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Comprehensive Analysis of Current Research Trends in Battery Technologies as Electricity Storage Devices for Electric Bikes: A Review

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Abstract ***– Over the last few years, reducing reliance on fossil fuels has become a global issue. To reduce greenhouse gas emissions, one of solutions in the transportation industry is to replace gasoline-powered vehicles with electric vehicles. Furthermore, in order for electric vehicles to be competitive, their comparatively high production costs must be reduced, and recharging durations must be improved to be comparable to those of gasoline-powered vehicles. Battery energy storage (BES) has now been widely applied for various purposes, one of which is for electric vehicles. This paper discusses a comprehensive analysis of battery energy storage technology regarding the storage method, operation, and cost of an electric bike (E-Bike). In addition, various E-Bike models with BES types that have been produced by various brands are presented. Therefore, later it can be taken into consideration for scientists in the use of BES on E-Bike.***

Keywords: ***Battery; Energy Storage; Electric Bike; Transportation;***

I. INTRODUCTION

Recently, there has been a surge in interest in electric vehicles (EV) to address issues such as greenhouse gases (GHG), poor air quality, oil shortage, and threat to global energy security [1]–[4]. An electric bike (E-Bike) is the most promising approach in eco-friendly mobility in densely populated urban areas, limited parking and circulation areas [5]. E-bike has a number of advantages over regular vehicles, including zero pollutants, reduced noise levels, and reasonable energy costs [6]–[8]. The growth of the E-Bike market in Europe and Asia-Pacific in 2018-2021 continued to increase [9]. This is shown in Fig. 1. Meanwhile, the Global electric bike (E-Bike) market is expected to record a CAGR of 12.27%, during the forecast period (2021-2026) [10].

As mentioned in the literature [6], [11] E-bikes utilize various types of batteries as energy source. Various properties of batteries energy storage (BES) include power and energy density, round-trip efficiency, life duration, discharge time, operating temperature, environmental and financial concerns [12]–[14]. The characteristics of batteries energy storage (BES) for E-Bike are chosen by considering cost, safety, energy density performance, power density and service life [15].

Furthermore, this study is divided into the following sections: The sorts of battery energy storage technology is discussed in Section 2. Section 3 compares and contrasts the various types of battery storage technologies depending on their properties. The expenses of each form of battery energy storage technology are analyzed and compared in Section 4. The battery storage technology that is suited for electric motorcycles is discussed in Section 5. Section 6 also serves as the paper's conclusion.

II. BATTERIES ENERGY STORAGE TECHNOLOGIES

A battery is an electrochemical device that stores an electric charge through a chemical reaction. Some of the numerous types of electrochemical storage include lithium-ion, lead acid, nickel cadmium, nickel metal hydride, sodium sulphur, and flow batteries. Primary

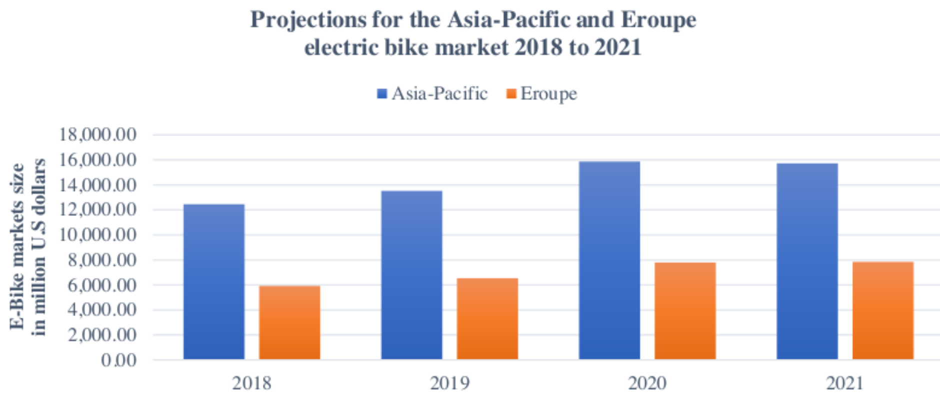

Fig. 1 Projected global e-bike market size in regions Asia-Pacific and Eroupe 2018-2021

(disposable) and secondary (rechargeable) storage batteries are the two main types (rechargeable). A Redox (reduction-oxidation) process occurs when a battery is charged and discharged. The reduction process is when electrons are delivered to the battery when the voltage is at its stationary during charging. On the other hand, the oxidation process is the discharge of electrons from the battery to the load. Rechargeable batteries include vanadium redox, lithium-ion, nickel metal hydride, lead-acid, sodium sulphur, zinc bromine, and nickel cadmium. [16]. The battery's life is influenced by the temperature in which it is kept. Although lower temperatures can minimise the rate of side reactions, excessively cold temperatures can harm some batteries.

Alkaline, Zinc-carbon, Silver-oxide, and Zinc-chloride batteries are non-rechargeable (primary) or single-use batteries. While, multiple charge and discharge cycles are possible with rechargeable (secondary) batteries [17]. Negative electrodes, positive electrodes, electrolytes, and separators are used to make this batteries. Electrical energy from the grid is transformed to chemical energy and stored in the battery throughout the charging process. The chemical energy in the battery is transformed to electrical energy and pumped into the grid during the discharge phase [18]. However, a chemical process can cause the interior parts of a rechargeable battery to corrode and fail. Corrosion can also turn active materials into inactive materials over time.

When it comes to batteries, toxic metals are one of the most pressing environmental challenges we face today. Batteries that have been used often contain toxic substances and contribute to e-waste, which is a serious environmental problem. It is vital to note how electric bike technology use battery storage systems. The current capacity function of a battery ($Q_{max}(I)$) [19] is deduced from eq. (1),

$$Q_{max}(I) = \frac{kcTQ^0_{max}}{1-e^{-kT}+c(kT-1+e^{-kT})} \quad (1)$$

Where c is the ratio of available charging capacity to total capacity. Meanwhile, the rate constant is k, and Q^0_{max} is the maximum battery capacity. In addition, the battery life is modelled using a multiple exponential curve that matches info on failure cycles vs. cycle depth, and represented using eq. (2) [19],

$$C_F = a_1 + a_2 e^{-a_3 R} + a_4 e^{-a_5 R} \quad (2)$$

The fitting constant is a_i, the cycle to failure is C_F, and the cycle range is R.

A. *Nickel Cadmium (Ni-Cd) Batteries*

An NiCd battery [20] is made up of a negative electrode (metal cadmium (Cd)), and positive electrode (NiO(OH)) as well as an electrolyte and a separator. eq. (3) represents the entire reaction during discharge,

$$2NiO(OH) + Cd + H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2 \quad (3)$$

NiCd battery technology is fairly old, and until recently, no breakthrough had been made. Utility, telecommunications backup, and consumer electronics all employ NiCd batteries. Despite NiCd batteries contain highly toxic heavy metals that might affect the environment (soil), these batteries can be safely disposed of at recycling facilities. The high charge/discharge cycles and profitability of these batteries, as well as their ability to function at low temperatures and charge quickly, are the main advantages. The disadvantages include rapid self-discharge, low cell voltage, low density energy, and Cadmium toxicity.

B. *Lead Acid Batteries*

This is also one of the oldest, most efficient, most extensively used battery types. Automobiles (i.e., cars), electronic devices (Uninterruptible Power Supply (UPS), watches, and so on), substation backup power, and communication systems use this storage. There are two types of batteries available: rechargeable and non-rechargeable. An interaction between lead electrodes, sulfuric acid, and electrolyte water produces a voltage in lead-acid batteries. During charge/discharge, the electrolyte water in lead-acid battery is involved in chemical processes. Sulfation is reduced and conductivity is increased when a carbon-based substance is added to the negative electrode [20], [21]. The mature technology, low auto discharge rate, low cost, good dependability and discharge power, and lack of memory effect are all advantages of this battery. The negatives, on the other hand, include low density energy, and slow charging rate. However, due to its toxic effect, this form of battery poses a significant environmental threat. This risk can be considerably avoided if well-maintained and handled with care. The threat of pollution to the environment can be considerably reduced by properly disposing the battery.

C. *Lithium-ion (Li-ion) Battery*

Electrodes (Metal Oxide serves as the positive electrode, whereas Carbon serves as the negative electrode) and electrolyte make up Lithium-Ion batteries [22], also known as Li-Ion batteries (i.e., Lithium salt). When charging and discharging, a chemical reaction occurs, Li-ion batteries run between the electrodes [22]. Eq. (4) represents the entire reaction,

$$iC_6 + CoO_2 \longleftrightarrow C_6 + LiCoO_2 \quad (4)$$

Electric cars, electronic devices, and utility applications have all used this sort of battery. Lithium-ion batteries have a low environmental impact when compared to lead-acid batteries. These batteries have a tendency to explode when exposed to high temperatures or short circuits. Li-ion batteries have many advantages, including high capacity and energy, long life, low internal resistance, power density, self-discharge, and high efficiency. Li-ion batteries, on the other hand, have a number of disadvantages, including safety issues, expensive costs, a relatively high internal resistance, inability to charge at low temperatures, and the necessity for power electronics [22].

D. *Vanadium Redox (VR) Flow Batteries*

The principle of reduction-oxidation is used in redox cells. This battery employs vanadium ions in four oxidation states to store chemical potential energy [23]. Eq. (5) represents the positive electrode response,

$$VO^{2+} + H_2O \longleftrightarrow VO_2^{+} + 2H^{+} + e^{-} \quad (5)$$

Eq. (6) represents the negative electrode reaction,

$$V^{3+} + e^{-} \longleftrightarrow V^{2+} \quad (6)$$

The anode and cathode exchange ions to generate electrical energy in this sort of battery. This battery's working temperature ranges from 10 to 40 degrees Celsius. The key benefits of this battery include high current, energy and power density, no harmful emissions, quick response time, extended cycle life, scalability for large applications, easy upgradeability, enhanced alternating efficiency, and independent energy and power size. The main downsides, on the other hand, include higher prices, increased architectural complexity, and lower efficiency [23].

E. *Zinc Bromine (ZnBr) Batteries*

This battery is typically utilized for backup power, modest load smoothing, and transmission and distribution peak shearing [24]. Scalability for large applications, high power, energy, and density, and partially independent energy and power measures are only a few of these batteries' significant advantages. The primary constraints include safety concerns (corrosive and toxic substances), early-stage technology, and expensive maintenance expenses.

III. COMPARISON OF BATTERIES ENERGY STORAGE TECHNOLOGIES

This section compares and analyses several types of battery energy storage (BES) from a technological, economic, and environmental standpoint. As a result, this section's purpose is to assess and compare the various selected battery energy storage. This section also assesses the possibilities for BES to be used in electric vehicles.

A. *Technical Criteria*

Based on data from literatures [25]–[35], power density, power range, discharge time, service life, energy density, efficiency, and technology maturity are the most important technical aspects to consider while evaluating the technical performance of the chosen BES. TABLE I summarizes the technical characteristics of all selected BES kinds.

B. *Energy and Power Density of BES Comparison Result*

The energy density (Wh/L) and power density (W/L) of a battery are measures how much energy and power it contains in relation to its volume. TABLE I shows how they are usually stated in Watt-hours/liter (Wh/L) and watts/liter (W/L) [36]. The energy density (200-400 Wh/L) and power density (500-2,000 W/L) of the lithium-ion type electrochemical ESS are higher than those of other ESS batteries in this scenario.

C. *Discharge Time of BES Comparison Result*

The Ah or mAh rating is divided by the current to get the discharge time. The amount of time to charge a battery is determined by its chemistry and charge current [37]. Ni-Cd, lead-acid, and VRB BES types have a longer discharge time (sec-hrs) than lithium-ion batteries in this case (20 ms).

D. *Round-Trip Efficiency of BES Comparison Result*

TABLE 1. Comparison of characteristics of types of BES technology

Types of technology ESS	Density		Roud-trip efficiency (%)	Life time (year)	Disharge time (ms-hr)	Cost (USD $/kWh)	Impact Environmental
	Energy (Wh/L)	Power (W/L)					
Battery (Ni-Cd) [14], [25], [26], [28]–[32], [39]–[41]	15-80	75-700	60-80	5-20	sec-hr	400-2400	High
Battery (Li-Ion) [14], [25]–[27], [32], [39]–[41]	200-400	500-2.000	85-90	5-15	20 ms	600-3800	Low
Battery (Lead-acid) [14], [25], [32], [39]–[44]	50-85	0-20	70-90	5-15	sec-hr	54-400	Moderate
Battery (ZnBr) [25], [26], [39]–[41], [45]	15-65	1-25	65-85	5-10	-	-	-
Battery (VRB) [26], [32]–[35], [39]–[41]	20-70	0.5-2	60-75	5-20	sec-10 hrs	190-1085	-

TABLE 2. Various types of E-Bike models with commercial BES types

Model E-Bike	Type Battery	Charge time (h)	Maximal Distance (Km)		Price ($)
			Full Trotle	With Padel	
Selis type Roadmaster [46]	Lithium (36V/10Ah)	5	35	50	951.84
Selis type Art of Indonesia (AOI) [47]	Sealed lead-acid (36 V/ 12 Ah)	-	35		458.29
Selis type RoadBike Storm [48]	Lithium-Ion (36 V/ 10,4 Ah)	5	70	>speed 10 Km/h	2749.76
U^WINFLY LB1 [49]	Lithium (48 V/ 15 Ah)	-	30 – 50		627.51
Polygon type Kalosi Miles [50]	Lithium-Ion (36 V /11.6 Ah)	6-8	95		1233.87
Polygon type GILI VELO [51]	Lithium-Ion (36 V / 7Ah)	4-6	80		1022.35
Polygon type GILI FITTE [52]		4-6	80		1092.85

Round-trip efficiency considers energy losses from parasitic loads and power conversions and (e.g., pumps, electronics, cooling, and heating) involved with operating the energy storage system [37]. This statistic is an important predictor of energy storage technologies' cost-effectiveness. Li-Ion (85-90 percent), in this case, lead-acid and ZnBr batteries have better round-trip efficiency than other types of batteries (70-90 percent and 65-85 percent, respectively).

E. *Life time of BES Comparison Result*

The longevity of an ESS is affected by a number of factors, including discharge depth, environmental conditions, as well as charge and discharge cycles. In every application, increasing the depth of discharge reduces the required energy storage capacity [37]. BES kinds such as Ni-Cd, Li-Ion, Lead-acid, and VRB have a long life duration more than 10 years.

F. *Economics Criteria and impact environmental of BES*

Toxic metals in battery storage are hazardous wastes. It will threaten the environment and human health if it is improperly disposed. Cadmium and lead batteries, for example, contain more dangerous components than lithium-ion BES [38]. Furthermore, in comparison to other BES types, the anticipated cost per kWh of Lead-acid BES and VRB is the lowest.

IV. TYPES OF BES USED IN COMMERCIAL E-BIKES

SELIS, UWINFLY, and Polygon have begun producing several models in the Asian E-bike industry, particularly in Indonesia [46]–[52]. Table 2 illustrates this. These brands are more likely to use Li-Ion BES. This is due to the fact that Lithium-Ion BES offers superior properties than other forms of BES [13][40]. However, because lead-acid BES is less expensive than other BES, the SELIS brand employs it [13].

BES lithium-ion type is more generally employed by E-bike brands, according to TABLE II. BES of the lead-acid kind is also available.

V. CONCLUSION

This paper discusses the many types of energy storage batteries (BES) on the market, as well as their charateristics. Based on the review's findings, a conclusion can be drawn, among the several types of BES, lithium-ion batteries are the most cost-effective alternative for E-Bike applications.. This is because the lithium-high Ion's energy density (200-400 Wh/L), high power density (500-2000 Wh/L), less weight, smaller size, good round-trip efficiency (85-95%), long service life (5-15 years), and minimal environmental impact. Safety, high energy density performance, high power density, and extended service life are among the charateristics necessary for an E-Bike. As a result, the lithium-ion type BES is the most suited kind for E-Bike applications. The cost for this type of BES, on the other hand, is relatively high, and the discharge time is much faster than other types of BES. This sort of BES has also been widely employed on E-Bikes by major brands. There are also Ni-Cd, lead-acid, and VRB BES that have higher round-trip efficiency, longer discharge time, and a longer service life.

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