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ABSTRACT: Small scale microgrids are increasingly being used for localized energy generation, distribution, and consumption. They offer benefits such as increased reliability, resilience, and the integration of energy sources. Common applications include powering remote communities, industrial facilities, or even individual homes with a mix of solar panels, wind turbines, and energy storage system. This microgrid can operate independently or connect to main grid, providing flexibility and optimizing energy use in specific areas. This paper presents into the advancements and challenges in energy storage systems (ESS), offering a comprehensive analysis of diverse technologies, including batteries, capacitors, and emerging alternatives. It surveys the application landscape, emphasizing ESS contributions to renewable energy integration, grid stability, and peak load management. This review paper critically evaluates efficiency, cost-effectiveness, and environmental implications, exploring innovative solutions and emerging technologies. By synthesizing current research, this review provides valuable insights into optimizing ESS for a sustainable and resilient energy future.

Keywords: Energy storage system, wind power forecasting, Efficiency, optimization, flexibility, power grid.

INTRODUCTION

Capturing energy created at one moment to be used at a later time is known as energy storage. It is essential for maintaining power grid stability, integrating renewable energy sources, and balancing supply and demand. Converting energy from forms that are challenging to store into forms that are easier or more cost-effective to store is known as energy storage. Manufacturing, the service sector, the future renewable energy sector, and all of the portable electronics that people have become fixated on depend heavily on energy storage [1]. An essential and significant contribution to the development of contemporary energy storage technology was made by lithium-ion batteries. While some technologies can store energy for a short while, others can do it for much longer. Currently, conventional and pumped hydroelectric dams are the main source of bulk energy storage. A group of techniques used to store energy on a wide scale inside an electrical power grid is known as grid energy storage. By storing and releasing electricity produced during times of low demand, energy storage systems (ESS) can increase the resilience and efficiency of the energy infrastructure [1]. Numerous technologies, including thermal storage, pumped hydro storage, and batteries, are used to create a variety of sustainable energy storage options. MG is composed of heterogeneously distributed components that are connected or separated, including energy storage systems (ESS) and distributed storage management functions like automation, control, and monitoring. The supporting design of distributed energy sources (DER) close to the cargo virtually eliminates transmission losses. ESSs are categorized differently depending on the study. For example, depending on the way in which the energy is stored, thermal, mechanical, and electrical energy storage. [1]

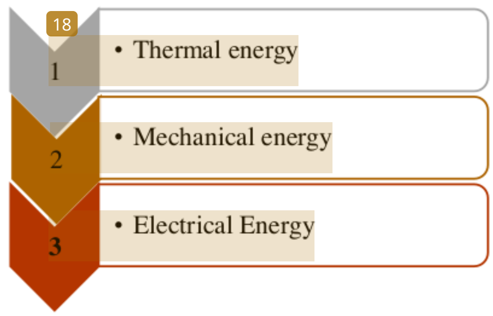

Fig 1: Different Classifications of energy storage system.

The main purpose of ESS is to gather energy from multiple sources, convert it, and store it for later use. Many authors have reviewed ESSs from different perspectives in the literature due to the wide variety of ESSs that are available with different uses. One of the most important pillars in our road towards a more robust and sustainable energy future is the development of energy storage systems. This study compares the utilization of shared electric heat energy storage with the scenario where each home has its own distributed thermal energy storage when the community's solar PV power is utilized for thermal energy generation and storage. Next, various-sized thermal storage units are tested so that the community can determine which one is the best fit.

I. WIND FARM WITH A MULTIPLE STAGE HYBRID ENERGY STORAGE SYSTEM

Over the past few decades, the production of wind power has grown significantly due to concerns about environmental pollution and the scarcity of fossil fuels. The Global Wind Energy Council (GWEC) report states that 60 GW of new wind power systems were put into place in 2015 [2]. The market for electric power is becoming increasingly interested in wind resources due to their inherent advantage of low marginal cost. But wind's erratic and sporadic behavior not only leads to significant stability and reliability issues, but it also makes wind energy less competitive in the market for electric power. In order to optimize the cooperative performance of wind-energy systems, multiple designs and control schemes have been examined from multiple angles, including energy dispatching, power quality control, and ESS sizing optimization.

A. Wind power forecasting

It involves making an estimate of how much power wind turbines will produce at a specific location and time. To forecast future wind power generation, meteorological data such as wind direction and speed are analysed. Precise prediction enhances overall dependability and efficiency by assisting grid operators in better managing the wind energy's integration into the power system. To anticipate wind power, a variety of methods are employed, such as machine learning algorithms and numerical weather prediction models [2].

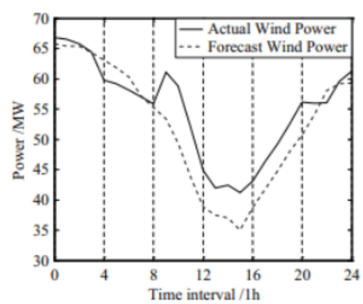

Fig 2: Forecast and actual wind power on May 18th [2]

This graph shows on the X-axis time interval and Y-axis shows power. When comparing the phase 1 forecast result with the actual wind power output on May 18th, it can nearly match the variation trend on wind generation. But within specific time frames, the Because the expected and actual outputs differ, there may be an over dispatch on day ahead market (DAM) energy management. Therefore, phase 2 refining will be considered in order to improve the forecasting result's reliability [2].

B. Efficiency

The efficiency of a wind farm with a multiple-stage hybrid energy storage system depends on various factors, including the specific technologies used, design configuration, and operational strategy. Integrating energy storage can enhance overall system efficiency by addressing intermittency issues associated with wind power. Benefits of a multiple-stage hybrid energy storage system may include improved grid stability, better utilization of renewable energy, and enhanced economic viability. However, the efficiency will be influenced by the conversion losses in each stage of the storage system and the round-trip efficiency of the storage technologies employed. To assess the efficiency accurately, detailed modelling and analysis of the specific components, such as batteries, flywheels, or pumped hydro storage, would be necessary. Additionally, the overall system's efficiency will be influenced by how well it is integrated into the wind farm's operation and grid interaction. In summary, the efficiency of a wind farm with a multiple-stage hybrid energy storage system is a complex parameter determined by the specific technologies chosen, their interactions, and the overall system design and operation.

II. INTEGRATION ENERGY STORAGE SYSTEMS IN DEMAND PORTS

As a result, improving efficiency in ports as a crucial interface in the global communication chain will have a key role in reducing cost and time, as well as increasing productivity. By developing electrical systems based on renewable energy sources, installing energy storage systems in ports improves demand control by optimizing power usage, reducing pea loads, and providing a reliable energy supply. This comprehensive technoeconomic solution improves efficiency, minimizes costs, and contributes to a sustainable and resilient ports infrastructure. Since ports' economic efficiency encourages continuous innovations to reduce the operating costs based on the reduction of processes operating time by automated means on the service continuity enhancement and energy-saving techniques [3].

A. Different load demands in ports

Ports have a variety of specialized electrical loads, including cold ironing and various kinds of cranes. The most important load at POLB's Pier E is STS cranes, which possess a peak load demand of about 4 MW/s. Given that it places a significant expense for the port, energy management is needed and power optimization techniques to lower the overall expense [3]. the following solutions can be implemented to use regenerative energy:

1) Coordination of cranes' DCs in STS group cranes.
2) Bidirectional switches to restore to the main grid.
3) ESSs [3].

Ports experiences varying load demands based on factors such as shipping schedules, cargo types, and economic activity. Busy ports often see higher demand during peak shipping seasons, while fluctuations can occur due to global trade patterns and geopolitical events. Container terminals may have different load demands compared to bulk or liquid cargo terminals, influencing overall port activity. The ports are locations where a microgrid can be used to organize and manage electricity in order to integrate all of the tenants, applications, and energy services in standard load management that is optimized to boost productivity and lower the cost of energy. The ports are necessary to set up the primary power distribution system that is suitable and sufficient to the demands of every tenant worldwide, including cranes, reefers, cold pressing, and managing the world's infrastructure for enhanced effectiveness.

Comprehensive Techno-economic solution for demand control in ports could involve implementing advanced technologies and strategies to optimize port operations include:

1. Smart Scheduling systems: Utilize predictive analytics and AI-driven scheduling systems to optimize ship arrivals and departures, reducing congestion and improving overall efficiency.

2. Automated container handling: Invest in automation technologies such as autonomous cranes and robotic container handling to enhance the speed and precision of cargo movements.

3. Energy Efficient measures: Incorporate energy-efficient technologies in port operations, such as green energy sources for equipment, and smart grid systems, to reduce operational costs and environmental impact.

III. BATTERY ENERGY STORAGE SYSTEM

There are many solutions for the energy storage and most of them are depending on Li-ion batteries. A comprehensive review of battery sizing, methods and applications in various renewable energy systems. Energy storage is a critical component of manufacturing, of the service industry, of the future renewable energy industry, and of all the portable electronics with which they became obsessed. Lithium-ion batteries played an important and vital role in the progression of modern energy storage technology [4]. The suggested BESS seeks to meet customer budget requirements by lowering production costs. The selection of this project is based on support for the sustacentric viewpoint. In the meantime, reaching numerous sustainability goals, like zero waste, get rid of dangerous emissions, and rely on solar power and decrease raw materials in a cycle that is closed.

A. Proposed solution

The amount of electricity consumed is broken down into four time periods. Because of this, the utility sets higher rates for electricity during the early morning and evening (known as "On-Peak") and lower rates during the day (known as "Mid-Peak") and at night (known as "Off-Peak"). The cost of energy in the morning and evening is greater than that in the daytime (~ 1.2) and at night (~ 1.8) [4]. High electricity bills are the result, which is a prevalent issue. To address the aforementioned issue, designing a modular Battery Energy Storage System (BESS) will be done as one of the innovation levers. The green arrows indicate how power is being supplied to the consumer. electricity network during On-Peak (behind the meter BTM) time from the BESS, which clearly takes the role of the utility energy source (off-grid).

The following are some advantages of the suggested course of action:

- Easier to produce a modular BESS with a unified incubator using certified and refurbished Li-ion batteries.

- On the other hand, lowering carbon emissions through the reduction of fossil fuel dependency can be viewed as an environmental benefit (Eco-Efficiency process).

Homeowners who struggle with high electricity bills can save approximately 30% by using this expandable and modular battery energy storage system (BESS).

B. Embedded sustainability

Using methods and tools that reduce environmental effect, encourage resource efficiency, and ensure the long-term viability of the energy storage solution are all part of integrating sustainability into battery energy storage systems (BESS). Targeting embedded sustainability in BESS requires taking into account the following important factors:

- Choosing the Right Battery Chemistry: Select battery chemistries with longer lifespans and less of an impact on the environment.

- Life Cycle Evaluation: To evaluate the environmental impact of the whole BESS—from raw material extraction through manufacturing, operation, and end-of-life disposal—conduct a thorough lifecycle analysis. This guarantees a comprehensive grasp of sustainability and assists in identifying areas for improvement.

- Recycling and Reuse: Give consideration to recyclability when designing BESS components. After batteries are used in BESS for the first time, investigate possibilities for reusing them in secondary applications. Establish procedures for the safe and effective recycling of batteries.

- Energy Effectiveness: Enhance the BESS's energy efficiency to lower overall energy usage and increase the system's sustainability.

Reconditioned and certified Li-ion batteries last longer, using them in Battery Energy Storage Systems (BESS) can save money and help the environment. Nonetheless, a number of obstacles and possible issues must be properly handled to guarantee the BESS's dependability, security, and efficiency. The following are the principal issues with utilizing certified and reconditioned Li-ion batteries:

- Variations in Battery Efficiency: Even with certification, the performance of refurbished batteries can differ. Variations in the original batteries' age, usage history, and manufacturing techniques can cause variations in their capacity, efficiency, and general performance.

- Remaining Lifecycle Limited: Refurbished batteries might only have a shorter lifespan than new batteries, even with certification. This may have an effect on the BESS's long-term viability and necessitate more frequent replacements, which would decrease its advantages for the economy and the environment.

- Problems Compatibility: issues may arise when integrating reconditioned batteries with brand-new or used battery packs. Variations in battery chemistry, charge-discharge characteristics, or communication protocols can result in subpar performance or potential safety hazards.

- Warranty Restrictions: Compared to new batteries, refurbished batteries frequently have minimal or no warranties. The absence of warranty protection may put you at risk financially if unanticipated problems occur while the BESS is in use.

C. Refurbished and certified Li-Ion batteries.

Used Li-ion batteries that have undergone a rigorous inspection, testing, and refurbishment process to guarantee they meet particular performance and safety standards are known as certified and refurbished Li-ion batteries. The objective is to decrease electronic waste, increase the lifespan of these batteries, and offer a reasonably priced substitute for brand-new batteries.

IV. SELF SUFFICIENCY OF ENERGY COMMUNITY BY COMMON ENERGY THERMAL STORAGE

The grid load is directly impacted by the energy consumption patterns of customers, particularly during peak hours. Demand response (DR) management has been used in a variety of control strategies to move energy consumption to off-peak hours in recent years. Optimization is essential for demand response (DR) energy management to be successful. Therefore, in order to increase customer participation, it is necessary to increase the benefits offered to them and encourage them to incorporate the new controlling approaches into their daily energy consumption pattern. However, the integration of renewables into buildings lowers their energy costs and reduces their reliance on grid utilities [5]. It examines a collection of homes with various living spaces and PV panel diameters. These homes' expenses and energy usage are evaluated in two scenarios. Each unit in the first scenario has a separate distributed thermal energy storage system. In the second example, a neighbourhood of homes with shared central thermal energy storage is taken into account. The goal of the homes and the community is to reduce import and export power in order to increase self-sufficiency [5].

A. System Modelling

In the context of energy communities, self-sufficiency pertains to the capacity of the community to fulfill its own energy requirements, frequently by producing and storing renewable energy. In order to achieve self-sufficiency, a typical energy thermal storage system can be very helpful. It stores excess energy when it is available and releases it when demand is high or renewable energy generation is low. It assesses two cases including houses with individual thermal storage and a community of houses with common thermal storage. In the case of individual houses Every home is presumed to have a distinct gross floor area, a sizeable photovoltaic panel, and independent energy generation and consumption. Thermal energy storage (TES) is what the storage is regarded as. A demand response control system is necessary to execute supply and demand matching when storage is used [5]. To reduce the amount of power imported and exported while taking the price of electricity into account as a weighting factor in this function.

$$\mathrm{Min}\sum_{t=1}^{8760}(Pimp(t)Wimp(t)+Pexp(t)Wexp(t))$$

As the price model that is used has different values for buying electricity price (Wimp) and selling electricity price (Wexp), the imported power (Pimp) and exported power (Pexp) should be considered separately. Roughly one-third of the purchase price is thought to be the selling price.

$$\text{Pimp}(t) + \text{Psolar}(t) - \text{Pload}(t) - \text{Pexp}(t) + \text{Psto}(t) = 0.$$

In this instance, the homes that are next to each other in case 1 are regarded as a single community network. As in case 1, it is assumed that every home has a photovoltaic system of its own and that consumption patterns remain unchanged. Instead of individual storage units, a single communal thermal storage is taken into consideration for the community area. To ensure that the supply and demand of the community units are suitably balanced, the size of the common thermal storage should be optimized [5].

B. problems and possible issues are identified:

Even though a common energy thermal storage system can make a big difference in an energy community's ability to be self-sufficient, there are drawbacks and difficulties that should be carefully considered. The following problems and possible issues are identified:

- Restricted Capacity for Storage: The capacity limitation of thermal storage systems is one of the major obstacles. Energy can only be stored for a limited amount of time. If renewable energy is produced at a low rate or there is a high demand, the storage system may run out of energy, which could result in shortages.

- Energy Conversion Efficiency: Energy conversion procedures are frequently used in thermal storage systems, and these procedures may naturally lose some of their efficiency. The system's overall efficacy may be impacted if the efficiency of repurposing stored thermal energy into electricity or usable heat is less than ideal.

- High Initial Costs: Putting in place a standard thermal storage system may come with a hefty price tag. A barrier could be the initial investment in technology, infrastructure, and integration, particularly for smaller or more economically constrained energy communities.

It is important to carefully consider how the thermal storage system will affect the environment. Environmental risks may arise from unintended consequences, such as the release of hazardous materials during the manufacturing or disposal process. A comprehensive strategy that includes careful planning, community involvement, technological innovation, and a clear grasp of the local regulatory environment is needed to address these issues. A common energy thermal storage system for community self-sufficiency can be made more successful overall by minimizing negative effects and optimizing it for changing technologies. Ongoing monitoring and system optimization can also help. While installing a common energy thermal storage system has the potential to make an energy community self-sufficient, there are obstacles and factors to take into account that need to be carefully thought through. Considering technical, economic, environmental, and social aspects necessitates an all-encompassing and integrated approach to the development and implementation of such systems.

V. PUMPED THERMAL ENERGY STORAGE

A new storage technology that can be used in grid-scale applications is called pumped thermal energy storage. This gadget stores electrical energy as thermal energy, which can be released immediately for thermal purposes or transformed back into power in accordance with the grid's requirements. The suggested energy storage system's capacity to function as both thermal and electrical storage aligns with the requirements of sector coupling for multi-energy systems that incorporate both thermal and electrical energy carriers [6]. This paper work aims to simulate the integration of Brayton-based pumped thermal electricity storage (PTES) storage in a multi-energy system at a city-district size, which involves electric, heating, and cooling demand. As an alternative to electrochemical batteries, pumped thermal energy storage is a new storage technology suitable for grid-scale applications. The study uses a mixed integer linear programming approach to optimize the system and show that multi-energy storage can reduce operating costs by 5% compared to traditional electric-to-electric storage operation. The challenges are balancing heat transfer rates, maximizing storage capacity, and minimizing energy losses [6].

A. Modelling

A new technology called pumped thermal energy storage (PTES) combines the ideas of thermal energy storage and pumped hydro storage. It entails storing energy as both electrical and thermal energy. PTES systems normally consist of two tanks, one at a high temperature and the other at a low temperature, each holding a heat transfer fluid. The system stores thermal energy by increasing the temperature of the high-temperature tank during times when there is an excess of electricity generated. Efficient design and operation of PTES systems rely heavily on optimization modelling. The following are important factors to take into account when optimizing PTES modelling in multi-energy systems:

- Goal Role: Specify the main goal of the optimization, such as lowering environmental impact, maximizing system efficiency, or minimizing energy costs.

- Parts of the System: Create a model of the various parts of the multi-energy system, such as the PTES system, conventional power plants, and renewable energy sources.

B. Methodology

A methodical and thorough approach is taken when implementing Pumped Thermal Energy Storage (PTES) in a multi-energy system in order to handle the intricate interactions between different energy sources and demands. In order to determine energy demands, evaluate available energy sources, and set broad goals for the PTES system, a comprehensive system analysis is first carried out. The next step is a site assessment that takes space availability, climate, and geographic factors into account. The configuration and design of PTES components are then painstakingly carried out, including the choice of a suitable heat engine, storage tank design, and suitable heat transfer fluid. To reduce operating costs, a Mixed Integer Linear Programming technique was used to optimize the system's performance. The simulation's qualitative findings demonstrated how the PTES appropriately engages with the community by providing the right amount of heating, cooling, and electricity discharges to meet demand. Furthermore, the quantitative analysis demonstrated that, in comparison to the conventionally suggested electric-to-electric usage for this technology, employing the PTES as a multi-storage capacity greatly lowers the operating costs.

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