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Smart Energy Meters in Renewable-Energy-Based Power Networks: An Extensive Review †

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Abstract: The substantial growth in energy utilization, and the expansion of renewable energy resources, mainly winds and solar, poses challenges to the environment and energy security. Therefore, smart energy meters (SEMs) are the bottom-line modules in such renewable-energy-based networks (REBNs). Apart from the measurement of energy flows, smart energy meters are capable of the give-and-take of complete information on the utilization of energy and the status of energy networks between end consumers and utilities. Moreover, according to the individual consumer's commands, the SEMs can also be utilized for the monitoring and control of the consumer's electrical devices. The presented paper scientifically reviews the present development of SEMs, together with the other meters such as smart gas (SG), smart heat (SH), and electricity (SE) meters. Furthermore, we present the various functions and applications of SEMs. Lastly, this paper provides conclusive remarks and the future direction of SEMs.

Keywords: renewable-energy-based networks; smart energy meters; smart grid infrastructure

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1. Introduction

The modern economy is driven by electrical power, and the worldwide GDP increased from 16,254 billion US dollars (USD) to 54,588 billion USD from 1971 to 2012. The main energy utilization was enhanced from 231,440 Peta-joules (PJ) to 559,818 PJ in a similar period [1]. Smart meter technology has evolved through different techniques in the last decade and has made this sector commercially viable. Energy resources are the future of the modern electrical world to produce green and clean energy. Elevated energy efficiency is seen as a critical way to address the issues, leading to the development of REBNs [2,3]. REBNs are used here to portray and encompass a broad concept that includes smart electricity grids, smart district heating (DH) networks, and smart natural gas (NG) infrastructures. Smart energy meters, contrary to conventional energy meters, measure energy utilization, exchange data on energy utilization, and inform consumers and utilities about the status of operations. More precisely, the ultimate crucial feature of SEMs in REBNs is bidirectional communication among meters and other devices, as well as between meters and meters [4,5].

Currently, different kinds of SEMs are employed in practice, for example, gas meters, electricity meters, and heat meters. To achieve the coordination of heating, electricity, and gas systems, it is critical to understand their features and functionalities, and also their future development [6].

By analyzing the present studies on smart energy meters, we found that the technologies and processes in the smart meter infrastructure are likely to advance substantially in the near future [7,8]. However, the information gaps that need to be closed for development purposes include the following:

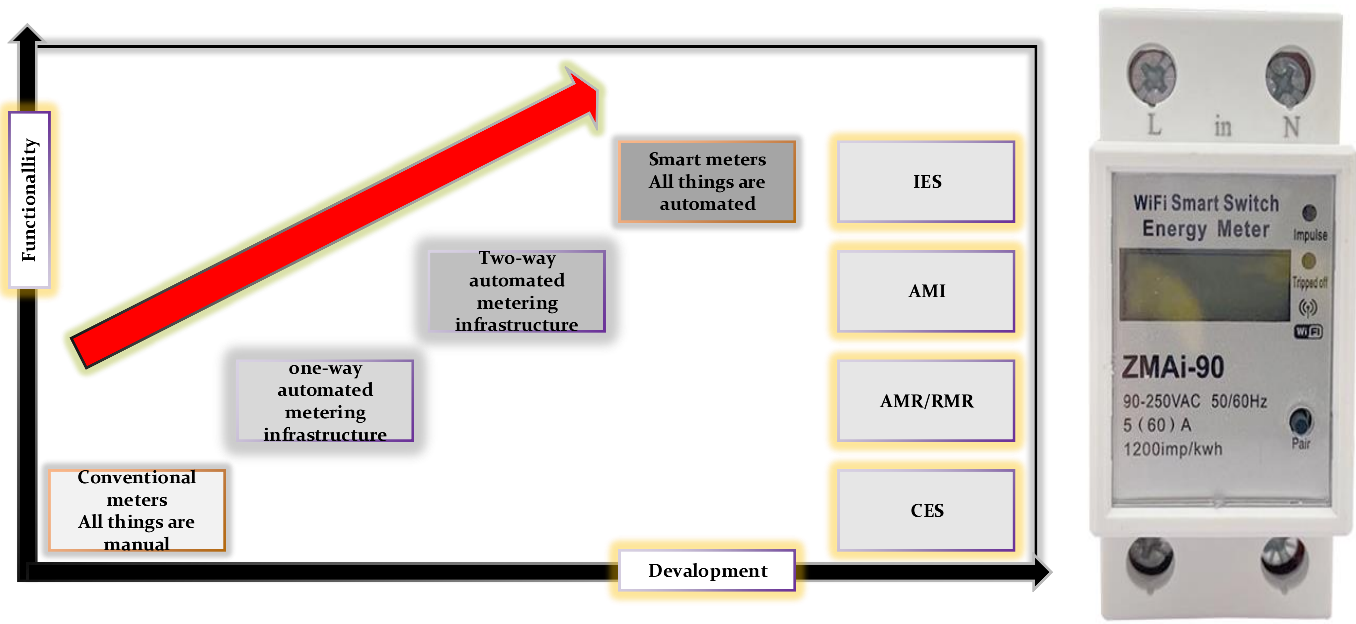
(1) There is a lack of systematic evaluation of what benefits can be achieved by using SEM. The present studies focus heavily on the technical information of the numerous occupations, some of which, however, may not be applicable or required at the present stage. On the demand side, the required functions should be assessed based on the profit margins [9].

(2) The Task Force on Smart Grids of the European Union Commission's Team of Experts 4 recommended that the advancement of electrical, gas, heating, and cooling networks be associated with each other, accomplishing what is known as cooperation, which can be beneficial. Energy efficacy has reached a high level and continues to create reliable, robust, and stable energy networks [10,11].

Therefore, this paper aims to provide a systematic review of SEM development, to achieve the aforementioned objectives. Therefore, the entire paper is organized as follows: Section 2 gives details of the current distribution of SEM and intelligent electricity (SE), intelligent temperature (SH), and intelligent gas meters (SG). Key activities and uses of SEMs, as well as a cost–benefit analysis, are set out in Section 3. Finally, the concluding comments and future SEM approaches are presented in more detail in Section 4.

2. Review of the Present Development of SEMs

The development of smart meters and installed functions can be seen in Figure 1a; however, in Figure 1b, a Wi-Fi smart switch (ZMAi-90) energy meter can be seen. Before smart meters, conventional electric meters were the prime instruments used to measure the flow of electricity. Estimated data are usually unveiled in an analog counter and should be recorded in person. Smart meters use two-way communication to measure energy and power consumption, charging information, and the state of power networks. The ability to use two connections is a key factor that separates standard meters from smart meters. Recent developments in smart meters, as well as infrastructure for renewable-energy-based networks (REBNs), perform the following functions [12,13]:



(a) (b)

Figure 1. (**a**). Development and featured functions of smart electricity meters (**b**). Wi-Fi smart switch (ZMAi-90) energy meter [4,12–14].

(1) End-to-end connections;
(2) Automatic and bidirectional balancing and paying customers accordingly;
(3) Monitoring of electrical equipment;
(4) Control of electrical equipment;
(5) System error detection and diagnosis;
(6) Data storage;
(7) Management of data;
(8) Complex applications such as demand-side management, power theft detection, system security improvements, load management, and smart urban development [14]. A detailed analysis of smart electricity (SE), smart heat (SH), and smart gas (SG) meters is summarized in Table 1.

Table 1. The detail analysis of smart electricity (SE), smart heat (SH), and smart gas (SG) meters.

Content	Smart Electricity Meter	Smart Heat Meter	Smart Gas Meter
Meter type	Electro-mechanical	Dynamic/static meter	Diagram/bellows meter
Meter development	Developing toward IENs		Beyond the stage of AMR
Deployment	Many deployment projects in Europe and USA, while some have been delayed.	Far from smart electricity meters, and few projects have been deployed, mainly remote reading meters.	
Functions and applications	Most smart electricity meters are equipped with basic functions, including regular and precise metering, data recording and alarming, and two-way communication.	No technical barriers to equip smart heat and gas meters with the functions of regular and precise metering, data recording and alarming, and two-way communication.	
Costs and benefits	The application of smart electricity meters can generate a significant amount of benefits, mainly for suppliers. The cost of smart meters is also very large and the distribution of the cost may be a problem.	The general costs and benefits for smart heat and gas meters are quite similar to those for smart electricity meters, although there so far have not been many large-scale deployment projects.	Compared with benefits, costs have a larger impact on decision making.

3. The Main Functionalities and Applications of SEMs

Based on a two-way communication function, a wide range of functionalities have been established and included in SEMs. Therefore, these changes have greatly increased the use of smart meters. Most of the features can be used to enhance the transmission of intelligent energy meters and smart heat meters.

3.1. Load-Side Management

Another important feature and one of the fastest-growing applications of SEMs is demand-side management. The general principle of power generation is that the supply side meets the energy requirement of the load side in such a way that the power system remains balanced. In contrast, demand-side management, which has become a prevalent concept in recent years, refers to a change in power consumption by managing consumer behavior [6,7,15].

3.2. Data Recording and Alarming

Another useful feature is to properly record data and send alarms, which is directly related to a normal and accurate meter. In addition, data recording and alarming are required for resources the monitoring of power networks, and they are beneficial to consumers who want to know more about their energy consumption [13]. Users should always purchase a set amount of energy and afterwards recharge it using an integrated circuit (IC) card or key card [15].

3.3. Regular Metering and Precision

Normal and accurate measurement is the extremely basic function of a power meter. The main goal of REBNs is to reduce energy spending and this depends on general and accurate statistics about energy allocation and demand. The current development of REBNs frequently necessitates intelligent meters to be used for hourly or even more frequent measurements [6].

3.4. Bidirectional Communication

The superlative, essential and silent feature of intelligent energy meters is two-way communication. When we talk about two-way communication, we refer to collaborative communication between service providers and end-users. A communication unit is required in SEMs, as it is responsible for sending measured data or instructions for particular actions [14].

Over 50 countries are going to deploy a plan to implement smart energy meters. Some of the large deployment programs are listed in Table 2.

Table 2. Large deployment programs in the world.

Country	Types of Meter	No. of Meters	Period
UK	Electricity meter, gas meter	53 million in total	By the end of 2019
France	Electricity meter, gas meter	35 million 11 million	By 2018: 2014–2020
Ireland	Electricity meter, gas meter	2.2 million 0.6 million	By 2019
Italy	Electricity meter	36 million	By 2011
The Netherlands	Electricity meter	7 million in total	2012–2015
Spain	Electricity meter	26 million	By the end of 2018
Malta	Electricity meter	250,000	By the end of 2014
Finland	Electricity meter	550,000	2009–2013
Denmark	Heat meter	30,000	By the end of 2013
Sweden	Heat meter	2.4 million	Since 2010
India	Electricity meter	150 million	2013–2025
USA	Electricity meter	Over 36 million	Since 2010
Australia (Victoria state)	Electricity meter	2.5 million	By the end of 2013
China	Electricity meter	230 million	By 2015
China (Tianjin)	Heat meter	1.17 million	By the end of October

4. Conclusions and Future Directions

According to this review, smart meter technologies and further wide-ranging applications assisted by SEMs have remarkable advantages over traditional energy systems. Furthermore, the future of REBNs progression is becoming increasingly clear. (1) The electricity meters will become intelligent and much more versatile as a result of a compostable framework, in which the meter is fabricated as an open structure with new functionality incorporated by adding new modules. Moreover, to accomplish the function of smart-metering, another option is set in a SEM unit into other appliances. (2) REBNs becoming "smarter" or "more intelligent" represent the basic path of progression for not only electricity grids but also DH and NG networks. In the future, more intelligent functions will be realized. (3) There are numerous energy networks. The networking of electricity, heat, gas, and even water is likely to occur, greatly improving the convenience and quality of people's lives.

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