

Smart Campus Energy Management System: Advantages, Architectures, and the Impact of Using Cloud Computing

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A microgrid is a kind of intelligent grid fueled by renewable energy sources. It may function as a standalone electrical or linked system to and from the primary grid. An academic microgrid will address several energy-use issues since universities are significant electricity consumers [1]. The purpose of this work is to discuss the components of microgrids, with a focus on energy management (EMS). In light of its essential function, the study provides several EMS designs and discusses how integrating cloud computing into the Microgrid architecture might increase EMS efficiency. The outcomes of the EMS data collecting utilizing the Kaa IoT platform are presented in the paper's conclusion.

Keywords: Microgrid, Agent, Cloud Computing, Energy Management System, Internet of Things.

Introduction

Given the significance of the electrical grid and the rise in the amount of power used, numerous studies have been conducted.

Aimed at enhancing the electrical system as it is. A smart grid is a pioneering project integrating several information and communication technologies (ICT) elements to monitor and regulate energy generation, transmission, and distribution. It is a cyber-physical system designed to enhance the present power infrastructure. One of the new features of smart grids is using microgrids.

Microgrids are energy systems that operate in linked or islanded modes to and from the primary power grid. They allow the deployment of energy generators at low voltage distribution. The smart grid's goal of supplying electricity using distributed energy resources that are renewable is another innovative feature (DER). Customers may actively participate in the energy generation by installing these DERs at their location. For example, a house is not automatically a microgrid because DER is implemented there. A client must install enough DER to be self-sufficient and run their microgrid independently of the electricity grid under certain circumstances.

An intelligent campus or university campus that uses several DERs is an example of a microgrid. The new Microgrid requires an Energy Management System (EMS) schedule management program to control the DERs so that the intelligent campus can utilize energy effectively since DER power cannot be guaranteed continually [2]. EMS capabilities include economic dispatch algorithms, monitoring, metering, control, protection, stability, and power quality analysis. These features are implemented at various levels depending on the microgrid's timing needs.

It has been suggested that cloud computing may be used to create intelligent grid EMS services. Nevertheless, not much research has been done on how cloud computing affects the implementation of various EMS services. This work aims to analyze the need for a cloud-based EMS on microgrids empirically. The study focuses on

using the Kaa platform to construct its architecture and researching the effects of latency on various cloud-based EMS operations.

Microgrid And Energy Management Systems

What Kind Of Relation?

According to the Consortium for Electric Reliability Technology Solutions (CERTS), a microgrid is a self-sufficient electrical system that can smoothly join and disengage from the primary grid without interfering with its loads. The

microgrid's processor, the Energy Management System (EMS), coordinates the loads, DGs, and DESs to create a dependable, affordable, sustainable, and ecologically friendly energy self-productive system.

Advanced IT Infrastructure: This comprises a system of sensors, meters, and software that gathers and analyzes data in real time so that the user can make choices. For example, the user may switch off the air conditioner when a sensor in the home detects no movement.

A Microgrid and an EMS have a mutually beneficial relationship. This essential computer software will ensure that the Microgrid has the following features: it will schedule generators using forecasting, adjust voltage, meet demand, provide a seamless transition between connected and islanded modes from/to the primary grid, minimize emissions, and maximize Microgrid utilization efficiently[6].

The Architecture of Energy Management Systems: A ANALYZE

The existing electrical system, plagued by several issues, including frequent blackouts that may result in enormous damage, will be entirely transformed by microgrids. For example, the district power supply was harmed by the terrible 9.0 magnitude earthquake that struck Japan in 2011. The Sendai Microgrid managed to provide electricity to hospitals and residents of nursing homes for three days in a row despite the deplorable conditions in the city[7].

Distributed Generators (DSs): These units provide power to microgrids. To continue operating sustainably, a microgrid requires an energy management system to oversee its operations. This system will synchronize the functions of the generators, storage, controls, and coupling points that make up the microgrid. Figure 2 shows an overall example architecture.

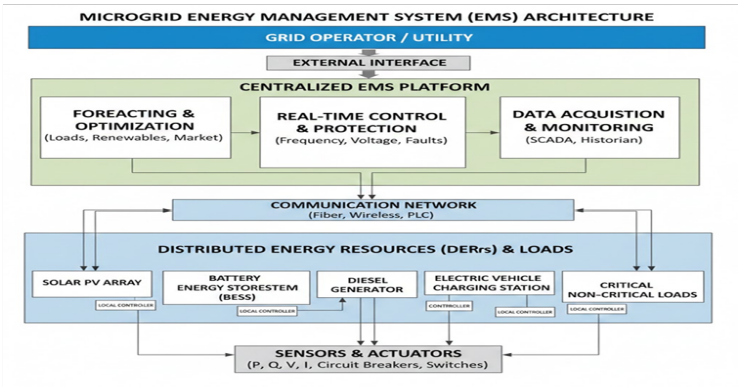


Figure 2: Overall Architecture of a Microgrid Energy Management System (EMS)

- To illustrate how an EMS functions, generators like wind turbines and solar panels are positioned close to the end consumers. To optimize advantages, combined heat and power plants will form the core of the microgrid.
- Distributed electricity Storage (DES): When the primary grid produces electricity at a low cost or when the DSs create an excessive amount of energy, a storage device, such as batteries, is required. The stored energy can be utilized during blackouts and peak periods.
- Controllable Loads: These electrical appliances, like electric cars, can modify how much power they use during peak hours.

Point of Common Coupling (PPC): a hub for electricity production, transmission, and customer-primary utility interface. The EMS is a microgrid processing unit that aggregates forecast data from external sources, analyzes historical and forecast data, optimizes electricity supply and demand, and provides users with interfaces to view, monitor, and control production and consumption. The microgrid will gather real-time data to track its operational condition and respond to system disruptions. MCC will also compile data from various microgrid local controllers connected to distributed energy resources and storage and control loads to make essential choices.

An EMS may oversee and operate the system in either a centralized or decentralized mode[5] to meet the main goals of the microgrid (provide electricity, engage in the energy market, manage critical load, etc.); this can be done by using a hierarchical structure, as shown in figure 3:

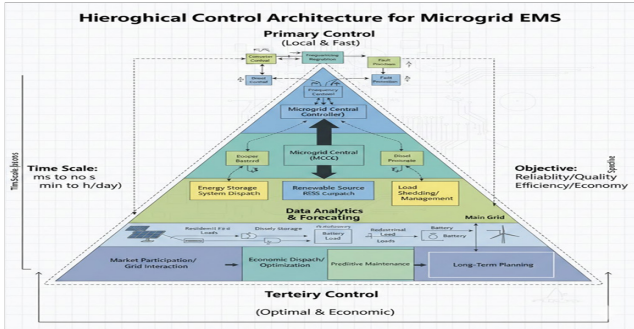


Figure 3: Hierarchical control architecture of a microgrid Energy Management System (EMS)

The components of this three-level hierarchical structure are:

- **Distributed Network Operator (DNO) and Market Operator (MO):** The DNO acts as a management aggregator for instructions and real-time data given by various Microgrids and the primary grid in an area composed of a network of Microgrids. A Microgrid and an electrical market in a particular region will exchange data via the MO system.
- **Microgrid Central Controller (MCC):** a coordinator of local controllers and an interface between DNO/MO and the controllers inside a microgrid.
- **Local Controllers (LCs):** These devices monitor and manage distributed energy supplies and controllable loads like water heaters, depending on whether a centralized or distributed strategy is used.

An Energy Management System should ideally function as a component of the Microgrid Central Controller. To participate in the energy market and communicate vital information like power availability, the latter has a two-

way communication channel with the DNO and MO. MCC will be important Depending on the strategy used; local controllers may display various functions and control types: in a decentralized approach, an LC will make choices locally, while in a centralized approach, an LC will obey directives from an MCC. For example, when the price of electricity on the market rises, the market operator will send information to the MCC, which will use an optimization algorithm to tell distributed energy resources to begin serving, allowing DER local controllers to make decisions in a decentralized manner.

A Microgrid operating in a centralized manner has to be a resilient system that can handle real-time data coming from various DERs, DES, and loads at scheduled intervals [5]. The information flow between MCC and LCs is shown in Figure 4, with two communication infrastructures serving as the means of information sharing. The load LC will transmit a request for demand, and the DER LC will communicate the power production level based on market pricing and DER production level. Using an optimization technique, MCC will utilize this data to tell DER to begin production, show the load distribution, and provide the market rates for the next time slot.

One of the numerous benefits of a centralized method is its simplicity of implementation. However, more information is transferred when more devices are used, which might cause a bottleneck in the processing and communication channels.

A decentralized or distributed strategy, in contrast to the centralized paradigm, seeks to increase the autonomy of the Microgrid DER and LC components. Intelligent controllers capable of making choices independently without receiving instructions from the Microgrid Central are used to accomplish this purpose.

In charge. To improve the operation of the Microgrid and maximize the production of the appropriate units, LCs will also be able to interact with one another and build an intelligent LC network. The Microgrid requires a system of several entities working together to accomplish this aim. The agent-based model is a crucial contender for distributed

control modes and an environment where agents can function regardless of location: grid and microgrid levels. This is because the agent-based approach is designed to divide a main problem into smaller ones and address each more minor problem separately.

One unique feature of using a multi-agent EMS control system over other distributed paradigms is that each agent can anticipate the future move and affect the neighbors of different agents. Agent Communication Language (ACL) allows agents to communicate with one another by exchanging values (e.g., power production level) and by carrying out orders and actions in the next time slot. It will be necessary to convey less information when local neighbors exchange information than when using a centralized strategy. Additionally, the MCC calculations will be performed at the agent level, reducing the strain on the network. It is important to note that an MCC may still be essential under a decentralized model, primarily by taking over an LC in case of a control failure.

Notwithstanding its benefits, such as being modular and flexible in a plug-and-play setting, the decentralized method has some security flows that may be hard to fix due to the architecture's nature. In addition, the information exchange between an EMS and local agents occurs across the communication channel in power systems. This infrastructure must be constructed appropriately to enable nearby agents to communicate information. This is a costly process. The internal Microgrid decentralized EMS control layered architecture is shown in Figure.

Cloud Computing And Energy Management Challenges: What Added Value.

Using a distributed design, the smart grid will provide dependable, economical, and efficient power management to end users. Given that the system is a heterogeneous data source, it is essential to use cutting-edge solutions to prevent technological issues and accomplish this aim, enabling users to access intelligent grid apps anywhere. Cloud computing, an emerging new approach, is an excellent model candidate since it is designed to provide on-demand access to computer resources that can efficiently handle large amounts of data.

Innovative grid applications may benefit from some of the top features and services cloud computing offers. The following categories apply to the primary services:

- Infrastructure as a service (IaaS) refers to an infrastructure that offers consumers scalable resources that may be changed on demand. Such resources include servers, load balancers, virtual machines, storage, and networks.
- Platform as a service (PaaS): A cloud computing service that, often via a web service interface, relieves the user of installing the hardware and software components required to create and execute new applications. Databases, web servers, and programming tools are all included in this service.
- Software as a service (SaaS): a business model where all programs are hosted and made available to users upon request. The primary benefit of using this service is that it removes the need to install and operate software on personal servers, saving money on licensing, installation, hardware installation, maintenance, and support.

Several additional features, including load balancing, dynamic pricing, home energy management systems, and building energy management systems, were introduced to address specific management concerns, given the significance of energy management in smart grids. However, other issues with the existing system might be resolved by using cloud computing technologies to guarantee dependable, economical real-time energy management:

- A Microgrid is a system comprising a dynamic number of sensors delivering massive volumes of data that must be evaluated quickly to fulfill a real-time demand or supply. This is why a scalable platform is necessary. Cloud computing infrastructure is perfect for dynamic and computationally massive data applications requiring scalable resources because of its dynamic elasticity, resource pooling (which will prevent restrictions during peak time), and on-demand self-service (which will allow customers to keep track of energy usage and pricing) features.

- There is a requirement for speedy demand response; thus, offer a new architecture called Cloud-Based Demand Response (CDR), which alters the! Utility-customer representation into utility-smart architecture via controller/agent architecture Home Energy Management System meters. CDR will result in a secure, scalable, dependable demand response through publisher/subscriber, topic-based group, and data-centric communication.

- Intelligent demand management is needed. A system capable of periodically forecasting demand will be created, enabling intelligent demand management to avoid peak time burden[10] through a software-as-a-service cloud-based platform, supporting heterogeneous devices from different layers in the smart grid and dynamic demand response.

- Dynamic Bandwidth Allocation (DBA) is required because peak hours, when demand is high and customers are supplied based on priorities and available resources, are among the issues with the conventional electrical system. Blackouts happen when supply is insufficient to meet demand. A cloud computing scheduling approach that demonstrated the relationship between distributors and customers was presented by X. Li and J. Chung Lo in [16]. The price and peak aware scheduling (PPAS) algorithm is based on dynamic pricing and the dynamic assignment of a peak threshold to prevent energy use above limits throughout the day. The suggested algorithm trials' outcomes demonstrated the energy distributor's and cloud computers' effective energy management.

- To achieve an early warning system and a practical, on-demand, scalable power monitoring service, [17] suggests a monitoring system for intelligent grid users that uses an advanced cloud services solution based on service-oriented architecture and enterprise service bus.

- A requirement to meet customers' energy requirements: By integrating external energy sources and storage devices with internal ones through virtualization in cloud computing applications, it is possible to build an

energy exchange mechanism between various Microgrids and satisfy customers' demands as outlined in the framework.

- a dependable and expandable data analytics platform is necessary to gather, classify (structured, semi-structured, and unstructured), store, model, and forecast solutions for Microgrid customers. An EMS analyzes massive data from several sources, including sensors and weather-predicting agencies. It uses machine learning methods that may be used in an academic microgrid to adjust to users' needs (faculty, staff, and students) and maximize system performance.

The current intelligent grid architecture's master-slave architecture, controlled utility demand response, and bandwidth limitations are just a few of its issues. Numerous research studies have shown that cloud computing applications benefit intelligent grid energy management.

Kaa Cloud-oriented EMS Design

When developing an ideal Campus Microgrid EMS platform, the following research challenges should be carefully considered: how much it will cost to implement the platform, how customizable the services can be, how scalable it is for other campuses, and finally, how well the platform performs in terms of delay[20].

We conduct studies to measure the reaction time for delay-sensitive intelligent grid applications using Kaa, a free and open-source cloud-based IoT platform. The

This platform was selected based on several capabilities listed in [22]. In short, it is a fully functional cloud-based middleware platform for the Internet of Things that can be deployed as a single node, cluster node, or sandbox. Initially, we used the architecture shown in Figure 6 and considered Kaa a single Linux node. Nevertheless, we chose Kaa Sandbox, a ready-made solution that includes every Kaa component in a simulated setting.

Conclusion

Scientists from several fields of study have shown interest in the large field of intelligent grid research. To comprehend the smart grid from a computer science viewpoint, it is essential to consider the study of wireless sensors, the Internet of Things, cloud computing, and big data analytics. This paper's primary goal is to demonstrate the value of an energy management system (EMS) in microgrids and how cloud computing may enhance EMS performance. We measured the delay for some grid delay-sensitive applications using an IoT platform hosted in the Kaa cloud. Our next effort will be to install a genuine IoT test bed with the Kaa platform as a cluster of Linux nodes.

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