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OPINION
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Power Prosumer Internet of Things: Architecture, Applications, and Challenges

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1 INTRODUCTION

Prosumers refer to users who not only consume energy as a power load, but also share energy with the power grid or other energy consumers as a power source, extensively consisting in the power consumption side, such as distributed photovoltaic prosumers, electric vehicles (EV), etc (Rathnayaka et al., 2011). Power Prosumer Internet of Things (PPIoT) is the application of the Internet of Things (IoT) in the smart grid, as well as the result of the development of information and communication technology to a certain extend. It will effectively integrate the communication infrastructure resources and prosumers in power system, promoting the transformation from traditional power distribution and consumption network to digital smart power grids.

Investigations on the architecture of the PPIoT is a crucial crutch for the optimized and efficient operation of the PPIoT. Firstly, on account of being the terminal link of power system, as the window for prosumers to broadly access and participate in the interaction with the power grid, the operation status of the prosumer network is the most immediate and intense to the experience of prosumers, and its secure and efficient operation is the core to ensure the reliability of power supply and power consumption. Secondly, the low voltage level, short construction period, as well as the limited influence scope of any single device makes the prosumer network relatively suitable for new technologies and devices to pilot, and promote rapidly. Thirdly, the construction and development of the PPIoT is a significant support to actualize friendly interaction between the power grid and prosumers. Therefore, investigations on the architecture of the PPIoT is the crux to achieve the integration of the power system and the IoT, which is conducive to boost the application of new technologies in all links of the IoT and the prosumer network, and provide a powerful crutch for the development of competitive business of the power grid.

2 ARCHITECTURE OF PPIOT

Based on the intelligent terminal acquisition equipment, various types of data such as electrical information and environmental conditions can not only be analyzed, transmitted, and simply decision-making controlled locally, but also transmitted to remote platforms or even the internet through the PPIoT. Meanwhile, the data is deeply perceived and processed efficiently by the demand of prosumers to provide more high-quality value-added services and actualize the interaction between prosumers, equipment and the power grid. In terms of the characteristics of the PPIoT, its network layer can be divided into perception layer, network layer, platform layer and application layer, as shown in **Figure 1**.

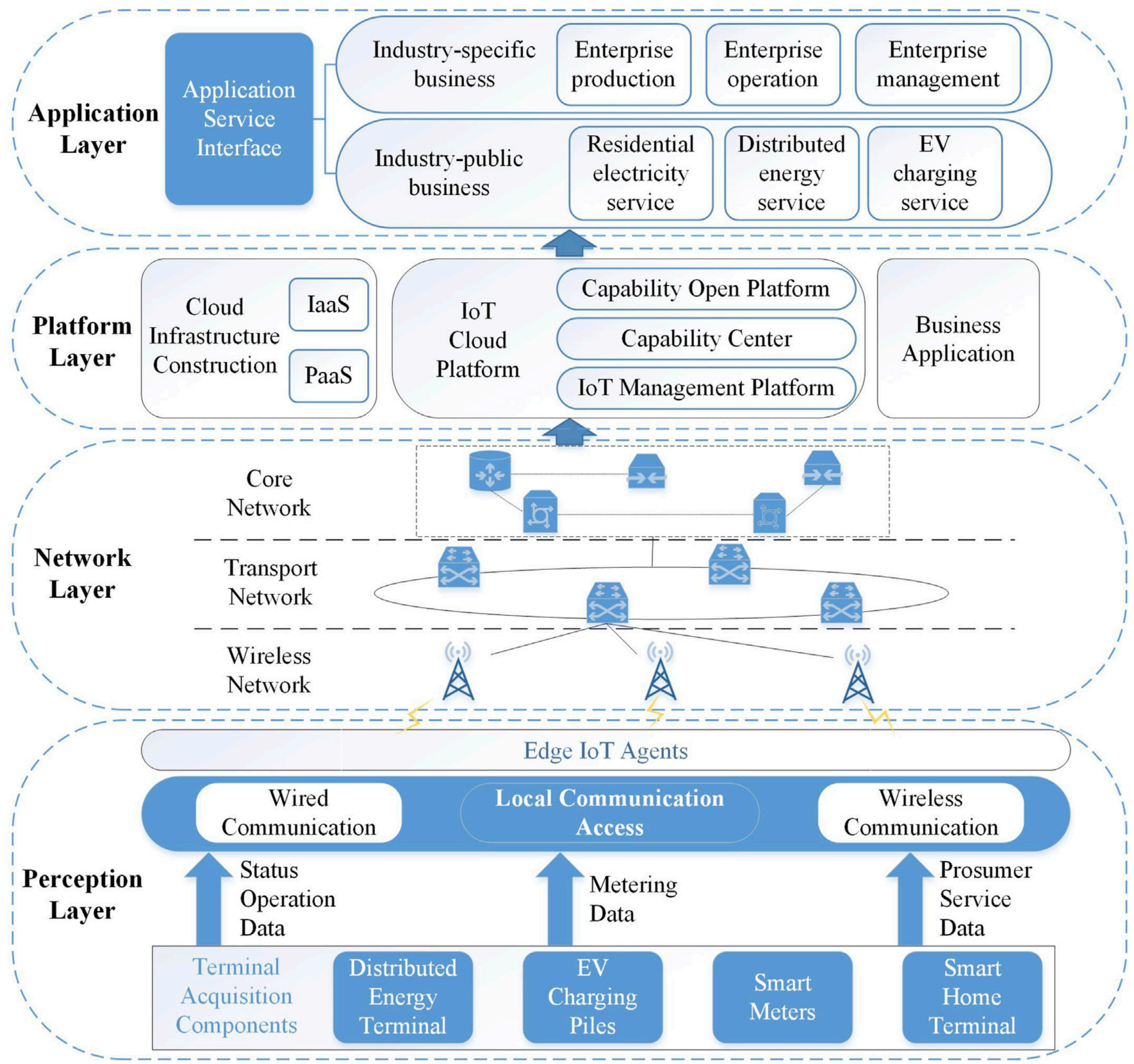

FIGURE 1 | Hierarchical architecture of PPIoT.

The perception layer is the sensing basis of the PPIoT, as well as the source of information and data of the network layer. The perception layer consists of terminal acquisition components, intelligent business terminals, local communication access, and edge IoT agents. On-site acquisition components measure and glean power facility data, congregate and upload data to the platform through intelligent business terminals. The production control data of the status operation data and metering data is connected to the business system through local communication, and the non-production control data is connected to the data platform through the edge IoT agent as demanded. The main technologies of the perception layer include intelligent perception technology (Bedi et al., 2018) and edge computing technology (Rusitschka et al., 2010).

The network layer realizes the transmission of gleaned information from the perception layer to the platform layer to ensure the effectiveness and security of information transmission. The network layer is comprised of wireless network, transport network, and core network. The wireless network provides the wireless link between the perception layer and the core network and allocates channel resources for service terminals. The transport network provides backhaul services from the base station to the core network as well as the transparent transmission services of point-to-point communication between any base stations. The core network achieves prosumer authentication, session management between the terminal and the core network, and terminal mobility management. The main technologies of the network layer include Wi-Fi technology (Srivastava et al., 2018) and WiMAX technology (Safak et al., 2007).

The platform completes the real-time collection and update of transmission data from the network layer, and provides cross-domain sharing of data resources to specific advanced application based on big data storage and analysis technology. It is logically divided into three parts: cloud infrastructure construction, IoT cloud platform, and business applications. The cloud infrastructure layer is required to realize the construction of cloud basic resources, including the basic resources of IaaS + PaaS layer. The IoT cloud platform includes IoT management platform, capability center, and capability open platform, realizing connection management, device management, application support, and network security (Wu, 2017), as well as the operation and maintenance management of the platform layer. The business applications are connected to the application layer based on the service interface provided by the capability open platform. The main technologies of the platform layer include big data storage and management technology (Huang et al., 2020a), prosumer identity management and access control technology (Sui and de Meer, 2020).

The application layer is the concentrated representation of prosumer business of the power grid, which is supposed to contain functions such as data services and business services. It is connected with the platform layer through the application service interface to realize the standardization of external data access for power distribution and consumption business applications. Various targeted application platforms are required to be constructed to achieve the interaction between the power grid, prosumers and integrated energy in accordance with the industry-specific business related to the production, operation and management of the enterprise, and the industry-public business such as residential electricity service (Onibonoje, 2021), distributed energy service (Slay and Bass, 2021), EV charging service (Kvisle and Myklebust, 2013).

3 APPLICATIONS OF PPIOT

The main application modes of the PPIoT include: intelligent perception and collection of information, environmental measurement and tracking, and intelligent control of equipment (Saleem et al., 2019). The power prosumer business involves power prosumer information acquisition, smart home service, power prosumer management, EV charging services, as well as coordinated operation of distributed power generation, and energy storage (He et al., 2018; Zeng et al., 2021). The application of IoT technology in the field of power prosumer is conducive to realize the sinking of the basic data connections, and the friendly interaction between power grid and prosumers.

Power prosumer information acquisition and equipment condition monitoring: the multi parameter sensing integration technology of the PPIoT is applied to deploy intelligent sensing terminal equipment such as intelligent electricity meter, which is capable to obtain more precise power equipment data (Chen et al., 2019). The gleaned data is utilized in the distributed data analysis infrastructure and different disaster recovery strategies can be effortlessly deployed or replaced in a plug-and-play manner to realize active awareness and rapid early warning of fault situation (Barbierato et al., 2019). The active collection of power generation data and load data of power prosumers is conducive to the flexible and collaborative regulation of distributed energy and active load.

Smart home management and power prosumer management: the local communication technology, intelligent data processing and edge computing technologies of the PPIoT can effectively improve the power prosumer management structure. A technology to process a large amount of information in a short time has been proposed, which generates power consumption trends and statistics from years of information storage, and then acquires the power demand of each distribution company (Correa et al., 2017). By deploying the edge computing layer near power prosumers and applying cloud edge collaboration technology, we can reduce the communication pressure between edge nodes and power grid dispatching center, and alleviate the problems of high real-time power grid operation, short data cycle and complicated tasks. Furthermore, a holistic energy management system has been proposed, which is jointly designed by microgrid and edge computing system and applied in smart home scenarios (Li et al., 2018).

EV charging services and household energy services: the application of low-power wireless communication technology and intelligent control terminal can fully obtain the diversified data of EV identity and battery status, which can be utilized to orderly charge electric vehicles and formulate active peak shaving charging management scheme (Huang et al., 2020b). The gleaned data of household energy system can be utilized to accurately formulate the power prosumer model and bring prosumer resources into the collaborative flexible control of power grid, providing prosumers with personalized services and diversified interactive modes such as optimizing contract energy management (Zhang et al., 2022) and power safety protection, and promoting the integrated development of source and load.

4 CHALLENGES

Although smart meters, wireless sensors, IoT computing platform and other advanced technologies of IoT have been applied in the aspects of household power information collection and power data processing, power equipment monitoring and management, the integration of power prosumer network and IoT is still in the initial stage, and the construction of PPIoT still needs to overcome several technical problems. The challenges faced by the development of PPIoT are put forward from two aspects as follows.

Insufficient coverage of power grid sensing terminal equipment: With the increasing coverage of distribution network and the increase of access equipment, the network becomes more sophisticated and heterogeneous. It is difficult to deploy massive sensors with different types and scattered locations. The measuring device faces problems such as large volume, high cost, high power consumption and difficult operation and maintenance, which makes the coverage of bottom terminal equipment insufficient and restricts the refinement of distribution system regulation. Therefore, it is urgent to improve the coverage of the bottom sensing terminal of the power grid and the robustness of the communication network.

Lack of unified data model and communication standards: The existing automation systems and communication information platforms promoted and applied in many pilot projects have diverse data specifications, therefore, the data cannot be effectively shared and managed, forming an information island. The construction of the future PPIoT should consider the seamless connection and information security interaction of multiple types of communication systems. It is requisite to consider the unification of data standards and models, system technical architecture and platform entrance, to achieve the connection, sharing and integration of data, improvement of data utilization, and interconnection between systems.

AUTHOR CONTRIBUTIONS

FP: writing the original draft and editing. YY: conceptualization. CZ and JZ: formal analysis. YF and RL: visualization and contributed to the discussion of the topic.

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REFERENCES

Barbierato, L., Estebsari, A., Pons, E., Pau, M., Salassa, F., Ghirardi, M., et al. (2019). A Distributed IoT Infrastructure to Test and Deploy Real-Time Demand Response in Smart Grids. *IEEE Internet Things J.* 6 (1), 1136–1146. doi:10.1109/JIOT.2018.2867511

Bedi, G., Venayagamoorthy, G. K., Singh, R., Brooks, R. R., and Wang, K.-C. (2018). Review of Internet of Things (IoT) in Electric Power and Energy Systems. *IEEE Internet Things J.* 5 (2), 847–870. doi:10.1109/JIOT.2018.2802704

Chen, H., Wang, X., Li, Z., Chen, W., and Cai, Y. (2019). Distributed Sensing and Cooperative Estimation/Detection of Ubiquitous Power Internet of Things. *Prot. Control Mod. Power Syst.* 4, 13. doi:10.1186/s41601-019-0128-2

Correa, E., Inga, E., Inga, J., and Hincapie, R. (2017). "Electrical Consumption Pattern Base on Meter Data Management System Using Big Data Techniques," in 2017 International Conference on Information Systems and Computer Science (INCISCOS), 334–339. doi:10.1109/INCISCOS.2017.19

He, Y., Chen, Y., Yang, Z., He, H., and Liu, L. (2018). A Review on the Influence of Intelligent Power Consumption Technologies on the Utilization Rate of Distribution Network Equipment. *Prot. Control Mod. Power Syst.* 3, 18. doi:10.1186/s41601-018-0092-2

Huang, C., Huang, Q., and Wang, D. (2020a). Stochastic Configuration Networks Based Adaptive Storage Replica Management for Power Big Data Processing. *IEEE Trans. Ind. Inf.* 16 (1), 373–383. Jan. 2020. doi:10.1109/TII.2019.2919268

Huang, Z., Fang, B., and Deng, J. (2020b). Multi-Objective Optimization Strategy for Distribution Network Considering V2G-Enabled Electric Vehicles in Building Integrated Energy System. *Prot. Control Mod. Power Syst.* 5, 7. doi:10.1186/s41601-020-0154-0

Kvisle, H. H., and Myklebust, B. A. (2013). "Development of Charging Station Data Services for New User Groups," in 2013 World Electric Vehicle Symposium and Exhibition (EVS27), 1–6. doi:10.1109/EVS.2013.6914835

Li, W., Yang, T., Delicato, F. C., Pires, P. F., Tari, Z., Khan, S. U., et al. (2018). On Enabling Sustainable Edge Computing with Renewable Energy Resources. *IEEE Commun. Mag.* 56 (5), 94–101. doi:10.1109/MCOM.2018.1700888

Onibonoje, M. O. (2021). "An IoT Design Approach to Residential Energy Metering, Billing and Protection," in 2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 1–4. doi:10.1109/IEMTRONICS52119.2021.9422580

Rathnayaka, A. J. D., Potdar, V. M., and Kuruppu, S. J. (2011). "An Innovative Approach to Manage Prosumers in Smart Grid," in 2011 World Congress on Sustainable Technologies (WCST), 141–146. doi:10.1109/WCST19361.2011.6114211

Rusitschka, S., Eger, K., and Gerdes, C. (2010). "Smart Grid Data Cloud: A Model for Utilizing Cloud Computing in the Smart Grid Domain," in 2010 First IEEE International Conference on Smart Grid Communications, 483–488. doi:10.1109/SMARTGRID.2010.5622089

Safak, A., Ozdem, M. S., and Uyanik, E. (2007). "Performance Analysis of WIMAX (802.16e) Systems," in 2007 IEEE 15th Signal Processing and Communications Applications, 1–4. doi:10.1109/SIU.2007.4298695

Saleem, Y., Crespi, N., Rehmani, M. H., and Copeland, R. (2019). Internet of Things-Aided Smart Grid: Technologies, Architectures, Applications, Prototypes, and Future Research Directions. *IEEE Access* 7, 62962–63003. doi:10.1109/ACCESS.2019.2913984

Slay, T., and Bass, R. B. (2021). "An Energy Service Interface for Distributed Energy Resources," in 2021 IEEE Conference on Technologies for Sustainability (SusTech), 1–8. doi:10.1109/SusTech51236.2021.9467416

Srivastava, P., Bajaj, M., and Rana, A. S. (2018). "Overview of ESP8266 Wi-Fi Module Based Smart Irrigation System Using IOT," in Overview of ESP8266 Wi-Fi module based Smart Irrigation System using IOT," 2018 Fourth International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 1–5. doi:10.1109/AEEICB.2018.8480949

Sui, Z., and de Meer, H. (2020). BAP: A Batch and Auditable Privacy Preservation Scheme for Demand Response in Smart Grids. *IEEE Trans. Ind. Inf.* 16 (2), 842–853. Feb. 2020. doi:10.1109/TII.2019.2926325

Wu, S. (2017). An Adaptive Limited Wide Area Differential Protection for Power Grid with Micro-sources. *Prot. Control Mod. Power Syst.* 2 (3), 220–228. doi:10.1186/s41601-017-0052-2

Zeng, L., Li, C., Li, Z., Shahidehpour, M., Zhou, B., and Zhou, Q. (2021). Hierarchical Bipartite Graph Matching Method for Transactive V2V Power Exchange in Distribution Power System. *IEEE Trans. Smart Grid* 12 (1), 301–311. Jan. 2021. doi:10.1109/TSG.2020.3016597

Zhang, K., Zhou, B., Chung, C. Y., Bu, S., Wang, Q., and Voropai, N. (2022). A Coordinated Multi-Energy Trading Framework for Strategic Hydrogen Provider in Electricity and Hydrogen Markets. *IEEE Trans. Smart Grid*, 1. doi:10.1109/TSG.2022.3154611

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