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COMPREHENSIVE ANALYSES OF METHODS OF ENERGY STORAGE SYSTEMS USAGE FOR MICROGRID

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Background. Energy storage systems (ESS) provide uninterrupted power access to users and aim to minimize energy losses. These systems are extensively utilized in microgrids, facilitating smooth transitions between grid-connected and isolated microgrid operations. ESS devices with high power density must manage fluctuating loads, such as substations and distributed power sources like wind turbines. Despite existing standards for ESS management, these regulations are often limited to specific areas, leading to interoperability challenges due to the absence of unified modeling approaches and data models.

Objective. The purpose of the paper is to explore methods for controlling energy storage systems and enhancing their interoperability. The study focuses on integrating ESS without necessitating changes in consumer control schemes and utilizing interoperable data models for rapid identification and configuration.

Methods. The research involves analysing various methods used in electricity management systems, identifying interaction conflicts, and emphasizing the development of an interoperable network. The study also considers the potential of an ontology-based control system to achieve the desired level of interoperability.

Results. The analysis indicates that most existing electricity management systems experience interaction conflicts, highlighting the need for an interoperable network. The proposed systems offer significant advantages in fault tolerance, reliability, and scalability. These systems ensure a smooth transition between networked and isolated operations in microgrids, allowing for instant reconnection to the grid when normal conditions are restored.

Conclusions. The findings suggest that developing an interoperable ESS is crucial for improving system efficiency and reliability. Future research directions include forming an ontology-based control system to enhance interoperability. This approach is expected to address current interaction conflicts and pave the way for more resilient and scalable energy storage solutions.

Keywords: *microgrid; HESS; BESS; ontology.*

Introduction

Distributed energy resources (DERs) ensure that consumers operate independently of the large electricity system. When considering a microgrid as a consumer, it is worth emphasizing the fact that it can reliably provide you with electricity and better quality of supply [2]. Microgrid control systems use the voltage drop control method [1] to switch the microgrid to an isolated mode of operation, which is one of the most popular modern solutions. Based on the fact that DERs cannot quickly distinguish whether a microgrid has entered isolated operation or not, if the static switch (which separates the microgrid from the upstream grid) uses conventional protection schemes, then unpredictable events can negatively affect the quality of electricity while the microgrid is in isolated operation.

With the widespread use of microgrids, the problem of using excess electricity and the need for storage systems has emerged. The use of energy storage systems (ESS) is becoming essential for these types of networks and also reduces the cost of power converters [2]. ESSs have become a popular solution for improving power quality, efficiency, and reliability in grids with a high level of renewable sources and nonlinear loads. The use of two series and shunt inverters shows that series inverters can compensate for voltage unbalance by injecting negative sequence voltage.

Electricity storage and accumulation is seen as a very important tool for the integration of microgrid systems based on renewable energy sources. Also based on research on the stability of microgrids, energy storage is an important tool for maintaining their stability. Thanks to the storage system, it becomes possible to provide the necessary power in case it is needed for compensation [8]. Battery storage is the simplest of its kind among grid electricity storage systems, but it is not the best for electricity compensation due to its low power density.

A storage system consisting of batteries does not have proper functionality in microgrids in the case of highly variable distributed power systems such as renewable energy sources. In this case, ultra-capacitors are used, which are between conventional batteries and capacitors in terms of energy density and power density [3]. They are installed where there is a shortage of charge from batteries.

A hybrid energy storage system (HESS), consisting of a battery and an ultra-capacitor, reduces the disadvantages of using a battery alone or an ultra-capacitor alone. The charge/discharge time and the ultra-capacitor compensate for transient demand over a short period. They compensate for the required power through the combined characteristics of their components. The HESS used in this example is a portable device consisting of an ultra-capacitor and a battery. Since the microgrid is a distributed power system, the load-side compensation technique can be used with this portable compensator. The ultra-capacitor contributes to the transient electricity demand when the battery is providing the rated power.

Moving on to the microgrid control system, interoperability is an important factor. As a microgrid is a subset of the power system domain, where power generation sources (such as renewables) are highly distributed and controlled by control systems from different suppliers, interoperability becomes an integral part of their interaction. If microgrids use storage and power conversion devices (as discussed earlier), this complicates the interoperability aspects of the entire system [13,14].

By analysing modern standard information models before the ontological formulation of the method for achieving microgrid interoperability [4], it becomes possible to understand the ontology of the microgrid management system (using UML (unified modelling language) modelling for standard information models). To compare all standard models and determine the most optimal information model, an ontological formulation is used, as a result of which interoperability for the microgrid management system can be achieved. Also, an ontological formulation for the intended information model can enable the reuse and integration of existing ontology rather than the creation of a new one based on knowledge about the subject area.

Main part

Battery storage system and its use in microgrids. Most of the distributed generation (DG) is integrated with battery energy storage systems (BESS) as part of microgrids, which can operate in grid, isolated, and combined modes. BESS with a photovoltaic (PV) generation system and flexible AC transmission system (FACTS) devices in a microgrid represented by a modified IEEE 37-bus distribution test system, where PV generation and BESS were implemented on the bus with the lowest voltage value in the system to study their impact on the stability and voltage profile [5].

The varieties of BESS are extremely numerous, but the most popular combination involves the use of batteries and super capacitors (a combination of the storage and release of energy from an electric field and a chemical reaction). Most microgrids include BESS, which can affect both the stability and reliability of the system, and they can be used in AC and DC microgrids. Fig. 1 shows the general structure of a microgrid with BESS connected to the main grid [2].

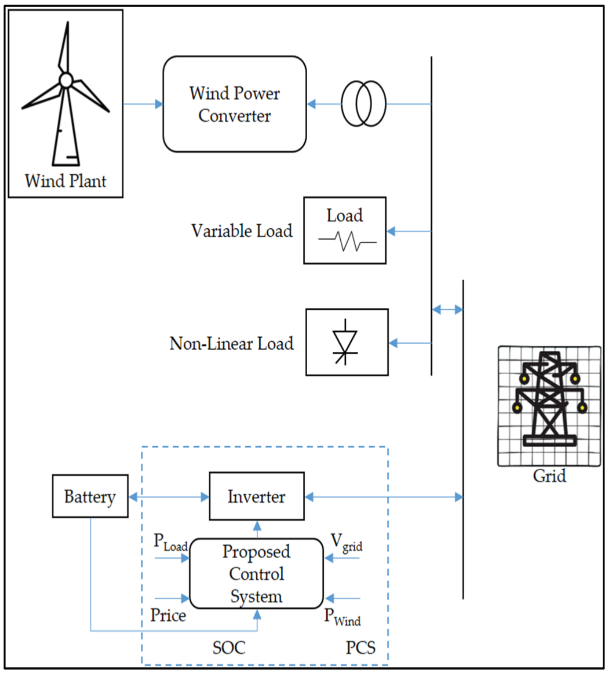

Fig. 1. Structure of the microgrid

If BESS is used in a DC microgrid, it also serves as an auxiliary power source in isolated mode and is modelled as a voltage source that regulates the bus voltage. If the system needs a fast source of active power to balance the system, BESS provides it, thanks to its ability to provide a fast response (much faster than some types of DG).

The main advantage of all types of BESS is the ability to store electricity when production is high and use it during times of high demand. When using power electronics, DC batteries can also compensate for reactive power. This feature gives BESS a wide range of applications in all types of microgrids [11].

Analysing the data from [5], the introduction of BESS affects the voltage stability margin (VSM) and the voltage profile. To achieve a relatively uniform voltage value in all nodes of the system, it is necessary to install a large number of BESS. Due to their high price, the author suggests using BESS devices together with FACTS. The modified IEEE 37 bus system is characterized by a noticeably low voltage imbalance.

Hybrid energy storage system. In microgrids, a load compensation method based on virtual impedance is used to improve stability. A hybrid energy storage system consisting of a battery and an ultra-capacitor to reduce the shortage in the case of using only a battery or only an ultra-capacitor is used to implement the storage-based compensation method [9]. Also, HESS works with a simple algorithm that is easy to implement. This increases the overall efficiency, cost-effectiveness, and lifetime, and reduces the size of the energy storage device and the load on the battery [3].

The main advantages of a hybrid energy storage system are:

- Reducing the total cost of a single storage system (due to the decoupling of energy and power, and the battery itself must maintain its rated capacity).
- Increased performance of the entire system.
- Increased storage life (by reducing dynamic loads and ensuring optimized operation).

The combination of a rechargeable battery and an ultra-capacitor was chosen as a hybrid energy storage system for microgrids (Fig. 2) with a flexible and intelligent algorithm for managing electricity consumption.

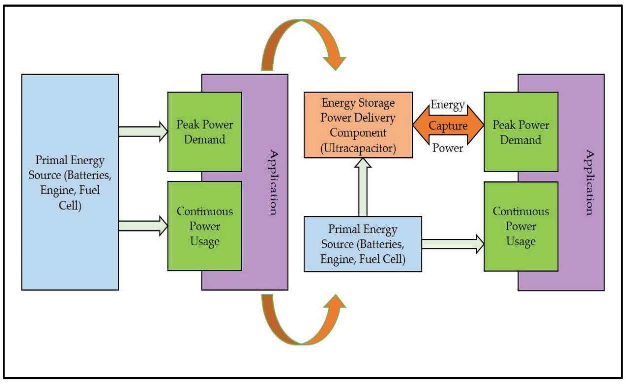

Fig. 2. Hybrid energy storage system for a microgrid

The battery initiates compensation according to an algorithm when the terminal voltage remains between 0.99 and 1.01 pu (relative unit). If the voltage tends to fluctuate out of this zone (upper or lower), the ultra-capacitor initiates compensation. Fig. 3 shows a comparative analysis of the transient surge handling/compensation performance between a battery-only compensator, an ultra-capacitor-only compensator, and a hybrid energy storage system as a compensator.

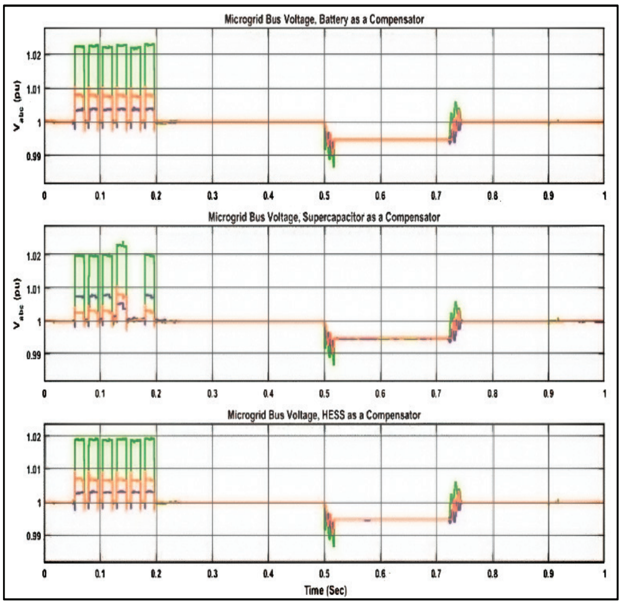

Fig. 3. Comparison of the voltage characteristics on the microgrid bus between a battery-only compensator, an ultracapacitor-only compensator, and a HESS compensator.

It shows that the transient peak that occurred in the microgrid system was compensated to 1.023 pu in the case of the battery-only compensator, compensated to 1.02 pu in the case of the ultra-capacitor-only compensator, and compensated to 1.017 pu in the case of the hybrid energy storage system. Thus, HESS can cope with transient surges most effectively among these three systems [3].

Using two-tier optimization. The proposed storage system does not require any modifications to the control scheme that customers have [1]. The control scheme of the grid-connected storage system, according to its new structure, ensures a smooth transition between grid-connected and autonomous microgrid operation. An applied study shows that the proposed storage system can provide high-quality electricity for sensitive consumers, as well as full utilization of intermittent sources [6].

A method of responding to an event:

- Detect a random event.

- Disconnect the complex from the upstream network, ensuring all loads are not reduced.
- Delete the event.
- Resynchronize the complex with the upper network.

Distributed energy resources (DERs) have a new potential that can independently operate consumers from the bulk power system. In the presented control strategy for islanded microgrid operation, it is shown that there is a need for storage devices and their management and load to minimize transients using a shutdown strategy (when the microgrid switches to islanded operation) [7]. However, since most events in the power system are temporary faults, such as voltage drops, a control strategy that instantly resets insensitive loads after a blackout is not very adequate.

An effective way to work with microgrid clients is to install a data storage system. The proposed data storage system with a network interface for consumer operation has different control modes according to each microgrid mode and real and reactive power management [10].

Ontological formulation of the microgrid management system. In this example, a microgrid plus control system (MPCS) is used as an integral part of the smart grid. MPCS integration is necessary for the exchange of information between nodes in the same domain. Most of the necessary standards already exist and are in use, but a large number of them were developed for system integration in a limited application area and they do not have a common data model or a common modelling approach (considering the smart grid) [4]. Thus, all interfaces between systems that do not fall under one standard require conversion from one standard format to another. There may also be a problem with displaying data models if the interface does not support any of the standards. To solve this problem, it is necessary to formulate an ontology with the help of which all types of standards and semantic models will be mapped to a standard information model.

The interoperability potential of the MPCS is measured by evaluating four properties, and the MPCS has a high level of interoperability because it is an open, decoupled, decentralized, and configurable system. Table 1 provides a description of each of the properties. Since MPCS satisfies all the defined properties for measuring interoperability, ontology-based modelling becomes an urgent need.

Table 1. Interoperability measurements for MPCS

Property	MPCS Characteristics
Open	Controllers are modified and upgraded with functionality and firmware
Decoupled	Each controller is unware of other controller functionality
Decentralized	Every controller acts with a specific localized goal by interacting with the rest of the system
Configurable	Type, number, and other attributes of the controller are configurable

Integration of MPCS into an intelligent network implies the need to exchange information between different nodes in the same domain. The main task in deploying interoperable MPCS solutions is to transfer abstract information between each node.

The workflow for generating OPC (Open Platform Communications) UA models for configuration and communication between controllers is shown in Fig. 4. The Information Model Service also has access to models from each controller in the MPCS network. The Information Model Service detects the input ontology and maps it to OPC UA according to the rules. Once the mapping is complete, the models are automatically generated and deployed to the target controller via client-server communication.

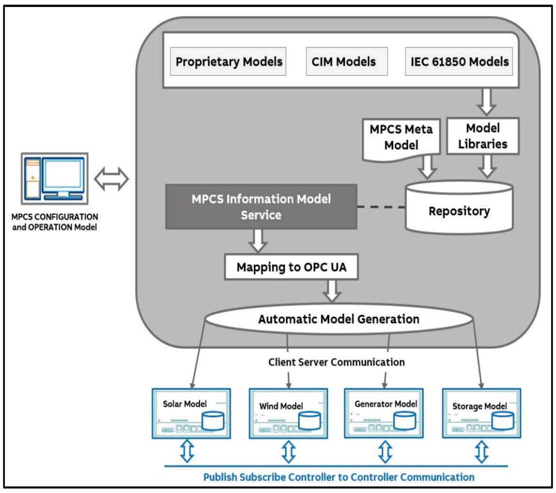

Fig. 4. The process of creating an interoperable model

Returning to the use of the hybrid energy storage system method [3], a significant increase in the independence of the microgrid in the state of islanding can be achieved. This system also allows the use of combined functions with higher energy and higher power density. The battery will provide a high power density with a short charge/discharge time, and the ultra-capacitor will compensate for transient demand over a short period, thus compensating for the required power through the combined properties of its components.

Directions for future research and its prospects. To achieve interoperability in the field of smart grids, IEC 61850 and the Common Information Model (CIM) are the predominantly used standards. CIM focuses on the organizational structures of the various components of the smart grid, while IEC 61850 focuses on the structure of information exchange between field devices and systems. CIM is used for the ontology of the power system domain and physical modelling. There is a need to define object classes for assets such as distributed energy resources, which may include solar generation, storage, DER unit controllers, and other power electronic devices. These object classes describe asset-specific attributes such as asset type, set points, charge status, limits, ramp rates, and others. The cumbersome work associated with the development of the IEC 61850 standard requires the development of an easy-to-engineer and interoperable system that would ensure the effective operation of the microgrid management system.

The UML model for CIM, IEC 61850, and OPC UA is used for one of the MPCS subsystems to achieve MPCS interoperability, taking into account modern standards. Given the growth of highly distributed smart grids, the formulation of an ontology for MPCS based on the adoption and integration of standard power system information models into the predefined OPC UA model is a large field for supporting interoperability. The OPC UA arena supports the integration of a variety of protocols and data models, achieving zero cost of transition from any information model to the OPC UA information model.

The next step will be to develop an ontological model for storage systems to further integrate networks with different management systems.

Conclusions

In this article, we have reviewed the main storage systems used in microgrids. We analysed different types of battery storage systems and their interaction with each other. As a result of the analysis, it was found that at the moment the requirement for interoperability of such systems is not fully met. Therefore, such systems require the formation of an ontology, which in turn will enable easy integration and autonomous operation of devices from different suppliers with different information models. Also, the direction of further research related to the integration of energy storage systems was identified.

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Комплексний аналіз методів використання систем зберігання електроенергії для microgrid

Проблематика. Системи накопичення енергії (ESS) забезпечують безперебійний доступ до електроенергії для користувачів і мають на меті мінімізувати втрати енергії. Ці системи широко використовуються в microgrid, полегшуючи плавний перехід між мережевими та ізольованими операціями. Пристрої ESS з високою щільністю потужності повинні керувати мінливими навантаженнями, такими як підстанції та розподілені джерела енергії, такі як вітрові турбіни. Незважаючи на існуючі стандарти управління ESS, ці правила часто обмежуються конкретними областями, що призводить до проблем інтероперабельності через відсутність уніфікованих підходів до моделювання та моделей даних.

Мета дослідження. Метою цієї статті є дослідження методів управління системами накопичення енергії та підвищення їхньої інтероперабельності. Основна увага приділяється інтеграції ESS без необхідності внесення змін до схем управління споживачами та використанню інтероперабельних моделей даних для швидкої ідентифікації та конфігурації.

Методика реалізації.. Дослідження включає аналіз різних методів, що використовуються в системах управління електроенергією, виявлення конфліктів взаємодії та акцентування уваги на розвитку інтероперабельної мережі. Дослідження також розглядає потенціал системи управління на основі онтології для досягнення бажаного рівня інтероперабельності.

Результати дослідження. Аналіз показує, що більшість існуючих систем управління електроенергією відчувають конфлікти взаємодії, що підкреслює необхідність створення інтероперабельної мережі. Запропоновані системи мають значні переваги у відмовостійкості, надійності та масштабованості. Ці системи забезпечують плавний перехід між мережевими та ізольованими операціями в microgrid, дозволяючи миттєво підключатися до мережі, коли нормальні умови відновлюються.

Висновки. Отримані результати свідчать про те, що розробка інтероперабельної ESS має вирішальне значення для підвищення ефективності та надійності системи. Подальші напрямки досліджень включають формування системи управління на основі онтології для підвищення інтероперабельності. Очікується, що такий підхід дозволить вирішити поточні конфлікти взаємодії і прокладе шлях до більш стійких і масштабованих рішень для зберігання енергії.

Ключові слова*: microgrid; HESS; BESS; онтологія.*