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Design and Development of an IoT Smart Home and Smart Grid Testbed in a Residential Living Lab

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***Abstract*—In this paper, we describe the design process for the deployment of a 50-household IoT smart home and smart grid testbed in a residential living lab environment. We examine our design choices and how we have implemented an "hourglass" paradigm with MQTT at its core to provide the necessary extensibility, modularity, and compatibility. The testbed is constructed utilizing peripheral devices such as commercially available off-the-shelf (COTS) sensors and gateways based on single board computers (SBCs) running open-source home automation frameworks. Furthermore, we address the development of essential tools vital for the ongoing monitoring and maintenance of the testbed infrastructure. Finally, we discuss on how we enabled efficient data discovery and exchange through ontologies and a semantically interoperable framework in order to support a series of illustrative pilot use cases that highlight the practicality and potential of our testbed. These include the application of machine learning techniques to facilitate data analytics, the orchestration of user engagement strategies, and the implementation of demand response schemes.**

***Index Terms*—IoT, smart home, smart grid, living lab, testbed, data interoperability, experimental infrastructure**

I. Introduction

Over the past few years, significant progress has been made in advancing communication networks from 5G to the emerging 6G. In contrast, the transformation of the power grid, known as the "smart grid," has been more gradual. The smart grid involves creating an intelligent, automated, and interconnected electricity network to optimize power delivery, monitor energy consumption in real-time, and accommodate diverse energy sources efficiently. The term "smart grid" was coined in the late 20th century, but its implementation has continuously evolved worldwide due to limited resources, infrastructure constraints, and other competing priorities hindering rapid deployment [1], [2].

Similar to communication networks, smart grid networks pave the way for various vertical applications and stakeholders in the energy domain. Alongside traditional System Operators (DSOs, TSOs), new players such as energy consumers, technology providers, IoT and communication companies, research institutions, and cybersecurity experts participate in modernizing electricity networks.

Internet of Things (IoT) technology plays a critical role in designing and implementing smart grids. The IoT paradigm enables real-time data collection, communication, and control of grid-connected devices and systems. Testing and validating IoT-based smart grid technology rely heavily on experimental platforms, providing controlled environments for researchers and stakeholders to evaluate real-world scenarios and the performance of their solutions for more efficient, reliable, and sustainable electricity grids.

To support this transformation and facilitate testing, we have deployed an experimental platform, an IoT smart home and smart grid testbed for innovative energy applications and IoT-based solutions. This platform enables constrained yet realistic testing before real-world deployment. It aims to evaluate new concepts, protocols, algorithms, and devices for various application domains, including analytics and data management, Electric Vehicle (EV) charging infrastructure, and demand response and load management.

The organization of the paper is outlined as follows: Section II presents similar activities, while Section III analyzes hardware and software components along with the reasons for specific decisions. Moreover, it covers the creation of necessary tools crucial for ongoing monitoring and maintenance of the testbed infrastructure. Moving on, Section IV the usage of ontologies for data interoperability is highlighted for enabling characteristic and illustrative pilot demonstrations of use cases, which form an integral part of research endeavors involving essential stakeholders. Finally, Section V concludes the work and outlines future plans.

II. Related Work

In the field of experimental infrastructures for the IoT smart home and smart grid, a large number of testbeds have been developed globally, but very few outside of a laboratory setting [3], [4]. To highlight vertical applications in the smart homes and smart grid domains, few have utilized a living lab environment with actual consumers. To our knowledge, no living lab has attained a scale of fifty households, providing the infrastructure to evaluate research and business use case scenarios.

A living lab based on student dormitories was implemented as a smart grid testbed at the Singapore University of Technology and Design (SUTD) [5]. The testbed is capable of monitoring, analyzing, and evaluating smart grid communication network design and control mechanisms, as well as testing the suitability of various communication networks for both residential and commercial buildings. It is based on student dormitories, which makes the case studies very specific to seasonality characteristics due to the fact that dormitories are typically occupied only during semesters and their occupants

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change annually. In our case, we focus on real houses in a city, which allows us to create a variety of consumer profiles based on the residents of each house, who may be single individuals, families, or roommates. PowerMatching City is a living lab Smart Grid demonstration in the Netherlands consisting of 25 interconnected households [6]. This project showcases a market model and coordination mechanism designed to enable essential multi-goal optimization within the smart grid. On the basis of a real-time (local) electricity market, it provides transparent cost relations for commercial optimization and simultaneous active capacity management.

In [7], the authors evaluate a system architecture that offers smart building monitoring and management in a university building. In [8], a testbed in Hamburg is created to collect network measurements for analyzing the impact of consumer Internet connectivity on (future) smart grid applications, while in [9], a 'Field Test Laboratory' in Wunsiedel provides a testbed to other utilities and developers of grid technologies to evaluate the economic benefit and the efficacy of any future investment into the smart grid. In Norway, a set of joint multisector initiatives [10], including living labs and demonstrations, aim to cast light on the challenges posed by the smart grid. In Korea, a testbed [11] was constructed to evaluate the safety, durability, and interoperability of smart grid technologies prior to their implementation on actual infrastructures.

Even though some of the aforementioned experimental infrastructures are large-scale, they are typically focused on demonstrating specific case studies, either concentrating on smart grid or smart homes, thereby missing the big picture of how IoT integrates both domains for new actors and business scenarios. In addition, once the demonstrations are complete, they are typically dismantled or abandoned because reproducibility and scalability were not among the initial requirements. Our work focuses on the provision of an experimental infrastructure that provides a living lab capable of hosting use cases based on Internet of Things (IoT) smart residences and smart grid applications, while remaining flexible and expandable with new devices and services.

III. Testbed Architecture

In the city of Volos in Greece, the experimental platform has been developed and deployed in approximately 50 households that comprise a living lab. The residences are outfitted with the necessary hardware for conducting experiments and evaluating IoT-based services in the smart homes and smart grid domains. The system is built using edge devices such as commercially available off-the-shelf (COTS) sensors and gateways based on single board computers (SBCs) operating open-source home automation frameworks. Additionally, open-source libraries are used to facilitate the integration of devices from various manufacturers and wireless communication technologies. For data storage, processing, and computationally intensive duties such as data analytics, cloud services are utilized. The selection of hardware and software components was influenced by scalability, reliability, and experimentation potential. By utilizing COTS sensors, the system enables rapid deployment in actual homes, where users can interact with commercial products rather than laboratory prototypes, without being limited to a particular vendor or communication technology. In addition, the SBC-based gateway offers an adaptable platform for parameterization and experimentation with open-source frameworks and custom services.

A. Hardware Components

1) IoT Gateway: An essential component for enabling an IoT-assisted home energy management system (HEMS) is a versatile IoT Gateway that supports home automation frameworks and digital services. This technology enhances energy resource utilization by addressing the gap between energy supply and grid demand. We chose the Raspberry Pi 4B as our IoT gateway due to its compact size, wide availability, cost-effectiveness, growth potential, wireless communication capabilities, and computational power.

The IoT Gateway seamlessly integrates with diverse energy-consuming devices and sensors within a home, such as smart plugs, energy meters, and sensors from various vendors employing different radio technologies. It establishes compatibility through embedded Wi-Fi and Bluetooth or USB dongles enabling radio technologies like ZigBee and Z-Wave.

Collecting data from edge devices, the IoT Gateway acquires information like energy consumption, power utilization, and environmental data, transmitting it to cloud-based services for analysis. Homeowners gain insights into their energy consumption patterns, facilitating informed energy management decisions through cloud capabilities.

Deploying the IoT Gateway enables remote monitoring and control of energy-consuming devices. It accesses data from sensors and energy meters with a 10-second measurement granularity, empowering users to proactively manage energy consumption.

Furthermore, thanks to the computational capabilities of the Raspberry Pi, it becomes possible to deploy specialized services. These services act as middleware to receive commands from external systems or services and seamlessly transmit them to the corresponding IoT actuators using the available networking interfaces. The external systems or services can encompass a DSO system linked with the HEMS, a demand response service, or even a mobile application under the homeowner's control. This versatility allows for a diverse range of applications and enhances the Gateway's capabilities to cater to various user needs.

This IoT Gateway described herein offers a potent solution for optimizing home energy management. Supporting seamless device integration, efficient data aggregation, real-time monitoring, and control, it proves critical for smart and energy-efficient homes. Its utilization of the Raspberry Pi SBC ensures practicality and scalability, making it an attractive choice for modernizing residential energy management systems.

2) IoT Edge Devices: IoT edge devices refer to the devices that form the outermost layer of an IoT network. These devices are responsible for collecting data from the physical world, processing it locally, and transmitting pertinent data to the gateway or cloud for further analysis and decision-making. In

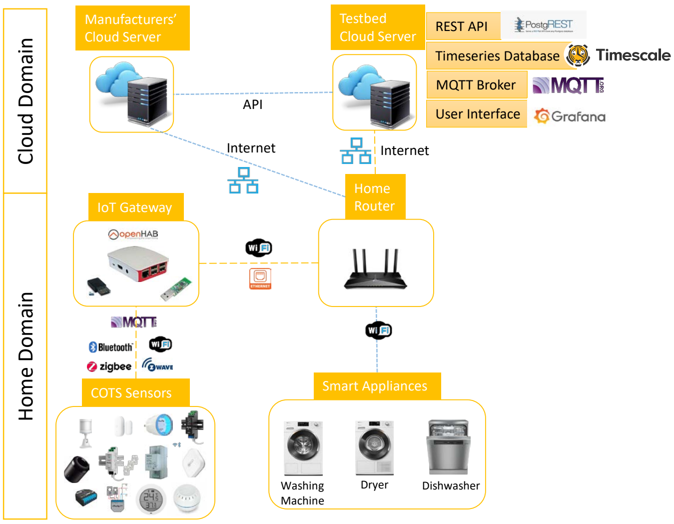

Fig. 1. Testbed Architecture

our living lab configuration, we have a variety of IoT devices ranging from tiny sensors to large devices such as smart home appliances. The following is a list of the fundamental categories of IoT edge devices used in our testbed:

- **Smart meters:** The IoT smart meters are installed on DIN rails within electrical panels to provide a standardized and simple method of receiving real-time energy consumption data without the need to interfere with the energy meter from the Distribution System Operator (DSO). In our configuration, we have experimented with numerous Z-Wave, Wi-Fi, and Ethernet-equipped energy meters. Specifically, our testbed encompasses the utilization of Z-Wave smart meters sourced from Aeotec and Qubino, as well as Wi-Fi/Ethernet smart meters provided by Shelly. This deliberate choice ensures a holistic understanding of energy consumption patterns while catering to various technological preferences.
- **Smart plugs:** For submetering, we've employed smart plugs equipped with ZigBee or Wi-Fi communication modules that can capture energy consumption data every second. In addition, smart plugs can be used for remote control of plugged-in devices, providing a means of transforming legacy dumb devices into smart connected devices. Our experimental infrastructure includes ZigBee smart plugs by BlitzWolf, while the predominant choice for equipping houses has been Wi-Fi smart plugs from Shelly.
- **Smart relays:** Similar to smart plugs, smart relays are designed to monitor and control electrical devices and are typically installed within electrical panels or distribution boxes, making them a permanent part of the electrical infrastructure. Smart relays are frequently used for lighting control, motor control, HVAC system automation, and the control of heavy-load devices such as electrical water boilers. Our selection of smart relays encompasses offerings from Shelly, ABB, and Legrand.
- **Sensors:** In the realm of sensors, there is no restriction on what can be detected, resulting in the creation and collection of a measurement data point. Z-Wave, ZigBee, Wi-Fi, and LoRa are the most prominent communication protocols used by the numerous IoT sensors. We have chosen to equip 50 houses with a basic set of ZigBee sensors, including an indoor and outdoor sensor for temperature and humidity, a door contact sensor, and a motion & luminosity sensor, in order to monitor the environment and have a basic set of data for augmenting energy measurements with environmental and human presence data points. Our predominant sensor sources have been ZigBee and Bluetooth devices from Xiaomi and Aqara, chosen for their dependable performance and cost-effectiveness.
- **IoT Actuators:** In the orchestration of a smart home, actuators play a pivotal role in effecting environmental adjustments in response to commands dispatched by IoT HEMS. Beyond the integration of smart plugs and smart relays, a key addition to the residences comprises IR (Infrared) hubs. These hubs are tasked with the control of devices employing infrared signals, encompassing televisions, air conditioners, and home entertainment systems. To fulfill this purpose, we've selected products from Broadlink for our IR hub implementations.
- **Smart Appliances:** Home appliances, such as washing machines, dryers, and dishwashers, that are equipped with IoT technology, can connect to the internet, and offer advanced features and control options. One of the key features of smart appliances is the ability to remotely schedule the operation's start time and shift it earlier or later based on various scenarios, including but not limited to commencing a cycle when energy consumption is minimal or in response to demand response signals. Our integration efforts have incorporated whitegoods offered by industry leaders including Miele, BSH-Siemens, and Whirlpool, facilitated through their respective development APIs.

In the architecture depicted in Fig. 1, nearly all edge devices are linked to the IoT gateway, which accumulates and transmits measurements to a centralized cloud server. The smart appliances are directly connected to the internet via the user's Wi-Fi, while we use the manufacturer's public API to retrieve all required measurements from their Cloud.

B. Software Components

The software architecture of the residential living lab is based on microservices, favoring fragmentation of functionalities over a monolithic architecture with a central controller. This concept is similar to the "hourglass" OSI network architecture paradigm. In this design, we maintain a standardized simple core responsible for basic data and communication routing. A variety of applications and devices can operate both above and below this core, resembling the top and bottom parts of the hourglass as can be seen in Fig. 2.

The core of this architecture is the MQTT protocol, which serves as the narrow standardized "waist". MQTT was chosen for its excellence in IoT and machine-to-machine (M2M) communication scenarios. It features a lightweight publish-subscribe messaging protocol designed to facilitate efficient communication in environments with limited processing power and bandwidth. This decision ensures seamless and effective communication across the experimentation testbed's diverse endpoints, making it an ideal foundation for the testbed's operational success.

For our experimental platform, we employ a central MQTT broker to which all IoT GWs are connected and use the publish-subscribe mechanism to send and receive data from/to the cloud. In addition, features such as persistent sessions and QoS capabilities are used to ensure message delivery reliability when IoT GWs are offline due to network or other issues.

We have implemented the data orchestration functionality of the IoT smart home and smart grid testbed on the MQTT broker's upper layer. Considering the time-series nature of the data, we had the option to choose between two leading solutions: TimescaleDB and Influx. TimescaleDB stands out with its SQL compatibility, integrating features like built-in user administration, negating the need for a separate metadata DB. It brings the advantages of a well-established relational database system, encompassing SQL support, a broader ecosystem, and supplementary features that InfluxDB lacks. However, both databases excel in managing time-series data efficiently. The selection between TimescaleDB and InfluxDB depends on specific use cases, the existing technology stack, performance requisites, and individual preferences.

The integration of the MQTT Broker and the TimescaleDB is based on the development of a custom backend agent tasked with receiving data from MQTT publishers (IoT devices or other sources) and forwarding it to the database for storage and further processing. Before transmitting data to the central database, the customized backend agent performs data filtering, aggregation, or lightweight analytics.

On the lower layer of the MQTT broker, we have implemented background services responsible for the forwarding of data from the various IoT devices that communicate with the gateway via ZigBee, Z-Wave, Wi-Fi, and Bluetooth. To ensure seamless connectivity and robustness, we've opted for a local MQTT broker instance running on the gateway, bridged with another MQTT broker instance hosted in the cloud. This bidirectional bridge allows messages published to one broker to be seamlessly forwarded to the other and vice versa. As a result, clients connected to different brokers can communicate as if they were directly connected to the same broker. The decision to use this architecture was motivated by our desire to maintain the functionality of smart home frameworks like OpenHAB even during network failures. With this setup, residents can continue to use their home automations even if connectivity to the Internet is temporarily lost.

At the lowest layer of the system, IoT devices act as MQTT clients, delivering data points and receiving commands from the MQTT Broker. In the uppermost layers of our architecture are the various applications built on top of the IoT smart home and smart grid testbed, including but not limited to data analytics, user interfaces, demand-response mechanisms, and additional vertical applications that will be discussed in Section IV.

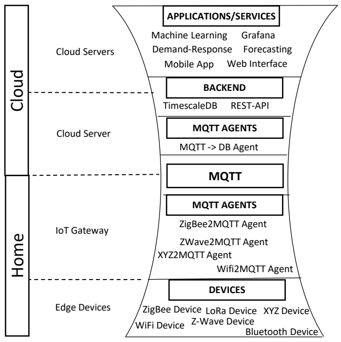

Fig. 2. The hourglass model

C. *Testbed Monitoring & Maintenance*

During the deployment and operation of 50 smart homes, it was discovered that continuous monitoring and maintenance is required for faulty equipment, battery replacement, and network troubleshooting with householders. As seen in Fig. 3(a), we have created a dashboard for visualizing the aggregate power consumption as well as the consumption of each individual home. Grafana was selected because it enables users to query, visualize, and receive alerts on time-series data via custom dashboards. From the perspective of the administrators of the experimental infrastructure, we are monitoring the health of the IoT gateways of each home, generating alerts when the continuous flow of data points is interrupted for longer than the administrator-specified threshold.

In addition to the administrative dashboards, homeowners have access to their own personal dashboard for monitoring their data and executing basic queries on historical data such as their monthly total consumption. Data pertaining to its indoor and outdoor sensors can be displayed alongside any other data source originating from sensors installed in the home, such as metering information from a smart relay connected to a specific appliance, such as the electric water boiler in Fig. 3(b). At this point, it is important to note that displaying data to users via Grafana dashboards is only one way of displaying their data. Users may also utilize other user interfaces, such as those that come with the open source home automation framework openHAB and are deployed on their GWs. Using a thin layer of REST API on top of the timescaleDB, it is possible to build a custom web portal or even a custom mobile application with all user interfaces operating in parallel without causing disruptions. Using the experimental infrastructure of our IoT smart grid and smart home residential living lab, the choice depends on the use cases of a pilot or the services that a stakeholder wishes to assess.

IV. Data Interoperability & Use Cases

The IoT smart home and smart grid testbed enables experimenters, researchers, and stakeholders to test and validate innovative IoT, smart grid, and smart home services. On top of the existing residential setup with actual consumers and real-time data from their smart homes, there is the possibility of engaging consumers and evaluating solutions with the help of the residents. This opens up a plethora of opportunities for the provision of pilot use cases, applications, and services.

(a) Admin Dashboard

(b) User Dashboard

Fig. 3. Graphical Interfaces

Subsequent sections will detail the most significant innovative use cases formulated within this residential experimental platform. Several of these use cases will also be showcased in pilot demonstrations, set to be analyzed as part of broader research efforts involving key stakeholders. The effectiveness of these applications fundamentally relies on the interoperability that facilitates a fluid exchange of data across a variety of services and stakeholders, each managing their own data sets.

To enable efficient data discovery and exchange, the SAREF [12] ontology was adopted within the Semantic Interoperability Framework (SIF) [13] developed by the InterConnect project. This process involved annotating all energy-related and IoT non-energy-related data to align with relevant SAREF ontologies, such as SAREF4ENER and SAREF4BLDG. Additionally, APIs were integrated with the SIF. This integration provided a means to expose and share our data and APIs with third parties. These collaborations supported various initiatives, including machine learning and forecasting analysis, user engagement and data visualization, as well as bi-directional communication for demand response use cases. In the latter, the framework facilitated sending actuation commands to our services via the SIF, enhancing our operational capabilities.

A. *Machine Learning & Forecasting*

From simple forecasting regression models to more advanced techniques like machine learning and deep neural networks for tasks such as classification, forecasting, and decision-making, data analytics can uncover valuable insights from the vast amount of collected data. By integrating energy consumption data with indoor and outdoor environmental sensors, as well as human presence data, we can enhance the precision of energy consumption forecast models. Moreover, employing a classifier, we could deduce whether a residence is unoccupied or occupied based on energy consumption, door sensor, and motion sensor data.

Considering energy disaggregation models, even in the absence of smart plugs and advanced submetering capabilities, the classification of active appliances solely through smart meter information could be assessed. These examples merely scratch the surface of the potential data analytics-driven applications that can be developed using the IoT smart home and smart grid testbed.

B. *User Engagement & Feedback*

As our experimental platform offers the benefits of a living lab, enabling smart-home residents to actively participate and share their data, it serves as a foundation for testing pilot use cases focused on user engagement and feedback. Researchers, including utility companies, can explore diverse incentive mechanisms to understand consumer behavior and gauge their willingness to modify consumption habits. By offering suitable incentives or benefits, consumers might respond by increasing, decreasing, or adapting their energy usage based on recommendations or alerts from grid operators.

In addition to utilizing real data from the living lab, user interfaces like web dashboards and mobile apps can be provided to users for validation purposes. These interfaces could serve a one-way function, providing information and guidance to consumers, or a two-way function, gathering consumer feedback and inputs, including their own consumption projections. Depending on the specific pilot use case or demand response (DR) strategy being assessed within the experimental platform, consumers can be engaged by soliciting their flexibility contributions through a user interface, accompanied by corresponding benefits. Another approach to engaging consumers in a DR scheme involves sending recommendations via mobile apps to those not equipped with smart plugs or remote-controllable smart appliances. This encourages them to curtail or adjust their energy usage.

C. *Demand Response*

The traditional electricity network primarily relied on one-way electricity flow and manual management, while the concept of smart grid introduces communication capabilities where smart appliances and devices can be integrated into the IoT ecosystem, allowing load management and energy consumption optimization. In our experimental platform with smart plugs, smart relays, and smart appliances, real-time remote control capabilities allow for the evaluation of demand response scenarios. Individual researchers, aggregators, grid operators, and utility companies could evaluate and validate various demand response services by analyzing the effect of the various parameters on the outcome.

Typically, a DR scheme requires data analysis that is used to forecast the energy consumption in the context of our living

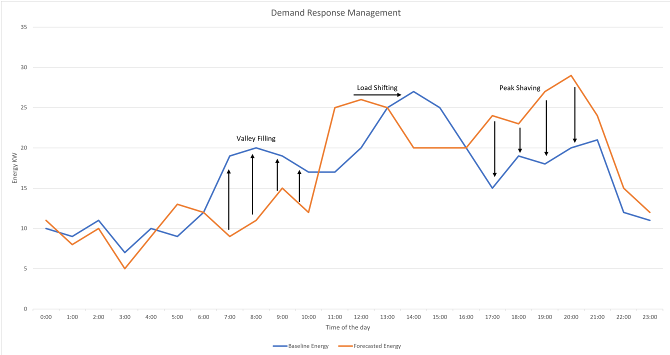

Fig. 4. Demand Response Management

lab and the engagement of the consumers if they are permitted to participate in the flexibility offerings in a dynamic manner as opposed to entering into a static contractual agreement with their utility company. Before evaluating the DR scheme, the relevant grid stakeholder develops these parameters and options. In Fig. 4, we can see an example of a forecast of energy consumption from 50 households compared to a baseline established by a grid stakeholder, which represents the expected energy consumption, production, or other relevant metrics at a particular point in time. Based on the forecast, the flexibility provider can attempt to fill the valleys, balance the load by shifting the scheduled operations of smart appliances and shave the peaks. Depending on the use case, the IoT HEMS could receive signals from a stakeholder such as a system operator or utility company and perform real-time remote control on a home's electric devices, thereby reducing or increasing the total consumption and achieving the objective of the evaluated DR use case. The home dashboard in Fig. 3(b), where the electric water boiler's power consumption is up to 3kW and the IoT HEMS turns off the heavy load device after receiving the command to do so, serves as an example of how such a mechanism could function.

V. Conclusion & Future Work

Our work revolved around the design, implementation, and deployment of an experimental infrastructure for IoT, smart home, and smart grid vertical applications. We analyzed the testbed's various hardware components, including the IoT gateway, peripheral devices such as sensors, actuators, smart plugs/relays, and smart appliances. We discussed our design decisions and how we've implemented an "hourglass" model with MQTT at its core to provide the required extensibility, modularity, and compatibility. The system is separated into distinct layers, allowing various top and bottom layers to interact via the standardized middle layer, thereby facilitating component compatibility. Next, we mentioned the necessary tools we have developed for testbed monitoring and maintenance. In the end, we highlighted the use of ontologies and SIF for data interoperability and presented some examples and insights of specific pilot use cases, such as data analytics using machine learning techniques, user engagement and feedback, and demand response schemes.

In the future, our aim is to gather valuable measurements and insights from the pilot use cases, which will undergo evaluation as part of research initiatives involving key stakeholders. We have intentions to broaden our living lab's scope, encompassing smart office buildings and even extending to smart retail establishments, including sizeable supermarkets. Furthermore, we have plans to enhance the experimental platform's capabilities with the incorporation of new IoT devices, such as air quality sensors, leak detectors, and intelligent thermostats. Additionally, we're working on developing customized dashboards that can facilitate tasks like remote device control, along with the integration of IoT actuators for homeowners. Our ultimate goal is to create an experimental platform that closely mirrors real-life scenarios and pilot use cases, creating an environment that emulates reality to the greatest extent possible.

Acknowledgment

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References

[1] "Energy Independence and Security Act of 2007," Public Law 110-140, 2007, 121 Stat. 1492.

[2] M. Ponce Jara, E. Ruiz, R. Gil, E. Sancristobal, C. Pérez-Molina, and M. Castro, "Smart Grid: Assessment of the past and present in developed and developing countries," *Energy Strategy Reviews*, vol. 18, pp. 38–52, 09 2017.

[3] M. H. Cintuglu, O. A. Mohammed, K. Akkaya, and A. S. Uluagac, "A Survey on Smart Grid Cyber-Physical System Testbeds," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 446–464, 2017.

[4] G. Lu, D. De, and W.-Z. Song, "SmartGridLab: A Laboratory-Based Smart Grid Testbed," in *2010 First IEEE International Conference on Smart Grid Communications*, 2010, pp. 143–148.

[5] W. Tushar, C. Yuen, B. Chai, S. Huang, K. L. Wood, S. G. Kerk, and Z. Yang, "Smart Grid Testbed for Demand Focused Energy Management in End User Environments," *IEEE Wireless Communications*, vol. 23, no. 6, pp. 70–80, 2016.

[6] F. Bliek, A. van den Noort, B. Roossien, R. Kamphuis, J. de Wit, J. van der Velde, and M. Eijgelaar, "PowerMatching City, a living lab smart grid demonstration," in *2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, 2010, pp. 1–8.

[7] T. G. Stavropoulos and et al., "System Architecture for a Smart University Building," in *Proceedings of the 20th International Conference on Artificial Neural Networks: Part III*, ser. ICANN'10. Berlin, Heidelberg: Springer-Verlag, 2010, p. 477–482.

[8] S. Meiling and et al., "Consumer-oriented integration of smart homes and smart grids: A case for multicast-enabled Home Gateways?" in *2013 IEEE Third International Conference on Consumer Electronics ¿ Berlin (ICCE-Berlin)*, 2013, pp. 279–283.

[9] G. Kleineidam, M. Krasser, and M. Reischböck, "The cellular approach: smart energy region Wunsiedel. Testbed for smart grid, smart metering and smart home solutions," *Electrical Engineering*, vol. 98, 12 2016.

[10] O. B. Fosso and et al., "Moving towards the Smart Grid: The Norwegian case," in *2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA)*, 2014, pp. 1861–1867.

[11] T. Kim, S. K. Park, and B. G. Lee, "What Is Appropriate Strategy for Smart Grid Business?: A Case Study of Test Bed in Korea," in *2010 Proceedings of the 5th International Conference on Ubiquitous Information Technologies and Applications*, 2010, pp. 1–5.

[12] R. García-Castro and et al., "The etsi saref ontology for smart applications: a long path of development and evolution," *Energy Smart Appliances: Applications, Methodologies, and Challenges*, pp. 183–215, 2023.

[13] "Semantic Interoperability Framework." [Online]. Available: https://tinyurl.com/2vh7yybv

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