

Energy storage devices will become widely available in the next several years as technology on fuel batteries, and new batteries for electro-vehicles improve, radically transforming power consumption. According to reference [52], a breakthrough had been reached in lithium battery charging and manufacturing technology. Lithium batteries in the future will be smaller and last for more extended periods and charging time will be 100 times faster than it is today. When significant capacity storage devices are added to a family, the users' power consumption mode is entirely altered, and AMI operation becomes more flexible. Users could choose storage devices as power supply equipment and provide power energy to the grid side using renewable source power generation when their load is at its peak. When the grid's power load is at its valley, the storage devices could be charged by renewable source power generation or grid side. All of this would be achieved automatically under the direction of the load intelligent management centre for users. The use of users' energy storage devices, which means increasing the reserve capacity of the power grid, would enhance the safe and stable operation of the power grid if the smart regulating strategy of the users' power load was appropriately configured [13].

5.3 Government Scheme

Smart meters are a legal requirement in the United Kingdom, and the government wants every home to have one. Furthermore, if a customer opts not to have a smart meter installed, they may be denied access to part of the market's prices. Again, even if consumers decline to have a smart meter installed today, they will be eligible for a free smart meter afterwards. This, together with potential solar panel incentives, may help you save money in the long run. The following are some of the government projects that are explained [43].

5.3.1 Feed-in tariff

The Feed-in Tariff (FiT) Scheme ceased in 2019; however, those enrolled may continue to make use of it. It is a government-sponsored initiative that aims to make renewable energy more accessible to UK residents. In Scotland, for example, the cost of solar panels has dropped by around 70% since 2010. Smart readers will assist you in calculating how much energy you generate and allowing you to export the energy you don't consume.

5.3.2 Smart export guarantee

Under the new Smart Export Guarantee (SEG) programme, customers are compensated to export to the grid during peak hours under the unique Smart Export Guarantee (SEG) programme. If there is a significant oversupply – such as the windy night in December – prices might go to zero, essentially paying providers to remove electricity off the grid [53]. All licenced electricity providers must comply with the SEG. With the Feed-in Tariff programme coming to an end, the government has asked energy companies to assist small-scale low-carbon heating producers financially. The SEG allows these generators to be compensated for the excess energy they return to the grid. The SEG applies to everyone who has a solar panel system with a capacity of at least 5MW. The Smart Export Guarantee would apply to a 5kW solar panel installation. A smart meter must also be installed in the home to measure the exports. Following the conclusion of the Feed-in-Tariff, the government agreed on the Smart Export Guarantee (SEG). From April 2019, this rule will apply to all new applicants [43]. Despite this, just 35% of UK households (14.3 million) have a smart meter, with 34.3 million more to be installed [53].

6. Case Studies

Table 2
Smart Meter Deployment, Features, and AMI Integration (by project) [54]

Project Name	Web Portals (Enrolled Customers)	Installed meters	Enabled Number of Smart Meters with Features				AMI Integrated with			
			Remote Connect/Dis-connect	Outage Reporting	Voltage Monitoring	Tamper Detection	BS	CIS	OMS	DMS
Sacramento Municipal Utility District (SMUD)	26,332	617,502	574,277	617,502	617,502	617,502	✓	✓	X	X
Glendale Water and Power (GWP)	926	85,582	85,582	85,582	85,582	85,582	✓	✓	X	X
Burbank Water and Power (BWP)	2,910	51,928	45,150	51,928	51,928	51,928	✓	✓	✓	X
Sioux Valley Energy (SVE)	5,411	27,641	710	27,641	27,641	27,641	✓	✓	✓	X
Black Hills Energy	4,677	68,980	632	68,980	68,980	68,980	✓	X	✓	X
Black Hills Corp./Colorado Electric Utility Company	1,783	44,920	840	44,920	44,920	44,920	✓	✓	✓	X
Center Point Energy	2,344,905	2,130,737	2,038,499	2,130,737	-	2,130,737	✓	✓	✓	✓
Central Lincoln People’s Utility District	38,620	38,620	37,380	38,620	38,620	38,620	✓	✓	✓	X
Detroit Edison Company	315,137	688,717	636,571	688,717	688,717	688,717	✓	✓	✓	✓
Golden Spread Electric Cooperative	10,405	88,411	7,720	67,995	44,185	55,876	✓	✓	✓	✓
Lakeland Electric	121,900	121,900	11,502	121,900	121,900	121,900	✓	✓	✓	X
Marblehead Municipal Light Department	10,215	10,215	134	10,215	10,215	10,215	✓	✓	✓	X
Modesto Irrigation	-	3,538	3,220	3,538	3,538	3,220	✓	X	X	X

District										
Oklahoma Gas and Electric Company	61,097	818,415	736,178	818,415	818,415	818,415	✓	✓	X	X
Woodruff Electric Cooperative	-	14,949	14,949	14,949	14,949	14,949	✓	✓	X	X

[a] BS: Billing System; CIS.
[b] Customer Information System.
[c] OMS: Outage Management System.
[d] DMS: Distribution Management System.
[Results from the smart grid investment grant program September 2016]

7. Issues and Challenges

Some relatable issues and challenges of AMI integrated with RES are explained below:

By 2020, the British government wants every home to have a smart meter. Furthermore, if customers opt not to have a smart meter installed, they may be denied access to part of the market's prices. Again, even if consumers decline to have a smart meter installed today, they will be eligible for a free smart meter afterwards. This, together with potential solar panel incentives, may help you save money in the long run [43].

The current grid feed-in tariff situation has to be improved to achieve optimal wind energy consumption. FiT and Net metering systems are both functional in promoting renewable grid integration and lowering energy usage. In contrast to the rise of solar technologies, wind energy production and integration are still lagging in the smart grid picture. One of the main reasons is pricing policies, which have increased the use of solar energy both in homes and in large-scale industries [55]. In a roof-top solar generation, "Time of Day" tariffing and the implementation of smart meters have increased the use of solar energy both in homes and in large-scale industries.

Using distributed generators based on wind or solar energy may be an excellent way to fulfil the high demand for power while lowering GHG emissions. However, increasing renewable energy penetration gets tricky when renewable power production is integrated into the utility system. Intermittence and fluctuation of energy, which causes voltage fluctuations; low-capacity factors (typical capacity factors for PV are 10%–20%) and for wind are 20%–40%; lack of correlation with load profiles; relatively large forecast errors and more complicated; congestion in power transmission due to large-scale system installations; congestion in distribution grid due to distributed renewable energy [56].

Distribution networks incorporating smart metering communications, distributed generation controls, and demand response at consumption locations might offer several security vulnerabilities. Several surveys and tutorials have recently elaborated on a variety of security issues in terms of confidentiality, integrity, and availability, ranging from passive to active attacks [57-62], such as eavesdropping, jamming, tampering, spoofing, altering, and other attacks against the protocol. Utility firms are using encryption and other cyber security measures to safeguard the security of smart meter data, applying security methods established for the banking and military industries.

Radio Frequency (RF) Exposure: RF emissions are produced by household electronic equipment such as mobile phones, wireless routers, and smart meters. RF exposure at really high levels may be detrimental to your health. To safeguard public health in the United States, the Federal Communications Commission (FCC) restricts the quantity of RF radiation that electronic devices, including smart meters, are permitted to produce. When properly installed and maintained, wireless smart meters emit much less RF than other typical home devices, such as mobile phones and microwaves [63].

8. Conclusions, Future Trends and Recommendation

Voluntary demand reduction, Direct Load Control (DLC), reconnection Scheduling, net energy metering (NEM), privacy preservation strategies, security model, online bill payments, and pre-pay billing plans are the capabilities, services, and applications discussed in this paper. The breadth and variety of an advanced metering infrastructure combined with RES benefit both customers and utilities by reducing the power supply-demand gap and allowing for more effective power system management. There is considerable potential to transform the paradigm of electric power supply with the introduction of enhanced smart meter and RES features.

When combined with distributed renewable energy sources, the AMI must adapt to a dynamic and changing socioeconomic environment in the short and medium-term. Electrical energy consumers' wants, needs, and requirements will change and become more complicated, but they will revolve around a similar factor. According to the authors, the following trends and suggestions will determine AMI's future growth, as the International Energy Agency indicated in its annual study entitled Energy Technology Perspective in recent years.

AMI must be implemented to get the most out of a flexible grid model that allows any point in the network to consume or create power at any voltage. Because electric companies would always know the behaviour of individual users (such as whether they are generating or consuming electricity) and the network to which they are connected (e.g. whether they are having any problems or not), having such a model would dramatically, safely, and reliably increase the penetration of renewable generation and storage (only consuming, only generating, or both).

The conventional idea of a supply point has to be liberalized, leading to the concept of "energy spots," which do not differentiate between users and electric providers, with no duplication of measurement and control equipment, provided that a single smart meter would be adequate. According to the authors, changes to the regulations and legislation are needed to recognize the roles and functions that distribution network operators must assume to control this type of installation and the rules that must be followed to ensure transparency and fairness of the process.

Appropriate mechanisms should be put in place to ensure that the market decides whether or not to accept a prosumer's injection of power into the grid, or, in other words, that the grid does not become a drain into which excess energy can be poured without control, that this energy production does not rely on subsidies or premiums, and that each type of "energy spot" pays the applicable tolls for the use and support of the networks.

Even though energy providers are likely to discontinue supplying clients with first-generation smart meters, consumers should evaluate the smart meter's compatibility with solar panels if they have them installed. They should speak with their electricity provider about this.

Power consumption by smart meters and grid sensors should be redesigned by combining on-site renewable energy use for energy efficiency in line with continuing research on green communications instead of typical Wireless Sensor Network (WSN) investigations. Furthermore, the idea of data aggregation differs from that used in legacy WSN. Because they effectively reflect state circumstances and individual loads used for monitoring/billing reasons at the utility control centre, most meters and sensors put on lines/premises contain considerable measurement data and cannot be fused in a typical method.

Acknowledgement
The authors would like to thank the Tenaga Nasional Berhad (TNB), Malaysia, for supporting this research under a TNB R&D Seeding Fund (U-TD-RD-19-07) and UNITEN R&D Sdn. Bhd. In addition, the authors acknowledge the publication support through J510050002—BOLDREFRESH2025—CENTRE OF EXCELLENCE from the iRMC of UNITEN.

References

[1] Fisher, Angelina, and Thomas Streinz. "Confronting data inequality." *Colum. J. Transnat'l L.* 60 (2021): 829. https://doi.org/10.2139/ssrn.3825724
[2] Meister, Jürgen, Norman Ihle, Sebastian Lehnhoff, and Mathias Uslar. "Smart grid digitalization in Germany by standardized advanced metering infrastructure and green button." In *Application of Smart Grid Technologies*, pp. 347-371. Academic Press, 2018. https://doi.org/10.1016/B978-0-12-803128-5.00010-6
[3] Kashyap, Ashwin, and Duncan Callaway. "Controlling distributed energy constrained resources for power system ancillary services." In *2010 IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems*, pp. 407-412. IEEE, 2010. https://doi.org/10.1109/PMAPS.2010.5528957
[4] Ikpehai, Augustine, Bamidele Adebisi, and Khaled M. Rabie. "Broadband PLC for clustered advanced metering infrastructure (AMI) architecture." *Energies* 9, no. 7 (2016): 569. https://doi.org/10.3390/en9070569
[5] Smolenski, Robert, Pawel Szczesniak, Wojciech Drozdz, and Lukasz Kasperski. "Advanced metering infrastructure and energy storage for location and mitigation of power quality disturbances in the utility grid with high penetration of renewables." *Renewable and Sustainable Energy Reviews* 157 (2022): 111988. https://doi.org/10.1016/j.rser.2021.111988
[6] Gold, Rachel, Corri Waters, and Dan York. "Leveraging advanced metering infrastructure to save energy." *Washington DC: American Council for an Energy-Efficient Economy (ACEEE)* (2020).
[7] Wang, Yi, Qixin Chen, Tao Hong, and Chongqing Kang. "Review of smart meter data analytics: Applications, methodologies, and challenges." *IEEE Transactions on Smart Grid* 10, no. 3 (2018): 3125-3148. https://doi.org/10.1109/TSG.2018.2818167
[8] Roscoe, Andrew J., and Graham Ault. "Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response." *IET renewable power generation* 4, no. 4 (2010): 369-382. https://doi.org/10.1049/iet-rpg.2009.0212
[9] Slootweg, Johannes G., Andre Postma, and F. Wild. "A practical approach towards optimizing the utilization of MV cables in routing network planning." In *Proceedings of the 19th International Conference on Electricity Distribution, CIRED 2007, Vienna, 21-24 May 2007*. 2007.
[10] You, Shi, Henrik W. Bindner, Junjie Hu, and Philip J. Douglass. "An overview of trends in distribution network planning: A movement towards smart planning." In *2014 IEEE PES T&D Conference and Exposition*, pp. 1-5. IEEE, 2014. https://doi.org/10.1109/TDC.2014.6863446
[11] Liu, Yan, and Noel N. Schulz. "Knowledge-based system for distribution system outage locating using comprehensive information." *IEEE Transactions on Power Systems* 17, no. 2 (2002): 451-456. https://doi.org/10.1109/TPWRS.2002.1007917
[12] Yaye, S. A. R. R., Bamba Gueye, and S. A. R. R. Cheikh. "Performance analysis of a smart street lighting application using LoRa wan." In *2019 International Conference on Advanced Communication Technologies and Networking (CommNet)*, pp. 1-6. IEEE, 2019.
[13] Zhang, Jingchao, Zhuoya Chen, Xiaohui Yang, Kai Chen, and Kui Li. "Ponder over advanced metering infrastructure and future power grid." In *2010 Asia-Pacific Power and Energy Engineering Conference*, pp. 1-4. IEEE, 2010. https://doi.org/10.1109/APPEEC.2010.5448797
[14] Barai, Gouri R., Sridhar Krishnan, and Bala Venkatesh. "Smart metering and functionalities of smart meters in smart grid-a review." In *2015 IEEE Electrical Power and Energy Conference (EPEC)*, pp. 138-145. IEEE, 2015. https://doi.org/10.1109/EPEC.2015.7379940
[15] "Advanced Metering Infrastructure Architecture and Components – Compass Security Blog." https://blog.compass-security.com/2013/02/advanced-metering-infrastructure-architecture-and-components/
[16] Bian, D., M. Kuzlu, M. Pipattanasomporn, and S. Rahman. "Analysis of communication schemes for Advanced Metering Infrastructure (AMI)." In *2014 IEEE PES General Meeting| Conference & Exposition*, pp. 1-5. IEEE, 2014. https://doi.org/10.1109/PESGM.2014.6939562
[17] Mohassel, Ramyar Rashed, Alan Fung, Farah Mohammadi, and Kaamran Raahemifar. "A survey on advanced metering infrastructure." *International Journal of Electrical Power & Energy Systems* 63 (2014): 473-484. https://doi.org/10.1016/j.ijepes.2014.06.025

[18] Kebotogetse, Otisitswe, Ravi Samikannu, and Abid Yahya. "Review of key management techniques for advanced metering infrastructure." *International Journal of Distributed Sensor Networks* 17, no. 8 (2021): 15501477211041541. https://doi.org/10.1177/15501477211041541
[19] Strbac, Goran. "Demand side management: Benefits and challenges." *Energy policy* 36, no. 12 (2008): 4419-4426. https://doi.org/10.1016/j.enpol.2008.09.030
[20] Gellings, Clark. *Saving energy and reducing CO2 emissions with electricity*. CRC Press, 2020. https://doi.org/10.1201/9781003151647
[21] Lee, Dong Su, Yong Soon Kim, and Seung Wan Kim. "Smart Meter Use Cases for New Energy Services." (2020). https://doi.org/10.46855/energy-proceedings-7196
[22] Manaz, M. A. M., D. B. W. Abeywardana, M. G. C. P. Mediwaththe, K. M. Liyanage, and A. Yokoyama. "Active and reactive power balancing of Ubiquitous power networks considering voltage constraints." In *2012 IEEE 7th International Conference on Industrial and Information Systems (ICIIS)*, pp. 1-6. IEEE, 2012. https://doi.org/10.1109/ICIInfS.2012.6304839
[23] Samarakoon, Kamalanath, Jianzhong Wu, Janaka Ekanayake, and Nick Jenkins. "Use of delayed smart meter measurements for distribution state estimation." In *2011 IEEE Power and Energy Society General Meeting*, pp. 1-6. IEEE, 2011. https://doi.org/10.1109/PES.2011.6039384
[24] Samarakoon, Kamalanath, and Janaka Ekanayake. "Demand side primary frequency response support through smart meter control." In *2009 44th International Universities Power Engineering Conference (UPEC)*, pp. 1-5. IEEE, 2009.
[25] "Welcome to MyTNB Portal - Net Energy Metering." https://www.mytnb.com.my/renewable-energy/net-energy-metering
[26] Mohammed, Hawzhin, Samet Tonyali, Khaled Rabieh, Mohamed Mahmoud, and Kemal Akkaya. "Efficient privacy-preserving data collection scheme for smart grid AMI networks." In *2016 IEEE Global Communications Conference (GLOBECOM)*, pp. 1-6. IEEE, 2016. https://doi.org/10.1109/GLOCOM.2016.7841782
[27] Bae, Mungyu, Kangho Kim, and Hwangnam Kim. "Preserving privacy and efficiency in data communication and aggregation for AMI network." *Journal of Network and Computer Applications* 59 (2016): 333-344. https://doi.org/10.1016/j.jnca.2015.07.005
[28] Abdallah, Asmaa, and Xuemin Sherman Shen. "A lightweight lattice-based homomorphic privacy-preserving data aggregation scheme for smart grid." *IEEE Transactions on Smart Grid* 9, no. 1 (2016): 396-405. https://doi.org/10.1109/TSG.2016.2553647
[29] Zhang, Zijian, Wenqiang Cao, Zhan Qin, Liehuang Zhu, Zhengtao Yu, and Kui Ren. "When privacy meets economics: Enabling differentially-private battery-supported meter reporting in smart grid." In *2017 IEEE/ACM 25th International Symposium on Quality of Service (IWQoS)*, pp. 1-9. IEEE, 2017. https://doi.org/10.1109/IWQoS.2017.7969167
[30] Ács, Gergely, and Claude Castelluccia. "I have a dream!(differentially private smart metering)." In *International Workshop on Information Hiding*, pp. 118-132. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011. https://doi.org/10.1007/978-3-642-24178-9_9
[31] Gov, S. "Advanced metering infrastructure and customer systems: results from the smart grid investment grant program." US Department of Energy (2016).
[32] "Document Details: | SmartGrid.Gov." https://www.smartgrid.gov/document/Bridging-the-Gaps-on-Prepaid-Utility-Service.html
[33] Aziz, A. F. A., S. N. Khalid, M. W. Mustafa, H. Shareef, and G. Aliyu. "Artificial intelligent meter development based on advanced metering infrastructure technology." *Renewable and Sustainable Energy Reviews* 27 (2013): 191-197. https://doi.org/10.1016/j.rser.2013.06.051
[34] Anzalchi, Arash, and Arif Sarwat. "A survey on security assessment of metering infrastructure in smart grid systems." In *SoutheastCon 2015*, pp. 1-4. IEEE, 2015. https://doi.org/10.1109/SECON.2015.7132989
[35] Hassan, Muneeb Ul, Mubashir Husain Rehmani, Ramamohanarao Kotagiri, Jiekui Zhang, and Jinjun Chen. "Differential privacy for renewable energy resources based smart metering." *Journal of Parallel and Distributed Computing* 131 (2019): 69-80. https://doi.org/10.1016/j.jpdc.2019.04.012
[36] Dedé, Alessio, Davide Della Giustina, Stefano Rinaldi, Paolo Ferrari, Alessandra Flammini, and Angelo Vezzoli. "Smart meters as part of a sensor network for monitoring the low voltage grid." In *2015 IEEE sensors applications symposium (SAS)*, pp. 1-6. IEEE, 2015. https://doi.org/10.1109/SAS.2015.7133616
[37] Azasoo, Julius Quarshie, and Kwame Osei Boateng. "A retrofit design science methodology for smart metering design in developing countries." In *2015 15th International Conference on Computational Science and Its Applications*, pp. 1-7. IEEE, 2015. https://doi.org/10.1109/ICCSA.2015.23

[38] Flath, Christoph, David Nicolay, Tobias Conte, Clemens van Dinther, and Lilia Filipova-Neumann. "Cluster analysis of smart metering data: An implementation in practice." *Business & Information Systems Engineering* 4 (2012): 31-39. https://doi.org/10.1007/s12599-011-0201-5

[39] Al-Wakeel, Ali, Jianzhong Wu, and Nick Jenkins. "K-means based load estimation of domestic smart meter measurements." *Applied energy* 194 (2017): 333-342. https://doi.org/10.1016/j.apenergy.2016.06.046

[40] Sanduleac, Mihai, Mihaela Albu, Joao Martins, Ma Dolores Alacreu, and Carmen Stanescu. "Power quality assessment in LV networks using new smart meters design." In *2015 9th International Conference on Compatibility and Power Electronics (CPE)*, pp. 106-112. IEEE, 2015. https://doi.org/10.1109/CPE.2015.7231057

[41] "Guidehouse Insights Names Oracle, Landis+Gyr, and Itron the Leading Smart Meter Analytics Providers | Business Wire." 2022. https://www.businesswire.com/news/home/20210413005128/en/Guidehouse-Insights-Names-Oracle-LandisGyr-and-Itron-the-Leading-Smart-Meter-Analytics-Providers

[42] "Get Smart: Next Generation AMI Meters Must Play a Key Role in the Energy Transition." https://www.power-grid.com/smart-grid/get-smart-next-generation-ami-meters-must-play-a-key-role-in-the-energy-transition/#gref.

[43] GreenMatch. "How Smart Meters and Solar Panels Work Together." https://www.greenmatch.co.uk/blog/smart-meters-and-solar-panels.

[44] "How to Read Your Solar Meter." https://www.solargreen.net.au/how-do-i-read-my-solar-meter-.html.

[45] Kwack, Sun-Geun, Gyo-Bum Chung, Jaeho Choi, and Ginkyu Choi. "Development of artificial-intelligent power quality diagnosis equipment for single-phase power system." In *2008 IEEE 2nd International Power and Energy Conference*, pp. 351-356. IEEE, 2008.

[46] Hussein, Ala A., Nasser Kutkut, Z. John Shen, and Issa Batarseh. "Distributed battery micro-storage systems design and operation in a deregulated electricity market." *IEEE Transactions on Sustainable Energy* 3, no. 3 (2012): 545-556. https://doi.org/10.1109/TSTE.2012.2191806

[47] "Smart Metering for Renewable Energy | Solar PV & Wind Power Systems." https://metermanager.co.uk/metering-for-renewables/

[48] Spertino, Filippo, Paolo Di Leo, and Valeria Cocina. "Which are the constraints to the photovoltaic grid-parity in the main European markets?." *Solar Energy* 105 (2014): 390-400. https://doi.org/10.1016/j.solener.2014.03.021

[49] Leiva, Javier, Alfonso Palacios, and José A. Aguado. "Smart metering trends, implications and necessities: A policy review." *Renewable and sustainable energy reviews* 55 (2016): 227-233. https://doi.org/10.1016/j.rser.2015.11.002

[50] Di Giorgio, Alessandro, and Francesco Liberati. "Near real time load shifting control for residential electricity prosumers under designed and market indexed pricing models." *Applied Energy* 128 (2014): 119-132. https://doi.org/10.1016/j.apenergy.2014.04.032

[51] Talavera, D. L., J. De La Casa, E. Muñoz-Cerón, and G. Almonacid. "Grid parity and self-consumption with photovoltaic systems under the present regulatory framework in Spain: The case of the University of Jaén Campus." *Renewable and Sustainable Energy Reviews* 33 (2014): 752-771. https://doi.org/10.1016/j.rser.2014.02.023

[52] Kang, Byoungwoo, and Gerbrand Ceder. "Battery materials for ultrafast charging and discharging." *Nature* 458, no. 7235 (2009): 190-193. https://doi.org/10.1038/nature07853

[53] "Balancing the Grid with Smart Meters - Energy Saving Trust." https://energysavingtrust.org.uk/balancing-grid-smart-meters/

[54] US Department of Energy, Electricity Delivery & Energy Reliability Unit. "Advanced Metering Infraestructure and Customer Systems." Results from the Smart Grid Investment Grant Program, 98. 2016. https://www.energy.gov/sites/prod/files/2016/12/f34/AMI Summary Report_09-26-16.pdf

[55] Sharma, Navonita, and Ajoy Kumar Chakraborty. "Development of Feed-In-Tariff using Unbundle Smart Meters for Small Scale Wind Power Generating Plant and Small-Scale Roof-Top Solar Plant." In *2019 8th International Conference on Power Systems (ICPS)*, pp. 1-6. IEEE, 2019. https://doi.org/10.1109/ICPS48983.2019.9067379

[56] Al-Badi, Abdullah Hamed, Razzaqul Ahshan, Nasser Hosseinzadeh, Reza Ghorbani, and Eklas Hossain. "Survey of smart grid concepts and technological demonstrations worldwide emphasizing on the Oman perspective." *Applied system innovation* 3, no. 1 (2020): 5. https://doi.org/10.3390/asi3010005

[57] Sridhar, Siddharth, Adam Hahn, and Manimaran Govindarasu. "Cyber–physical system security for the electric power grid." *Proceedings of the IEEE* 100, no. 1 (2011): 210-224. https://doi.org/10.1109/JPROC.2011.2165269

[58] Kim, Mihui. "A survey on guaranteeing availability in smart grid communications." In *2012 14th International Conference on Advanced Communication Technology (ICACT)*, pp. 314-317. IEEE, 2012.

[59] Mo, Yilin, Tiffany Hyun-Jin Kim, Kenneth Brancik, Dona Dickinson, Heejo Lee, Adrian Perrig, and Bruno Sinopoli. "Cyber–physical security of a smart grid infrastructure." *Proceedings of the IEEE* 100, no. 1 (2011): 195-209. https://doi.org/10.1109/JPROC.2011.2161428

[60] Yan, Ye, Yi Qian, Hamid Sharif, and David Tipper. "A survey on cyber secure

[61] Pallotti, Emiliano, and Federica Mangiatordi. "Smart grid cyber security requirements." In *2011 10th International conference on environment and electrical engineering*, pp. 1-4. IEEE, 2011. https://doi.org/10.1109/EEEIC.2011.5874822

[62] Yang, Yi, Tim Littler, Sakir Sezer, Kieran McLaughlin, and H. F. Wang. "Impact of cyber-security issues on smart grid." In *2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies*, pp. 1-7. IEEE, 2011. https://doi.org/10.1109/ISGTEurope.2011.6162722

[63] "Emerging Technologies: Solar Power, Wind Power, Smart Grid and Smart Meters - Electrical Safety Foundation." https://www.esfi.org/emerging-technologies-solar-power-wind-power-smart-grid-and-smart-meters