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Implementation of LFP Batteries for Energy Storage at Small hydro power station

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Abstract. With the application of energy storge system (ESS) in large powerplants are become increasingly mature, there's an absent of small hydropower stations. Small hydropower stations, though considered as a clean energy, are facing government regulations about restrict it outflows due to environmental protection. To help these small hydropower stations survive, ESS is needed. In this article, the battery that was used in large powerplants ESS is explored to figure out how to adopt the technology into way smaller powerplant by analysing technological, economic and construction factors. The results suggest that ESS using LFP battery can significantly improve energy consistency under outflow restriction. However, on the economic aspect, with the rapid decrease in the battery prices and different policy in different regions, the outcomes can be diverse, but the overall dropping battery prices and increasing demand of renewable energy led to a promising future. This article has illuminated the direction for the development of technology.

1 Introduction

As global environmental awareness rises, there has been a growing demand for clean and renewable energy solutions to mitigate the adverse impacts of fossil fuels. Hydropower, one of the most established renewable energy sources, has been a key contributor to clean energy production worldwide. According to the International Renewable Energy Agency (IRENA), Hydropower is an important component of power systems worldwide. It is the largest source of renewable electricity and can enables a higher penetration of variable renewables such as solar and wind by providing balancing and flexibility services. In addition to electricity, hydropower offers additional benefits like recreational activities, improved resistance to drought and flooding, and storage for drinking and irrigation water [1]. While large hydropower plants dominate the sector, small hydropower stations (SHPs), defined as stations with a capacity of less than 10 MW, are increasingly gaining attention due to their lower environmental impact and potential for providing decentralized, off-grid power solutions, particularly in remote regions.

However, small hydropower stations face unique challenges, primarily due to fluctuating water availability, seasonal variations, and strict governmental regulations that restrict outflows to protect downstream aquatic ecosystems. These regulations, often driven by

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environmental protection policies, can limit the operational flexibility of SHPs, leading to difficulties in ensuring a stable and continuous power supply. One promising solution to this problem is the integration of energy storage systems (ESS), which enable surplus energy to be stored for times when demand is low and released when required.

Although lead acid batteries continue to be the most commonly used battery technology, lithium-ion is the main battery technology for new storage applications [2]. In recent years, Lithium Iron Phosphate (LFP) batteries have emerged as a leading candidate for energy storage solutions in various renewable energy systems due to their superior thermal stability, long cycle life, and environmental safety compared to other lithium-ion technologies. Despite the extensive research on large-scale energy storage systems [3], the application of LFP batteries in small hydropower stations remains underexplored, particularly within the context of regulatory challenges that restrict water flow and environmental impacts downstream [4].

This research focuses on assessing the potential of LFP battery technology to enhance the operational efficiency of small hydropower stations under environmental constraints by analysing the following subjects including energy efficiency, energy density, duration of and energy losses during energy storage, speed of electricity generation, technology feasibility and cost-benefit analysis.

2 Technology Analysis

Compared to conventional lithium and lead acid batteries, LFP batteries are safer, last longer, need no maintenance, charge more efficiently, and discharge more quickly.

2.1 Energy Efficiency

Kang et al. [5] established that the efficiency of lithium-ion depends on current and State of Charge (SoC), and provide a method to compute energy efficiencies. In this part of we will be using the following expressions:

$$\eta_{net,ch} = \frac{W_{net}}{W_{ch}} \tag{1}$$

$$\eta_{net,dis} = \frac{W_{dis}}{W_{net}} \tag{2}$$

$$\eta_{ch,dis} = \eta_{net,ch} \cdot \eta_{net,dis} = \frac{W_{dis}}{W_{ch}} \tag{3}$$

With:

-$\eta_{net,ch}$: Net charging efficiency

-$\eta_{net,dis}$: Net discharging efficiency

-$\eta_{ch,dis}$: Combined efficiency of the charging and discharging cycle

-W_{net}: Net energy remaining after system losses

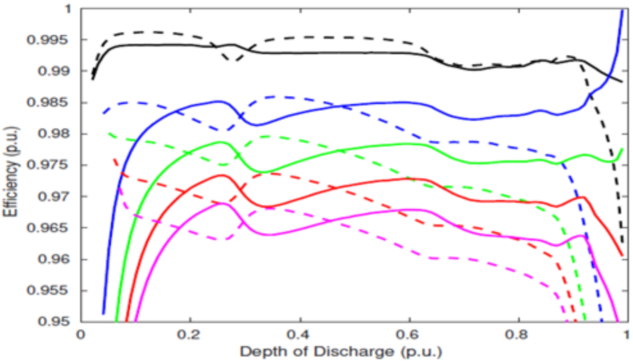
-W_{ch}: Energy input during charging process

-W_{dis}: Energy output during discharging process.

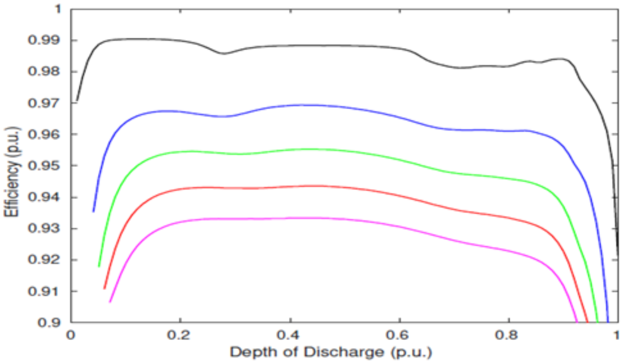
Using the equations above, the results of efficiency from discharge/charge cycles at different C-rates (C/20, 1C, 2C, 3C and 4C) were presented [6]. Charge and discharge efficiencies can be calculated by using equations (1) and (2). Afterwards, global efficiency can be calculated from half-cycle efficiencies with equation (3).

As shown in fig.1, charge efficiency and discharge efficiency are around 95% to 99%, cycle efficiency around 90% to 99%. Moreover, the efficiency remains in a high level of efficiency between 20% and 80% DoD (Depth of Discharge) and rapidly drops in two ends, which means without extreme use, the efficiency can be even higher.

Although LFP batteries may normally function in a temperature range of -20°C to 60°C, 0°C to 45°C is when they work at their best.To guarantee optimum performance, safety, and lifespan, the battery must be kept within its prescribed temperature range.



(a) Charge and discharge efficiency (respectively continuous and dashed lines).



(b) Cycle efficiency.

Fig. 1. Efficiency for different C-rates [6].

2.2 Capacity Losses During Usage

During usage, discharge capacity is mainly affected by Equivalent Full Cycle (EFC), temperature, DoD, and discharge rate.

2.2.1 Equivalent Full Cycle

LFP battery remains over 80% of its initial capacity after 4000 EFC, hence we can assume that even with daily use, LFP battery can last over 10 years, as shown in fig.2.

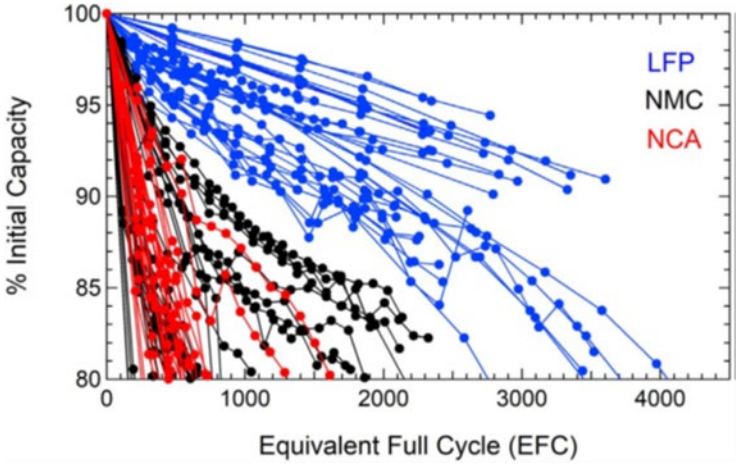


Fig. 2. Discharge capacity retention for all LFP (blue), NMC (black), and NCA (red) cells [7]

2.2.2 Temperature

The degradation of LFP battery capacity over time under different temperatures. There's roughly a 5% difference between 35 and 25 degrees, thus is vital to maintain an ideal temperature for LFP battery, as shown in fig.3.

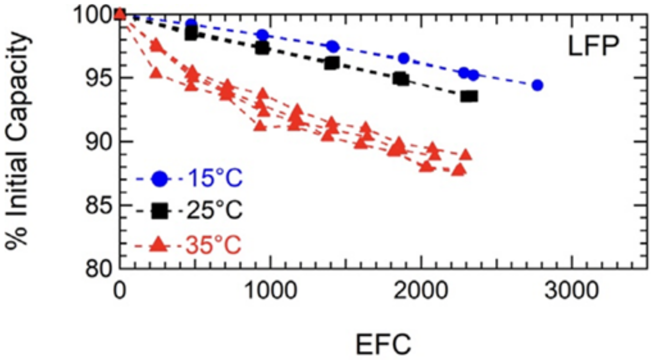


Fig. 3. Discharge capacity fade as a function of temperature [7]

2.2.3 Depth of Discharge

While maintaining excellent durability, LFP battery can be even more durable. Shallow discharge cycles (40-60%) provide the best longevity, while full discharge cycles (0-100%) lead to faster degradation, as shown in fig.4.

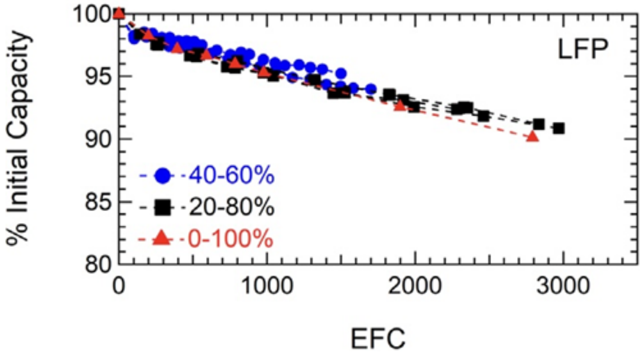


Fig. 4. Discharge capacity fade as a function of Depth of Discharge (DoD) [7]

2.2.4 Discharge Rate

Fig.5 highlights the importance of controlling the C-rate in order to maximize the lifespan of LFP batteries. Both extremely low and high C-rates negatively impact LFP battery life, while moderate C-rates like 1C and 2C are more balanced for maintaining long-term capacity retention.

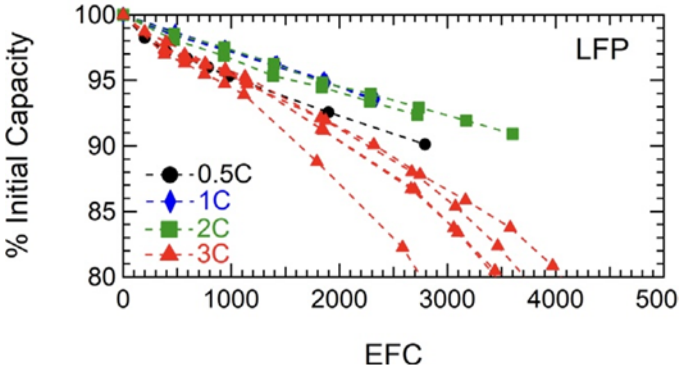


Fig. 5. Discharge capacity fade as a function of Discharge rate [7]

3 Economic Analysis

3.1 Primary Revenue Stream

The primary revenue stream in an energy storage system in China is Peak-valley arbitrage. In energy storage stations, peak-valley arbitrage is a lucrative business strategy that charges and discharges the storage system by taking advantage of the pricing differentials between peak and off-peak times in the power grid. Peak-valley arbitrage's basic concept is to maximize profits by storing energy during off-peak, low-priced times and releasing it during peak, high-priced times.

When the price differential between peak and off-peak electricity reaches 0.6 to 0.7 RMB/kWh or higher, companies using energy storage systems are considered to achieve profitability through peak-valley arbitrage.

In the case of small hydro power station, since its electricity cost is extremely low, primarily consisting of minimal operational expenses, an energy storage system will assist it to achieve peak-valley arbitrage, therefore maximizing its profits.

At the end of September 2024, provincial grid companies released the October 2024 proxy purchase electricity price list for grid enterprises. A total of 18 provinces and cities had a maximum price difference exceeding 0.7 yuan/kWh. The top three were Zhejiang, Guangdong, and Shanghai, with peak-valley price differences of 1.3522 yuan/kWh, 1.3481 yuan/kWh, and 1.2367 yuan/kWh, respectively.

3.2 Cost Analysis

Construction costs, storage battery costs, labor costs, operation and maintenance costs, disposal expenses, and other factors were taken into account when creating the energy storage power station cost model [8].

With battery being the major cost, there's two ways to obtain it. First is through one-time purchase, without any extra fees, it is supposed to be the cheapest way on average per year over the battery's lifecycle.

However, benefiting from the fierce competition in electric vehicles. The cost of LFP batteries continues to decrease rather rapidly.

Hence, with the constant dropping prices of battery, instead of purchasing battery, renting can be a cheaper way to established an ESS in a longer term. Many companies nowadays provide battery rental service. With rental battery, though costs are higher in the short term, the overall cots will be lower if battery prices continue to decrease. Moreover, with battery technology developing rapidly, renting provides access to the latest and more efficient battery.

4 Construction Analysis

4.1 Comparison of Installation Methods

4.1.1 On-site Building Installation

In this method, a dedicated structure (commonly called an energy storage building) is constructed, typically using a reinforced concrete frame. Battery stacks, power conversion systems (PCS), switchgear, transformers, and other equipment are installed inside the building. Depending on the scale, an energy storage building may contain multiple rooms for batteries, PCS, and switchgear. This approach is mainly used for large-scale energy storage stations, and most large domestic energy storage projects connected to the power grid adopt this method. The on-site building installation generally has lower upfront installation costs but entails higher long-term maintenance requirements and a longer construction period. It is also less flexible in terms of mobility.

4.1.2 Prefabricated Cabin Installation

This method uses a standard container design as a base, modified and enhanced to accommodate battery stacks, PCS, and switchgear inside the prefabricated cabin. It is commonly used for small- to medium-scale energy storage systems, such as distributed energy storage and mobile energy storage solutions. The prefabricated cabin installation offers advantages in construction speed, flexibility, and mobility. Given the project's requirements and site conditions, the prefabricated cabin installation method is selected for this project.

4.2 Analysis of Energy Storage System Efficiency

The energy storage system interfaces with the grid through PCS (Power Conversion System) and two primary circuits in the main path. During the charging and discharging processes, each stage incurs a certain amount of energy loss. Additionally, the battery system itself experiences energy loss during charge-discharge cycles.

According to current industry standards and technology, the overall efficiency of the charge-discharge process (Overall Efficiency) is determined by the PCS efficiency (~97%), battery charge-discharge efficiency (~90%), and line loss (~3%). The energy loss in the charge-discharge cycle (~10%) mostly occurs during charging. Therefore, for every 1Wh of storage capacity (with a 90% Depth of Discharge, or DOD), approximately 0.87Wh (1 * 0.9 * 0.97 * 0.997) can be discharged, and the charging process requires around 1.034Wh (0.9 / (0.9 * 0.97 * 0.997)).

5 Conclusions

The Tesla Victoria Big Battery and CATL's National Energy Storage Demonstration Project have both demonstrated the feasibility and advantages of lithium-ion Energy Storage Systems (ESS) in energy storage, as well as the gradual improvements in LFP battery technology. This paper analyzes the advantages of LFP and its application in small hydropower stations. Technically, LFP is the unequivocal first choice due to its superior performance. Economically, as the electric vehicle market develops, the cost of LFP batteries is expected to decline. Furthermore, ESS has become commercially mature, with affordable ESS rental services providing greater flexibility for private power generate applications. While battery prices decrease and the demand for clean energy is rising. Therefore, from a long-term perspective, small hydropower can achieve ecological protection and stable power output through flow control with the assistance of ESS, presenting significant future profit potential. However, the current profitability primarily depends on varying local government policies, and the costs of ESS remain relatively high.

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