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Advanced Metering Infrastructure in Smart Grids: Towards a More Efficient and Sustainable Energy System

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ABSTRACT

The current high energy demand and the urge to fight climate change, in accordance with the United Nations Sustainable Development Goals, have promoted the utilisation of digital tools that contribute to more efficient and sustainable energy systems. Thus, an Internet of Things (IoT) application in the energy sector can be the implementation of Advanced Metering Infrastructure (AMI) which has a great potential to contribute to more reliable energy grids and the introduction of renewable energies. AMI is a three-component technology composed of smart meters, a complex communication network and a data management system which combined enable a two-way communication. This study discusses the multiple benefits that AMI deployment can offer, including real-time data readings reported to the customer and the utility operator – supporting better decision making as well as energy and costs savings –, better O&M of the grid, automated billing with better accuracy, and less greenhouse gases emissions. Likewise, the risks and challenges derived from this technology are explored, considering data privacy and security, investment required, social acceptance and inclusion, among others. Finally, the minimum requirements for AMI proper functioning and opportunities for future improvement are covered to achieve greater efficiency in a sustainable and trustable energy system that involves stakeholders.

Keywords: Sustainable energy systems, Advanced Metering Infrastructure (AMI), Smart meters, Two-way communication network, Renewable energies.

NONMENCLATURE

Abbreviations	
AMI	Adavanced Metering Infrastructure
EPRI	Electric Power Research Institute
HAN	Home Area Network
IoT	Internet of Things
LPWAN	Long Power Wide Area Network
MDMS	Meter Data Management System
NB-IoT	Narrow Band Internet of Things
NAN	Neighbouring Area Network
RE	Renewable Energy
SM	Smart Meters
SDGs	Sustainable Development Goals
3GPP	3rd Generation Partnership Project
WAN	Wide Area Network

1. INTRODUCTION

In 2015, the United Nations proposed the Sustainable Development Goals (SDGs) to act in different areas with the objective to balance social, economic, and environmental sustainability worldwide. Amongst the 17 SDGs is the aim to ensure access to affordable and clean energy, which is closely related to the need of expanding the share of renewable energy alternatives, as well as the urgency of implementing more efficient energy systems that can cope with the increasing global energy demand. Thus, energy sustainability can be promoted with the inclusion of Industry 4.0 – which concerns digitalisation and automation. Digital transformation can be applied through different technologies such as digital twins, blockchain, Internet of Things (IoT) and more. One of the possible applications is the Advanced Metering Infrastructure (AMI), a technology that contributes to

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moving towards more sustainable and efficient energy systems.

AMI is a key element in smart grids [14], which plays an important role towards sustainable energy as it promotes the participation of renewable energies, support a more efficient utilisation and consumption in the electricity system [6]. AMI integrates hardware and software elements as it is composed of smart meters, communication networks and data management systems that facilitate two-way communication between customers and utilities, supporting instantaneous data recording and transmitting [4][7][9][10]. In consequence, it enables customer participation in energy consumption management [5], and allows remote reading, shorter interval measurements, real-time decision-making, more efficient operation, and maintenance [9], and a better accuracy in the billing [2][5][13]. Thus, a more sustainable approach for the energy sector can be enhanced, also considering transparency, reliability, and efficiency for stakeholders.

2. ADVANCED METERING INFRASTRUCTURE (AMI) TECHNOLOGY

There are three main components in the AMI technology. Firstly, Smart Meters (SM) allow the data collection of different parameters (e.g., customer electricity consumption, functioning parameters as temperature or voltage levels, and more) with a frequency of less than 1 hour [4][13]. Besides, SM can contribute to tamper detection, outage monitoring and remote connection/disconnection. On the other hand, the communication network required for the information transmission is a major constituent of AMI considering the large amount of data involved. In addition, the communication network to be chosen in the AMI system shall be based on its technical suitability in terms of reliability and coverage, latency, bandwidth, and security, as well as the deployment costs [14]. Thirdly, a data management system that stores, processes, and integrates the collected data with other key information and control systems is required [4].

The two-way communication characteristic allows the AMI system to collect information for asset monitoring and management, while simultaneously enabling the smart devices (or SM) to receive command signals from the controlling office to take the optimal actions. There are various technologies that can deliver the outcomes required as: Zigbee, Bluetooth, Wi-Fi, Narrow-band Internet of Things (NB-IoT), and more. Communication flows considering three major layers, the wide area network (WAN), the neighbouring area network (NAN) and the home area network (HAN). WAN represents the backbone of the system, interconnecting all the distributed smaller areas data; NAN is the bridge between the collected data from different HANs and the WAN; HAN composed by multiple sensor-based controllers.

One of the communication technologies that could potentially boost the AMI communication is NB-IoT as it can provide multiple advantages to the overall functioning as: low-latency – for quicker data collection and transmission, and timely decision-making [5], less power consumption with longer lifetime batteries, lower delay sensitivity, and massive capacity; it is cost-effective [14]. This technology works based on cellular networks and can provide significant coverage; thus, this is a suitable alternative to implement in the AMI communication being capable of supporting large-scale connectivity. It is one of the Long Power Wide Area Network (LPWAN) technologies which utilises the NB of existing Third Generation Partnership Project (3GPP) telecommunications networks.

2.1 Overall Benefits

The introduction of AMI in the energy grid can boost an extensive variety of benefits to customers, as well as utilities administrators and operators. Regarding customers, AMI provides feedback on energy use in a real-time basis which has a significant impact on usage allowing them to monitor their consumption patterns and optimise them, generating savings in energy and costs – 1% to 8% of the total annual electricity use [4]; also it enables consumers to receive a potential income from selling energy back to the grid [8]. As for the utilities administrators, AMI enables opportunities for better measurement and verification of energy savings which assists project managers to assess the system performance and take the corrective actions in a timely manner. Finally, the utilities operators benefit from AMI as it facilitates conservation voltage reduction (CVR) on distribution networks, decreasing demand, energy use and line losses in both ends – customer and utilities sides –, related to more sustainable and efficient utilisation [4].

From an overall point of view, reduction in peak demand, and decreases of O&M costs as a more efficient asset management can be achieved from the data collection promoting preventive maintenance, quicker leak detection and repairs. The latter implies that additional advantages are achieved like better service provision – since outage restoration can be done more precisely and quicker, and increased accuracy in customer billing [13]. Besides, it enhances theft and tampering detection which result in a better asset management, preventing misuse of electricity and non-technical losses [7]. Regarding the communication network itself, NB-IoT can provide cost savings, minimise power consumption, can easily integrate with the existing cellular network, offers a long range and deep penetration, as well as billions of connections per cell [11].

2.2 Social and Environmental Impacts

AMI offers diverse benefits regarding the environment and consumer perspective. In terms of environmental impact, this technology facilitates a faster and more efficient integration of Renewable Energies (RE) [8]. This is translated in emissions reductions in about 0,635 tonnes-CO_2/MWh per RE produced, as well as other GHG emissions. Besides, this system supports the reduction of oil usage, specifically regarding SM and WAN [1]. On the other hand, in terms of social impact, AMI supports an increased satisfaction of consumers from personal improvement and better well-being because of changing their energy behaviour and consumption [2]. Likewise, as the energy supply is more efficient and reliable, when outages occur the system operation will be restored very quickly, minimising disruptions to users and boosting trust.

However, there are some negative social impacts linked to the deployment of AMI. The introduction of smart grids may contribute to social exclusion as a lack of targeted inclusion of energy poor households from the socio-spatial characteristics [12]. Moreover, lack of access to ordinary groups into the renewable energy grid contribution can occur [12]. Thus, it was observed that instead of promoting stakeholders' inclusion and the prosumers concept, the scheme was favouring the retailers at sub-distributor levels. On the other hand, the implementation of automated and remote reading may result in job loss as the manual readings will not be required, and the manual control can be done by less personnel. Finally, a new set of skills should be developed by the workforce, to match the requirements of Industry 4.0 [13].

2.3 Costs

Since it is a three-main component technology there are various elements to consider when analysing its capital expenditure (CAPEX) as hardware, software, installation labour, software integration and others. Figure 1 indicates the average cost breakdown based on different AMI deployment in energy systems in the US. It should be noted that the total cost represents the procurement and installation for the overall system. Furthermore, the Electric Power Research Institute (EPRI) in the US indicates that smart meters represent the 45% of the AMI total costs, whereas the communication network accounts for the 20% [13][14].

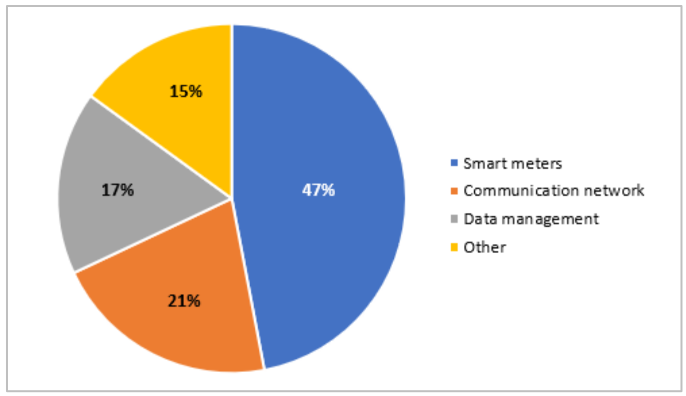

Fig. 1. AMI average total costs breakdown – Based on 56 AMI deployment case studies in the U.S.

According to a case study in Saudi Arabia's electricity infrastructure, AMI deployment costs $ 1,53 billion USD distributed as shown in Figure 2. In addition, operational costs (OPEX) are expected to be around $ 0,45 billion USD. On the other hand, the financial benefits offered by this technology are derived from the replacement of manual meters with SM, the minimisation of technical and non-technical losses improving reliability, upgrading metering system and having better billing accuracy; translate into $ 3,80 billion USD. Therefore, the B/C Ratio equals 2,50 which indicates that the project could proceed [1].

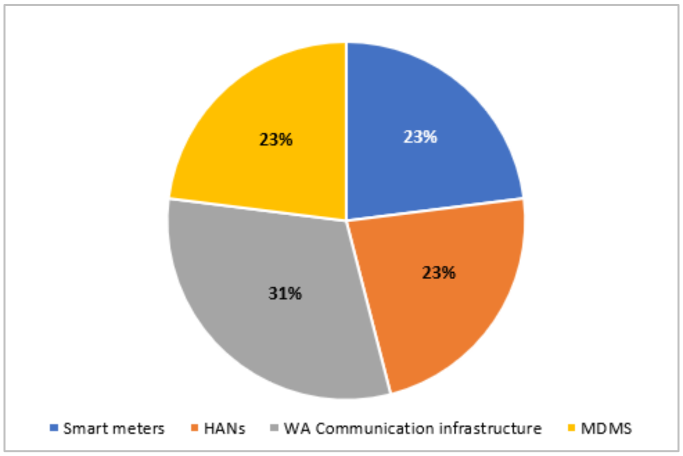

Fig. 2. AMI average total costs breakdown – Based on 56 AMI deployment case studies in the U.S.

2.4 Section of theory/calculation

Considering AMI's complexity, there are risks and challenges related to it, which are explored below.

- Data privacy and security concerns from customers [4][9].
- Higher dependency on Information and Communication Technologies (ICT). For instance, the communication networks that are cellular-based (e.g., NB-IoT) are weaker against natural disasters or terrorist attacks; hence, if one of these events occur there might be a massive power failure.
- Transition towards digitalisation might be challenging in terms of maintaining technical interoperability and compatibility between Industry 4.0 tools and previous ones.
- Utility Investment. Some utility operators worry about the way to transfer these additional and new costs to users.
- Public might be distrustful of the technology deployment as it offers savings for the customers as well as the possibility of additional income, which seems suspicious as it goes against the utility's benefits.

2.5 Performance and Opportunities for Future AMI Improvement

AMI should be able to provide the collected data directly to the user, thus the user can take advantage of the real-time feedback and optimise his consumption patterns. Likewise, the system shall have this characteristic towards the metering operator to enable efficient and effective O&M and promoting better planning. As for the commercial aspects, it should be able to conduct automated billing and allow remote control supply. Hence, with the aim to achieve the previous minimum requirements, some opportunities could be explored for future implementation:

- Introduction of next generation SM with larger memory, faster processing, and longer lasting batteries.
- Inclusion of 5G technology for communication network in AMI.
- Increase customers' participation to promote engagement with AMI technology.

3. CONCLUSIONS

AMI can highly contribute to smart grid, with a two-way communication the real-time remote reading is enabled for better asset management by the utility operator, while also providing consumption feedback to customers. Thus, better decision making can be enhanced which is translated into energy and costs savings. AMI requires proper technology that allow the quick and reliable communication. One option for a reliable and efficient is the NB-IoT as it has low-latency, lower power consumption and massive capacity; this is a form of LPWAN. It should be noted that the average cost of AMI deployment is between $130 and $600 USD/SM in the U.S. or ranging from $195 to $218 USD/SM in the European Union; it includes the three main components of the system. However, it is not possible to define the average percentage for each component's price; important differences were found regarding the cost distribution.

AMI supports customers decision making to modify their consumption patterns or even to act as prosumers selling energy back to the grid. On the other hand, the real-time measurements and quick communication allow the identification of leakages and theft in a timely manner; also, preventive maintenance can occur as forecasting improves from this vast data collection. Hence, AMI allows a better management of outages and a quicker repair to supply the service as quickly as possible, minimising disruptions for users. Besides, this technology promotes the inclusion of renewable energies, and GHG emissions and oil usage reductions. According to a case study, the implementation of AMI in the electricity infrastructure of Saudi Arabia reported a total of $ 1,52 bn USD of costs and $ 3,80 bn USD from benefits; the CBA ratio was of 2,50, meaning that the project could proceed.

Withal, this technology has some risks and challenges attached as the data security and privacy concerns – and derived regulatory issues –, a high dependence on ICT systems subject to failure, a significant investment required – in terms of money, time, and new skillset from staff –, and finally, the public perception of this technology should be improved. There are some opportunities for better delivery of the service such as: inclusion of new generation of metering devices, upgrading the communication system to enable better data protection and security, coverage and trust. Promoting transparency and clear information diffusion to promote customers' engagement and trust.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] Alaqeel, T. A., & Suryanarayanan, S. (2019). A comprehensive cost-benefit analysis of the penetration of Smart Grid technologies in the Saudi Arabian electricity infrastructure. Utilities Policy, 60. https://doi.org/10.1016/j.jup.2019.100933

[2] Buchanan, K., Banks, N., Preston, I., & Russo, R. (2016). The British public's perception of the UK smart metering initiative: Threats and opportunities. Energy Policy, 91, 87–97. https://doi.org/10.1016/j.enpol.2016.01.003

[3] Farhangi, H. (2010). The path of the smart grid. IEEE Power and Energy Magazine, 8(1), 18–28. https://doi.org/10.1109/MPE.2009.934876

[4] Gold, R., Waters, C., & York, D. (2020). Leveraging Advanced Metering Infrastructure To Save Energy.

[5] Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2013). A Survey on smart grid potential applications and communication requirements. IEEE Transactions on Industrial Informatics, 9(1), 28–42. https://doi.org/10.1109/TII.2012.2218253

[6] Hu, Z., Li, C., Cao, Y., Fang, B., He, L., & Zhang, M. (2014). How smart grid contributes to energy sustainability. Energy Procedia, 61, 858–861. https://doi.org/10.1016/j.egypro.2014.11.982

[7] Kumar, M. (n.d.). Sensitivity: LNT Construction Internal Use IoT enabled Advanced Metering Infrastructure for Smart Cities with Hybrid Communication technology.

[8] Marques, V., Costa, P. M., & Bento, N. (2021). Accelerate energy transition with smarter regulation for faster grid digitalization.

[9] McHenry, M. P. (2013). Technical and governance considerations for advanced metering infrastructure/smart meters: Technology, security, uncertainty, costs, benefits, and risks. Energy Policy, 59, 834–842. https://doi.org/10.1016/j.enpol.2013.04.048

[10] Montero, J., & Finger, M. (2021). A modern guide to the digitalization of infrastructure.

[11] Nugraha, M. A., Nashiruddin, M. I., & Hutagalung, G. (2021). Narrow-Band Internet of Things for Smart Metering Infrastructure in Urban Area: Medan City Case. ICOIACT 2021 - 4th International Conference on Information and Communications Technology: The Role of AI in Health and Social Revolution in Turbulence Era, 215–220. https://doi.org/10.1109/ICOIACT53268.2021.9563972

[12] Sareen, S. (2021). Digitalisation and social inclusion in multi-scalar smart energy transitions. Energy Research and Social Science, 81. https://doi.org/10.1016/j.erss.2021.102251

[13] U.S. Department of Energy. (2016). Advanced Metering Infrastructure and Customer Systems: Results from the Smart Grid Investment Grant Program.

[14] Wan, L., Zhang, Z., & Wang, J. (2019). Demonstrability of Narrowband Internet of Things technology in advanced metering infrastructure. Eurasip Journal on Wireless Communications and Networking, 2019(1). https://doi.org/10.1186/s13638-018-1323-y

[15] World Bank Group. (2016). THE BOTTOM LINE - Can Utilities Realize the benefits of Advanced metering infrastructure?