Consideration on Present and Future of Battery Energy Storage System to Unlock Battery Value

Ji-Soo Kim, Jin-Sol Song, Chul-Hwan Kim, Jean Mahseredjian, and Seung-Ho Kim

***Abstract*—To address environmental concerns, there has been a rapid global surge in integrating renewable energy sources into power grids. However, this transition poses challenges to grid stability. A prominent solution to this challenge is the adoption of battery energy storage systems (BESSs). Many countries are actively increasing BESS deployment and developing new BESS technologies. Nevertheless, a crucial initial step is conducting a comprehensive analysis of BESS capabilities and subsequently formulating policies. We analyze the current roles of BESS and review existing BESS policies worldwide, which focuses on key markets in Asia, Europe, and the U.S.. Using collected survey data, we propose a comprehensive three-phase framework for policy formulation, providing insights into future policy development directions.**

***Index Terms*—Battery energy storage system (BESS), policy analysis, recycling, renewable energy, economic and subsidy support policies, long-duration energy storage, safety standard.**

I. Introduction

ELECTRICITY serves as a critical resource, vital for sustaining our modern civilization, accommodating our ever-expanding population, and driving technological progress. Nonetheless, electricity poses a significant challenge due to its intrinsic difficulties in storage and its transient nature upon consumption. Indeed, the integration of renewable energy sources with intermittent output characteristics, such as solar and wind power, can pose challenges to the stability and reliability of power grids [1]-[3]. The variability in energy generation from these sources can lead to grid instability, including voltage fluctuations and frequency deviations. Battery energy storage systems (BESSs) play a crucial role in addressing these challenges. BESS units are seamlessly integrated into the power grid to regulate frequency and are coupled with renewable energy sources to alleviate intermittent output [4]-[10]. As a result, the adoption of BESS technology continues to rise, necessitating the establishment of comprehensive policies and regulations to address this growing demand.

Across the globe, nations are implementing diverse economic policies, notably subsidies, with the intent of expediting the widespread adoption of BESS [11]. These policies function as incentives, stimulating investments in BESS technology and thereby facilitating its pervasive incorporation. Concurrently, substantial investments are being directed towards research and development endeavors, aiming at propelling advancements in high-capacity and extended-duration BESS technologies. These investments constitute a pivotal stride towards augmenting the efficacy and longevity of BESS units. Moreover, meticulous efforts are underway to formulate stringent safety regulations, particularly addressing fire hazards, which loom as a significant concern in the deployment of BESS. Ensuring the safety of BESS installations stands as an utmost priority, which is crucial for their seamless integration into the power grid.

This paper delves into the roles and market trends associated with BESS, conducting a comprehensive analysis of current BESS policies. It scrutinizes the unique method adopted by leading BESS market countries to regulate BESS and explore technological developments across multiple policy categories: ① economic and subsidy support policies; ② long-duration BESS development policies; ③ BESS recycling policies; ④ safety policies.

The exponential rise in renewable energy integration into the power system has engendered multifaceted challenges within the power system. Amidst these complexities, BESS emerges as pivotal solutions, capable of fulfilling diverse roles [12]-[14]. Extensive research underscores the efficacy of BESS in regulating power system frequency through its charge and discharge capabilities, mitigating the intermittency inherent in renewable energy sources. Furthermore, BESS facilitates peak shifting, contributing significantly to grid stability.

Although there are existing technical review papers for various BESSs, there are only a few review papers on policy-related BESS [15]-[19]. However, policy analysis must precede technical evaluation. Different countries have varied regulations pertaining to BESS. Examining the BESS policies in developed nations is particularly crucial; it can guide future policy formulations in countries entering the field.

Manuscript received: September 28, 2023; revised: December 23, 2023; accepted: May 8, 2024. Date of CrossCheck: May 8, 2024. Date of online publication: June 13, 2024.

This work was supported by the National Research Foundation (NRF) of Republic of Korea grant funded by the Korean Government (MSIP) (No. 2021R1A2B5B03086257).

J.-S. Kim (corresponding author) and J. Mahseredjian are with the Department of Electric Engineering, Polytechnique Montréal, Montreal, Canada (e-mail: kjs7107@naver.com; jean.mahseredjian@polymtl.ca).

J.-S. Song and C.-H. Kim are with the Department of Electrical and Electronic Engineering, Sungkyunkwan University, Suwon, 16419, Republic of Korea (e-mail: wlsthf6@naver.com; chkim@skku.edu).

S.-H. Kim is with Global Electricity Co., Ltd, Siheung, 15117, Republic of Korea (e-mail: steve@globalups.co.kr).

DOI: 10.35833/MPCE.2023.000723

BESS plays a key role in enhancing grid stability and understanding these policies can offer insights into supporting the integration of renewable energy into the power grid. Moreover, each region establishes specific technical standards and safety regulations concerning energy storage systems. A comprehensive grasp of these policies ensures that BESS projects comply with essential standards, thereby elevating safety and reliability. Lastly, analyzing country-specific BESS policies aids in identifying emerging markets and potential avenues for growth.

II. Global Market Status and Forecast

As per the data provided by the energy research from BloombergNEF, the global energy storage capacity witnessed a substantial increase in 2022, with a total addition of 16 GW/35 GWh, which denotes a significant 68% surge compared with the preceding year [20]. Projections indicate a sustained annual growth rate hovering around 23%, leading to an anticipated installation of an additional 88 GW/278 GWh of energy storage capacity by 2030. Forecasts also suggest that the cumulative capacity is set to escalate to 508 GW/1432 GWh by the same year. Moreover, the global energy storage market, valued at approximately 11 billion USD in 2021, is anticipated to expand remarkably to a valuation of 262 billion USD by 2030 [20]. The global additional energy storage capacity [21] is presented in Fig. 1.

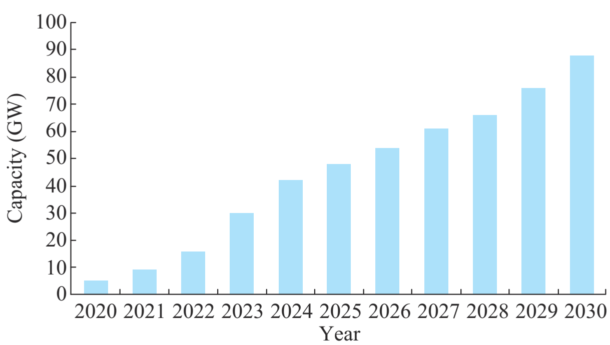

Fig. 1. Global additional energy storage capacity.

The U.S. stands prominently as a key player in the energy storage domain, boasting a robust market, particularly evident through substantial large-scale projects situated notably in states, such as California and Texas. Presently, these states command the most significant portion of the market share. Projections indicate that by 2030, the America region is anticipated to account for approximately 21% of the global total energy storage capacity. However, the recent rise in battery costs, escalating from 141 $/kWh in 2021 to 151 $/kWh in 2022, as depicted in Fig. 2, has posed challenges. Moreover, China's previous dynamic Zero-COVID policy and the ongoing conflict between Russia and Ukraine have resulted in project delays within the U.S. [21]. China plays a pivotal role in the world's most crucial global supply chains. Nevertheless, China's previous dynamic Zero-COVID policy might potentially disrupt supply chains connected to manufacturing components essential for the BESS project. Furthermore, the conflict between Russia and Ukraine could impact economic stability, potentially causing uncertainty in investments or financing for energy projects within the U.S.. With China in the process of reforming its energy storage targets, it is expected that China will soon surpass the U.S. in this market, as shown in Fig. 3.

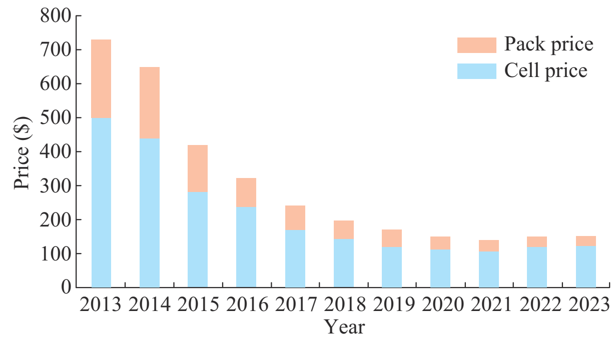

Fig. 2. Cell and pack prices for lithium-ion battery.

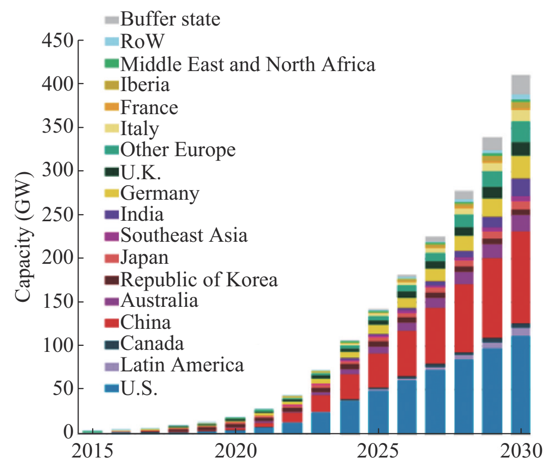

Fig. 3. Global cumulative energy storage system installation.

In China, a frontrunner in the Asian energy storage market, the State Grid Corporation of China (SGCC) has set an ambitious target of elevating battery storage capacity to an impressive 100 GW by 2030. Recent reports underscore a substantial upsurge in China's production of lithium-ion batteries designated for energy storage purposes. This surge marked a notable 146% increase, reaching 32 GWh in 2021, contributing to 10% of the total lithium-ion battery production (324 GWh). This surge in production reflects an extraordinary 106% rise and culminates in a market valued at 600 billion yuan (95 billion USD) [22]. Noteworthy was the exceptional growth of China's battery energy storage market, which expanded by over 400% in 2022, predominantly propelled by domestic companies. Leading firms in China are actively pursuing global expansion, offering competitively priced products. This unparalleled market evolution in China plays a pivotal role in steering the development of the global BESS market [22]. Additionally, Japan has recently introduced subsidy policies for batteries, while Republic of Korea has established plans to secure a cumulative capacity of 25 GW/127 GWh in energy storage by 2036 [22]. In the Europe, Middle East, and Africa (EMEA) region, projections estimate a 24% share of the total storage capacity by 2030 [22]. Over the past year, a significant investment of 1 billion euros has been allocated to support storage projects in countries such as Greece, Romania, and Spain. Consequently, an additional 4.5 GW/7.1 GWh of energy storage capacity is incorporated in 2022. This region anticipates achieving a cumulative energy storage capacity of 114 GW/285 GWh by 2030, with countries such as the U.K., Germany, Italy, and Greece leading this advancement [23].

As the complexity of power systems escalates, the stability of the power grid faces mounting challenges. The burgeoning BESS market presents a myriad of solutions for addressing grid stability issues. These solutions encompass areas such as integrating renewable energy sources, enhancing grid resilience, balancing loads, regulating frequency, and managing peak demands. Despite the rapid expansion of the BESS market, policy development often lags behind this growth trajectory. To effectively bolster the burgeoning BESS market and ensure its sustained success, proactive policymaking is imperative. Policymakers need to introduce novel policies and update existing ones in a timely manner. In this paper, the comprehensive examination of current policies and its analysis of future policy requisites mark a crucial stride toward regulatory frameworks with the evolving dynamics of the market. Such alignment holds the potential to spur innovation, attract investments, and foster sustainable growth within the BESS industry. Moreover, it stands poised to address emerging challenges and capitalize on forthcoming opportunities.

III. Policies for Economic Support and Subsidies

Subsidy policies across various countries serve as pivotal catalysts in expediting the widespread adoption of renewable energy sources, particularly solar power generation, and BESS in both industrial and residential applications. These well-crafted policies are strategically designed to enhance the accessibility and affordability of renewable energy and energy storage technologies.

Numerous countries implement subsidies aimed at mitigating the installation costs of solar power generation systems and BESS. These subsidies effectively mitigate a portion of the initial expenses incurred in procuring and installing these technologies, rendering them financially more appealing to both homeowners and businesses. Additionally, tax incentives, such as deductions and credits, are commonly extended to individuals and enterprises investing in renewable energy and energy storage. These tax incentives function to alleviate tax liabilities, thereby effectively reducing the overall installation costs associated with solar panels and BESS.

Moreover, certain regions provide subsidies directly linked to the performance of BESS during peak load periods. Owners of BESS stand to benefit from financial incentives or rebates based on the quantity of energy discharged from their systems when the grid experiences heightened demand. This proactive method incentivizes the utilization of energy storage to alleviate strain on the grid during peak periods, thereby promoting its advantageous role in stabilizing the power grid.

A. Asia

1) China

China's prominence in the global BESS market is reinforced by its proactive stance in introducing successive policies aimed at developing the BESS industry. Notably, in 2021, the unveiling of three pivotal documents delineated a comprehensive blueprint with the ambitious goal of achieving full-scale marketization of new BESS by 2030 [24]-[26]. A standout example, the "Notice on Measures to Relax Electricity Rates by Time Zone," has significantly widened the price differential between peak and off-peak electricity demand, establishing a 4:1 ratio for electricity rates. This strategic measure acts as a compelling incentive, encouraging users to embark on their own BESS projects [27].

Moreover, local Chinese Governments have unveiled a spectrum of policies aimed at reinforcing support for BESS initiatives. Many projects have specifically sought an increase in BESS capacity, particularly linked to new and renewable energy sources, with a targeted range between 10%-20%. There is a strong emphasis on designing energy storage systems with a minimum duration of 2 hours to ensure efficacy and reliability. Furthermore, to expedite the development of BESS, an operational subsidy of 0.1 ¥/kWh is being extended for the power generated from BESS, contributing significantly to the overall advancement of this burgeoning sector [27]. This concerted effort signifies China's proactive method towards nurturing and fostering a robust landscape for energy storage systems within its market.

2) Japan

In support of Japan's strategic energy-mix objectives and commitment to achieving carbon neutrality, the Japanese Government takes a proactive step aligned with prevailing market conditions. In its FY2021 supplementary budget, a significant allocation of 13 billion JPY is earmarked to incentivize the adoption of stand-alone BESS through subsidies. The inception of the initial subsidy program, designed to offset the construction costs of stand-alone BESS, welcomes applications from February 16, 2022 to March 11, 2022.

To meet the eligibility criteria, a BESS has to qualify as a stand-alone system with a minimum output capacity of 1000 kW. Specifically, a stand-alone BESS with an output capacity ranging from 1000 kW to below 10000 kW could receive a subsidy equivalent to up to one-third of the total construction cost. Conversely, a stand-alone BESS with an output capacity of 10000 kW or higher is eligible for a subsidy of up to half of the total construction cost. Both scenarios have a maximum subsidy cap per application set at 2.5 billion JPY. These details are outlined in Table I, with subsidies designated exclusively for essential costs related to design, equipment supply, and/or construction, as stipulated [28]. This initiative represents a strategic investment by the Japanese Government to accelerate the integration of stand-alone BESS into the country's energy infrastructure, aligning with its broader sustainability goals.

TABLE I
SUBSIDY RATE AND THE MAXIMUM AMOUNT

Category	Subsidy rate	The maximum amount (JPY)
Design, equipment, and construction costs of BESS: ① manufactured using new technology and ② assembled via the secondary use of storage battery modules used to drive electric vehicles (EVs)	Up to 1/2	2.5 billion
Design, equipment, and construction costs of BESS under capacity from 1000 kW to 10000 kW	Up to 1/3	1.0 billion
Design, equipment, and construction costs of BESS under capacity of more than 10000 kW	Up to 1/2	2.5 billion

3) Republic of Korea

The Korean Government initiated a small-scale BESS supply support project in 2012, offering substantial assistance covering 70% of the installation costs for BESS. This policy extended to supporting BESS installations for wind power starting in 2015 and for solar power from 2016. Additionally, a subsidy support policy targeting buildings was implemented in 2017, which led to a notable increase in BESS installations. However, a concerning trend emerged as numerous fire incidents associated with BESS installations were reported. Consequently, the subsidy support for BESS installation was discontinued after 2020 as a precautionary measure.

Another subsidy support policy in Republic of Korea is linked to peak demand management. Under this policy, when BESS is utilized to reduce peak demand power, the average peak demand power reductions (APDPRs), multiplied by the unit price of the base rate applicable to the representative customer are deducted from the base rate [26]. This method incentivizes the use of BESS to mitigate peak power demands, promoting a more efficient and stable power grid while considering safety concerns that lead to the discontinuation of the installation subsidies. In Republic of Korea, there is a designated maximum load time of 6 hours per day. Within this timeframe, 3 hours, as specified in Table II, are categorized as A hours, while the remaining hours are classified as B hours. The APDPR calculation method is as follows [29]:

$$APDPR = \frac{d_{ch,A}\omega + d_{ch,B}}{3N_{week}} \tag{1}$$

where $d_{ch,A}$ and $d_{ch,B}$ are the discharge amounts with A and B hours, respectively; ω is a weight with $\omega = 1.23$ for indoors and $\omega = 1.1$ for outdoors; and N_{week} is the number of weekdays in the month.

TABLE II
SPECIFIED DISCHARGE TIME

Season	Discharge time
Summer	14:00-15:00, 15:00-16:00, 16:00-17:00
Winter	09:00-10:00, 10:00-11:00, 17:00-18:00
Spring and fall	14:00-15:00, 16:00-17:00, 17:00-18:00

If it becomes unfeasible to verify the discharge amount due to communication breakdowns, equipment malfunctions, remote data non-receipt or similar issues, and calculations rely on the reception rate of remote meter reading. If the reception rate of remote meter reading within the designated time zone stands at 90% or above, any unconfirmed time delay is computed based on the maximum load time. However, if the reception rate falls below 90%, time-specific data of the customer will be furnished subsequently, and settlements will be conducted accordingly. Presently, this support scheme is slated to remain effective until March 31, 2026 [29].

B. Europe

1) U.K.

In U.K., batteries can avail a 0% value added tax (VAT) rate when incorporated into an installation alongside a qualifying material, such as a solar energy system [30]. However, it is crucial to highlight that batteries presently do not feature on the list of energy saving materials (ESMs) themselves. Consequently, when installed as standalone products, batteries do not qualify for the 0% VAT rate.

Solar Energy U. K., a representative body encompassing over 350 member companies within the U.K. energy sector and beyond, actively advocates for the inclusion of batteries on the list of ESMs. Their ongoing advocacy aims to underscore the significance of this inclusion, ensuring that batteries, when integrated into energy-saving installations, can benefit from the same favorable VAT treatment accorded to other qualifying materials.

2) Germany

Germany stands at the forefront of renewable energy development in Europe, steadfast in its ambition to achieve a minimum of 80% electricity consumption sourced from renewables by 2050. To facilitate the seamless integration of solar power generation into the power grid, Germany has instituted a range of subsidy programs.

Firstly, homeowners in Bavaria benefit from the “Energy Storage Photovoltaic Program” [31]. This initiative enables the purchase of solar power storage units starting at a capacity of 3 kWh. These units, applicable for detached or semi-detached houses, receive subsidies in tandem with new photovoltaic systems via the “Energy Bonus Bavaria” endeavor. The subsidy commences at 500 euros for a 3 kWh storage unit, with an additional 100 euros for each extra kWh of storage capacity, capped at 30 kWh.

Secondly, in Baden-Württemberg, the “Grid Service Photovoltaic Battery Energy Storage” funding program, well-received in 2018 and 2019, recommenced on April 1, 2021 [32]. This program encouraged the investments in electricity storage concurrently with newly installed photovoltaic systems.

Thirdly, Berlin introduces the “EnergiespeicherPLUS” program, extending funding for electricity storage units connected to newly installed photovoltaic systems [33]. Eligible applicants meeting program requirements may receive funding of 300 €/kWh of storage capacity, up to a maximum of €15000. It is worth noting that the availability of funds for this program may be limited, potentially leading to periods where new applications cannot be submitted due to fund exhaustion.

These initiatives in Germany are strategically designed to incentivize the adoption of renewable energy technologies, particularly solar power and energy storage systems. These efforts play a crucial role in expediting the country's transition towards sustainable and clean energy sources.

C. U.S.

The U.S. Investment Tax Credit (ITC) for energy property stands as a pivotal tax incentive program, offering tax credits for investments in diverse renewable energy projects [34]. This program extends its benefits to a wide array of renewable energy technologies, encompassing fuel cells, solar panels, geothermal systems, small wind turbines, and notably, energy storage systems like batteries. By providing this tax credit, the program acts as a substantial motivator for both individuals and businesses to channel investments into clean and sustainable energy solutions. As a result, it significantly encourages the widespread adoption of renewable energy technologies and energy storage systems throughout the U.S..

Moreover, various states across the U. S., in conjunction with federal programs, offer incentives to homeowners keen on installing home energy storage systems and other renewable energy solutions. These initiatives are strategically designed to stimulate the adoption of clean energy practices while aiming to diminish reliance on conventional energy sources. A recap of the mentioned programs is as follows.

1) California: Self-generation Incentive Program (SGIP)

California's SGIP offers rebates to incentivize the installation of renewable energy systems, including solar panels and energy storage, in various types of properties, including residential, commercial, and industrial properties. This program supports self-generation and grid resilience [35].

2) New York: NY-Sun Incentive Program

New York's NY-Sun Incentive Program provides financial incentives for the installation of solar panels and energy storage systems. It is accessible to residential, commercial, and industrial properties, contributing to the expansion of solar energy adoption in the state [36].

3) Hawaii: Hawaii Battery Bonus Program

Hawaii Battery Bonus Program offers substantial rebates to encourage residents to install home energy storage systems. This initiative aligns with Hawaii's commitment to clean energy and grid reliability [37].

IV. Development Policies of Long-duration BESS

The exploration of long-duration BESS stands as a global focal point, driven by the escalating demand for dependable and sustained energy storage solutions. Vanadium redox flow batteries (VRFBs) have garnered substantial interest owing to their potential for prolonged cycling capabilities and suitability for long-duration energy storage (LDES) [38]-[40]. However, the realm of research extends beyond VRFB, encompassing ongoing investigations into alternative materials and technologies. The primary objective is to cultivate cost-effective and reliable BESS options that align with the demands of evolving energy landscape. These demands encompass seamless grid integration, bolstering renewable energy initiatives, and fulfilling the burgeoning need for LDES solutions.

A. Asia

1) China

China has unveiled ambitious plans for advancing its new energy storage capacity, setting forth a roadmap that envisions transitioning from the initial commercialization phase to expansive development by 2025. This strategic trajectory aims to achieve an installed capacity surpassing 3×10^7 kW. This initiative dovetails with China's overarching commitment to establishing a fully market-oriented new energy storage sector by 2030. The dual impetus behind this endeavor is twofold: to stimulate the consumption of renewable power resources and ensure the robust and stable operation of the power system.

The National Development and Reform Commission (NDRC) and the National Energy Administration delineate the spectrum of new energy storage, encompassing electricity storage methodologies, such as electrochemical, compressed air, flywheel, and supercapacitor systems. Notably, this categorization excludes pumped hydro, which is a method reliant on water stored behind dams for generating electricity as needed.

Anticipating substantial technological advancements, the NDRC forecasts a notable evolution in electrochemical-based new energy storage, projecting a more than 30% reduction in system costs by 2025 compared with end-of-2020 levels. Analysts underscore that accelerating the development of new energy storage technologies will significantly contribute to China's environmental objectives, namely, peaking carbon emissions by 2030 and achieving carbon neutrality by 2060. Moreover, this strategic push aligns seamlessly with China's broader vision of cultivating a clean, low-carbon, safe, and highly efficient energy system [41].

2) Japan

In Japan, while there is not a distinct policy exclusively focused on the development of next-generation batteries, there are several ongoing development initiatives. Notably, Sumitomo Electric is set to provide an 8-hour duration VRFB to a newly established municipal power company in Niigata [42]. This LDES system will find its placement at the premises of a public sewage treatment plant situated in Kashiwazaki city within Niigata Prefecture.

3) Republic of Korea

The Korean Government is gearing up to invest a substantial sum, ranging between 29 to 45 trillion won, constructing backup facilities for renewable energy. This investment is guided by the application of the BESS low- and high-cost scenarios for National Renewable Energy Laboratory (NREL) in U.S.. The comprehensive plan entails the adoption of batteries utilizing diverse materials and technologies, encompassing lithium, sodium-ion, redox flow, and magnesium.

Short-duration BESSs will serve the purpose of maintaining grid frequency and ensuring a real-time balance between supply and demand. Conversely, long-duration BESSs will play a critical role in addressing situations of oversupply by facilitating load leveling and reducing output control.

Notably, there are ambitious plans to install approximately 20.85 GW of long-duration BESSs, including VRFB, by

2036. The projected cost for this extensive installation is estimated to range between 22.8 trillion and 39.0 trillion won [43]. The Korean Government has set clear battery capacity objectives, as shown in Table III.

TABLE III
BATTERY CAPACITY TARGETS FROM KOREAN GOVERNMENT

Year	Short-duration BESS (GW/GWh)	Long-duration	
		BESS (GW/GWh)	Pumped-storage hydroelectricity (GW)
2023-2026	0.05/0.03	0.16/0.83	-
2027-2030	1.16/0.73	3.10/18.47	-
2031-2036	3.66/2.29	20.85/124.97	1.75

B. Europe

1) U.K.

The U. K. Department for Energy Security and Net Zero has earmarked 30 million euros in grants to support three pioneering LDES projects leveraging innovative energy storage technologies. Among the recipients, Synchrostor, Invinity Energy Systems, and Cheesecake Energy have secured funding for their respective initiatives.

Synchrostor and Cheesecake Energy will each receive 9.4 million euros to propel the development of their thermal energy storage systems. Meanwhile, Invinity Energy Systems is set to receive 11 million euros to advance the progression of a VRFB [27].

Of particular importance is the Invinity Energy System project, which is centred on a 4-hour 30 MWh VRFB and stands out as a remarkable undertaking. It marks the largest deployment of the technology in the U.K. and represents the most substantial project of Invinity Energy System to date. Furthermore, Synchrostor, headquartered in Edinburgh, is actively advancing a pumped thermal energy storage demonstration project, showcasing a commendable 1 MW of power capacity [44].

2) Germany

Fraunhofer Institute in Germany is actively engaged in the "RedoxWind" project, generously funded by the state of Baden-Württemberg and the German Federal Ministry of Education and Research (BMBF). The core initiative of this project involves the development of a sizable redox flow BESS, directly integrated into the intermediate DC circuit of a wind turbine. This integrated unit, comprising a generator and a BESS, is set to serve as a pivotal pilot project at Fraunhofer-Institut für Chemische Technologie (ICT) in Pfinztal [45].

The primary objective of the RedoxWind project is to adapt wind farms for battery operation, focusing notably on upscaling redox flow technology from laboratory-scale to industrial-scale stacks capable of producing several kilowatts. A key emphasis lies in capitalizing on the synergies between wind power plants and BESS. This innovative connection between wind farms and batteries holds significant potential, poised to offer self-sustaining electricity supply solutions for isolated applications, companies, or energy-efficient villages [45].

C. U.S.

The U. S. Department of Energy (DOE) launched the Long-duration Storage Shot in July 2021, with a bold aiming to achieve a levelized cost of energy storage of 0.05 $/kWh by 2030 [46]. This ambitious target signifies an immense 90% reduction from 2020 baseline costs. The primary objective behind this cost reduction endeavor is to establish dispatchable clean energy derived from LDES as the most economically viable choice for electricity consumers. To realize this goal, a comprehensive method is necessary, encompassing a wide spectrum of energy storage technologies that surpass conventional lithium-ion batteries. This inclusive method involves considering solutions spanning electrochemical, mechanical, thermal, flexible generation, flexible buildings, and power electronics. LDES systems, defined as those capable of storing energy continuously for more than 10 hours, stand poised to play a pivotal role in establishing a low-cost, dependable, and carbon-free power grid.

The cost-effectiveness and efficiency gains realized through improved energy storage will simplify the process of capturing and storing clean energy for use during periods when energy generation is insufficient, or demand exceeds supply. For example, it would enable the utilization of solar-generated power during nighttime, or the application of nuclear energy produced during low-demand periods when demand surges. Notably, the state of California recently allocates 31 million USD in funding for a hybrid microgrid project featuring VRFB and zinc hybrid cathode battery technologies. This project marks the initial beneficiary of a 380 million USD fund. Other initiatives stemming from the Bipartisan Infrastructure Law include a 335 million USD program supporting battery recycling and 675 million USD program allocated for research and development of critical minerals. In total, approximately 7 billion USD in support for EV and stationary energy storage battery value chains will be disbursed through this legislation [47].

V. BESS RECYCLING POLICIES

Many countries are indeed grappling with the challenge of managing waste batteries as the EV industry continues to expand. While there is growing interest in recovering and recycling materials like lithium and nickel from these batteries, specific target figures for recycling rates may not be universally established outside the European Union (EU).

Nevertheless, Governments, research institutions, and businesses are actively investing in research and development efforts, supporting startups, and fostering market development in the field of battery recycling and reuse. These initiatives aim to create more sustainable solutions for handling waste batteries and extracting valuable resources, contributing to environmental goals, and reducing the strain on raw materials. As the battery market matures and technologies continue to evolve, it is likely that more countries will establish concrete recycling targets and regulations to address this pressing issue. In the meantime, the emphasis remains on innovation, investment, and collaboration to develop effective and economically viable recycling methods for batteries.

A. Asia

1) China

NDRC of China has unveiled significant goals and measures outlined in the 14th Five-year Circular Economy Growth Plan, extending until 2025. One of the key objectives highlighted in this plan is to address deficiencies in the resource recycling system within the major industries in China [48]-[51].

Regarding the battery, the plan outlines the intention to create a new energy vehicle battery and waste battery history management platform. Also, to enhance the recycling and recovery of waste batteries, the plan emphasizes the need for new energy vehicle production companies and waste battery reuse companies to collaborate in standardizing the recovery service network. This could involve self-construction of recycling infrastructure, joint efforts, or delegating authority to specific entities for managing the collection and recycling of waste batteries. Last, the plan also highlights the importance of improving the level of value diagnosis and safety management technology related to batteries.

2) Japan

In Japan, the adoption of EVs has been relatively low, with a penetration rate of only 0.6% in 2021. However, due to this low-adoption rate, there have been various instances of recycling used EV batteries for alternative purposes in daily life. For example, Mitsubishi Motors embark on a battery recycling initiative where they collect used EV batteries and repurpose them as storage batteries at their manufacturing facility. Additionally, the Forest Country Club in Shizuoka Prefecture finds a creative way to reuse waste EV batteries by utilizing them to power electric golf carts. However, as the Japanese Government recently announces a ban on the sale of new internal combustion engine vehicles after 2035, there has been a growing emphasis on fostering the battery industry to support the transition to electric mobility. To facilitate this growth, the Government has committed to a significant investment of 100 billion JPY and is providing subsidies to advance battery-related technologies and infrastructure [52].

In Japan, a non-profit organization (Japan Portable Battery Recycling Center) manages Japanese battery recycling. Active programs are also being developed to reuse batteries for home emergency power [52].

3) Republic of Korea

In September 2022, the Korean Government announced that it would exempt batteries from used EVs from waste regulations, establish a safety inspection system for reuse, and establish a separate registration and management system from EVs. Previously, the storage capacity of waste used as recycling material was limited to 30 days or fewer of the daily processing capacity, but this has been extended to 1080 days [53].

As the EV market continues to grow, there are plans to encourage and nurture the reuse and recycling of waste EV batteries as a new business venture. To support this initiative, a substantial amount of 48.8 billion won has been allocated, which will be directed towards various activities including research and development efforts and support for startup companies. The goal is to harness the potential of waste EV batteries and create a robust battery cluster ecosystem by 2025 [54].

B. Europe

The EU has established the following recycling and recovery rate policies [55].

The target for collecting portable battery waste is to achieve a rate of 63% by the end of 2027 and 73% by the end of 2030. For waste batteries from light transport, the collection rate should reach 51% by the end of 2028 and 61% by the end of 2031. These goals are aimed at enhancing battery waste collection. Regarding lithium recovery from spent batteries, the target of collection rate is set at 50% by the end of 2027 and 80% by the end of 2031. These targets may be subject to revision based on market and technological developments and the availability of lithium. The recycling requirements for industrial and EV batteries specify a minimum recovery of 16% cobalt, 85% lead, 6% lithium, and 6% nickel. This ensures that a significant portion of these materials is reclaimed during recycling processes. For nickel-cadmium batteries, the recycling efficiency target is 80% by the end of 2025, while the target for other types of waste batteries is 50% by the end of 2025. These targets promote more effective recycling practices. These policies are designed to promote sustainability and responsible recycling practices within the EU, which can be summarized in the following Tables IV and V [55].

TABLE IV
RECYCLING TARGET FOR EACH CATEGORY

Category	1st target year	Recycling target for 1st year (%)	2nd target year	Recycling target for 2nd year (%)
Battery waste for portable battery waste	2027	63	2030	73
Battery waste for light transport	2028	51	2031	61
Lithium from lithium-ion battery	2027	50	2031	80
Nikel-Cadmium batteries	2025	80	-	-
Other batteries	2025	50	-	-

TABLE V
THE MINIMUM RECYCLING REQUIREMENTS FOR INDUSTRIAL AND EV BATTERIES

Category	The minimum recycling requirement (%)
Cobalt	16
Lead	85
Lithium	6
Nickel	6

C. U.S.

In 2018, California enacted legislation aimed at studying and formulating policy recommendations for the reuse and recycling of EV lithium-ion batteries [56]. This law entrusts the California Environmental Protection Agency (CalEPA) with the responsibility of establishing an advisory group to examine and provide policy guidance regarding the reuse and recovery of "lithium-ion batteries sold with motor vehicles". The law specifies that these policy recommendations must, at a minimum, encompass the following aspects:

1) Considerations throughout the lifecycle of EV lithium-ion batteries.

2) Examination of opportunities and barriers related to reusing EV LiBs in stationary BESS.

3) Best practices for managing end-of-life EV lithium-ion batteries.

4) Evaluation of the environmental impact of various management practices.

5) Consideration of both in-state and out-of-state options for recycling EV lithium-ion batteries.

In November 2019, CalEPA established the lithium-ion Car Battery Recycling Advisory Group, which was tasked with collaboratively investigating and addressing the management of EV lithium-ion batteries. The mandate of the group required quarterly meetings between April 1, 2019 and April 1, 2022. It also mandated consultations with universities and research institutions engaged in battery recycling research, manufacturers of EV and hybrid vehicles, and representatives from the recycling industry. These recommendations aim to ensure that as many EV lithium-ion batteries in California as possible are reused or recycled at the end-of-life stage in a safe and cost-effective manner, with the goal of achieving close to 100% recycling and reuse rates.

Also, the U.S. Environmental Protection Agency (EPA) intends to introduce new regulations aimed at enhancing the handling and recycling of end-of-life solar panels and lithium batteries. Certain solar panels, upon reaching their end-of-life stage, contain significant quantities of metals like lead, meeting the criteria for hazardous waste under the Resource Conservation and Recovery Act. To address this, the EPA is proposing to incorporate solar panels into the universal waste regulations. This initiative involves devising streamlined management protocols specifically for end-of-life solar panels.

Furthermore, the EPA is developing a distinct universal waste standard tailored for lithium-ion batteries from the universal waste category of the existing general battery. Although lithium-ion batteries are typically safe when appropriately used, stored, and charged, mismanagement of post-end-of-life can lead to potential fire hazards. By establishing a dedicated waste category for lithium-ion batteries, the EPA aims to heighten safety standards, minimize incidents of fires resulting from mishandled end-of-life lithium-ion batteries, and further encourage battery recycling efforts [57].

VI. Safety Policies

Since everything in the power system is connected to consume electricity, if one component breaks, all elements can be affected, so safety is very important, and countermeasures must be prepared [58].

Absolutely, safety is paramount when it comes to BESSs due to their role in storing and discharging electricity. Proper safety rules and guidelines must be followed meticulously to prevent any potential fire hazards. This includes adhering to established safety standards, conducting regular inspections, implementing effective fire prevention measures, and ensuring that the BESS components and installations are designed and maintained to minimize the risk of fires. By prioritizing safety, we can harness the benefits of BESS technology while safeguarding against potential hazards.

BESS safety regulations can indeed be broadly categorized into North American and European standards, with variations and adaptations being used in different parts of the world. In particular, Asian countries adopt or modify these North American standards to suit their specific needs and regulatory environments.

A. Asia

1) China

The Chinese National Standard (GB/T) has established safety standards for lithium-ion batteries used in EVs through GB/T 31467.3. The standard outlines requirements for batteries to meet safety criteria, such as electrical, mechanical, and environmental safety. Additionally, the GB/T cites the standards shown in Table VI [59]-[66].

TABLE VI
Standards for a Domestic BESS in China

Category	Standard
Lithium-ion traction battery pack and system for EVs: safety requirements and test methods	GB/T 31467.3
Degrees of protection provided by enclosure	GB 4208
Safety specifications for electrically propelled road vehicles: on-board rechargeable energy storage system	GB/T 18384.1
Safety specifications for electrically propelled road vehicles: protection of persons against electric shock	GB/T 18384.3
Terminology of EVs	GB/T 19596
Road vehicles: environmental conditions and testing for electrical and electronic equipment – (general)	GB/T 28046.1
Lithium-ion traction battery pack and system for EVs: test specification for high power applications	GB/T 31467.1
Lithium-ion traction battery pack and system for EVs: test specification for high energy applications	GB/T 31467.2

2) Japan

The Japanese Industrial Standards (JIS) has established safety standards for lithium-ion batteries used in various applications through JIS C 8714 standard. The standard outlines safety requirements for batteries, including electrical, mechanical, and environmental safety. Additionally, the JIS C 8174 cites the standards shown in Table VII [67]-[71].

TABLE VII
Standards for a Domestic BESS in Japan

Category	Standard
Safety tests for portable lithium-ion secondary cells and batteries for use in portable electronic applications	JIS C 8714
Audio, video, and similar electronic apparatus – safety requirements	JIS C 6065
Information technology equipment: safety	JIS C 6950
Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications	JIS C 8712
Rubber, vulcanized or thermoplastic	JIS K 6253

3) Republic of Korea

In Republic of Korea, fires began to occur in ESS in 2017, and since then, 16 ESS fires have occurred in 2018 and 11 ESS fires have occurred in 2019. Accordingly, preparing measures to prevent fires has become a very important topic [72]-[76].

In Republic of Korea, safety regulations for BESS are implemented according to the KC 62619 standard. This standard outlines the safety and misuse environment test methods specifically designed for secondary lithium cells and batteries. The standards referenced in Table VIII provide detailed criteria and guidelines for conducting these tests and ensuring the safe operation of BESS installations under various conditions and environments [72]-[76].

TABLE VIII
STANDARDS FOR A DOMESTIC BESS IN REPUBLIC OF KOREA

Category	Standard
Safety requirements for secondary lithium cells and batteries, for use in industrial applications	KS 62619
Guidelines for including safety aspects in specifications	KS A ISO/IEC Guide 51
Safety standards for portable sealed secondary cells and batteries for portable devices	KS C IEC 62133
Secondary lithium cells and batteries used for industrial purposes	KS C IEC 62620
Performance and safety requirements	SPS-C KBIA-10104-03-7312

B. Europe

1) U.K.

In the U.K., all electrical installations that the public interacts with as part of the daily activities must typically adhere to the IET wiring regulations, known as BS 7671. Currently, there is no dedicated chapter within BS 7671 specifically addressing BESS installations. Instead, the relevant requirements must be considered and applied from applicable sections within the regulation to ensure the safe and compliant installation of BESS. All the requirements and the corresponding standards used for compliance are typically listed, as shown in Table IX [77]-[86].

TABLE IX
THE MINIMUM REQUIREMENTS FOR A DOMESTIC BESS IN U.K.

Category	Standard
Requirements for electrical installation	BS 7671
Grid connectivity requirement	G98/1
Product safety regulations: general product safety directive	BS EN 62619
Product safety regulations: low-voltage directive	BS EN 62109-1, BS EN 62109-2, BS EN 62477-1, BS EN 62368-1
Product safety regulations: EMC directive	BS EN 61000-6-3, BS EN 61000-6-1
Dangerous good regulations	UN 38.3

2) Germany

European standards are to be applied in the member states by law and are therefore also relevant in Germany. The separate standards related to BESS in Germany are shown in Table X [87]-[92].

TABLE X
STANDARDS FOR A DOMESTIC BESS IN GERMANY

Category	Standard
Safety aspects of lithium-ion batteries	DKE/AK 371.0.5
Planning and integration of ESSs in energy building systems	VDI 4657
Safety requirements for secondary lithium cells and batteries for use in industrial applications	DIN EN 62619
Requirements of battery systems with lead accumulators and Nickel Cadmium batteries	DIN IEC 62485-1
Requirements of flow batteries	DIN EN 62932-1
Safety requirements for connection between low-voltage power grid and BESS	VDE-AR E 2510-2

C. U.S.

In the U.S., there are various standards related to batteries, among which the standards for a domestic BESS in U.S. are shown in Table XI [93]-[96].

TABLE XI
STANDARDS FOR A DOMESTIC BESS IN U.S.

Category	Standard
Safety standards for portable lithium primary cells and batteries	ANSI/NEMA C18
Standard for safety for lithium-ion batteries	UL 1642
Standard for safety for household and commercial batteries	UL 2054
Standard for safety for general requirements for battery	UL 2595

VII. DISCUSSION AND FUTURE DIRECTION OF BESS POLICIES

Sections III-VI present the current BESS policies of various countries, and a summary of each policy can be found in Table XII. When analyzing policies in this way, the following policy development process is necessary. Classifying BESS policies into three distinct temporal phases offers a comprehensive framework for understanding policy formulation, as shown in Fig. 4. The 1st phase prioritizes promoting BESS deployment, supported by robust economic incentives and subsidies. Simultaneously, this phase ensures reliability through the implementation of stringent safety policies.

The 2nd phase transitions towards activating BESS recycling policy, addressing the challenge of waste management associated with widespread BESS deployment. Proactive recycling initiatives become pivotal during this phase to manage the increasing volume of retired BESS units.

In the 3rd phase, attention turns towards the advancement of more efficient BESS technologies, notably long-duration BESS. As these technologies mature, it becomes imperative to revisit the initial economic and safety policy development process to align with the evolved landscape and emerging technological advancements. This cyclical method facilitates continual refinement and adaptation of policies to match the evolving dynamics of BESS technologies and their deployment.

TABLE XII
SUMMARY TABLE OF POLICIES BY COUNTRY

Category	Asia			Europe		U.S.
	China	Japan	Republic of Korea	U.K.	Germany	
Subsidy	Widening of price gap between peak and off-peak electricity demand; expansion of operation subsidies for power generated from BESS	Expansion of BESS installation subsidies (amount varies by capacity of BESS)	Increased BESS power sale amount to reduce peak demand	Tax exemption when installing BESS for renewable energy connection	Subsidy for BESS installation interconnected to renewable energy	Tax deduction when installing BESS; incentive provided in conjunction with federal programs
Long-duration BESS	30% cost reduction target for new BESS; research on electrochemical, compressed air, flywheel, and supercapacitor systems	No special country-specific policies; VRFB will be deployed by companies	Establishment of large-scale VRFB installation plan; research in encompassing lithium, sodium-ion, redox flow, and magnesium	Grant allocation to support LDES projects; research on thermal energy storage systems, VRFB, advancing a pumped thermal energy storage	Development of redox flow BESS	90% cost reduction goal of BESS; research on electrochemical, mechanical, thermal, flexible generation, flexible buildings, power electronics, and VRFB and zinc hybrid cathode battery technologies
BESS recycling	Goal of developing a vehicle battery and waste battery history management platform; standardization of service networks for recycling and recovery of waste batteries	Providing subsidies to foster waste battery industry; reusing waste batteries as storage batteries	Increased storage period of used batteries; providing research funds for reuse and recycling of waste batteries	Establishment of waste battery recycling and recovery rate policy within EU; target year and recall target for each ingredient were set		Establishment of Automotive Battery Recycling Advisory Group; achievement of a recycling and reuse rate close to 100%
Safety	Based on international standards, regulations are used to suit each country's circumstances					

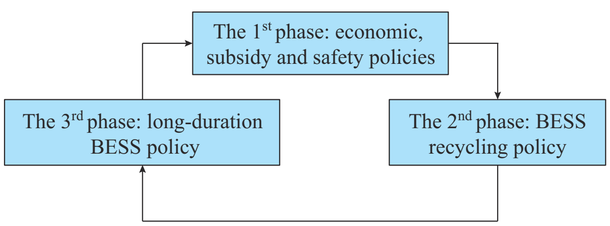

Fig. 4. 3Three phases related to BESS policy.

The policies related to investment and subsidies in BESS typically fall into two categories: tax exemption during BESS installation and leveraging revenue generated from BESS electricity sales. In many developed nations, widespread deployment of BESS has made tax exemption during installation less relevant. However, distributed BESS continues to engage in electricity trade, focusing on selling electricity during peak periods using the time of use (ToU) method.

Several studies have proposed alternative methods to replace the current ToU method [97]-[99]. These methods typically employ optimization algorithms to suggest a calculation method for determining optimal fares during flexible time periods rather than fixed ones. Recently, probabilistic techniques have been utilized to assess grid conditions and establish corresponding rates. ToU relies on fixed time zones and is easily comprehensible for consumers, which lacks flexibility in swiftly adapting to changing power system scenarios. Therefore, there is a need for policy enhancements aimed at developing a more user-friendly and adaptable interface, surpassing the limitations of the existing ToU method. These enhancements should facilitate the ease of use for consumers while ensuring profitability and responsiveness to evolving energy system dynamics.

In the domain of BESS recycling policy, many nations recognize its significance and have made substantial investments. However, there remains ambiguity regarding the specific materials to collect the procedural frameworks. As of 2023, only the EU has outlined the areas that require improvement [55], while other countries are endeavoring to introduce similarly well-documented policies tailored to their unique circumstances. Consequently, the ongoing policy status across various countries, as illustrated in Fig. 4, signifies a shift from the 1^{st} phase to the 2^{nd} phase. There is an immediate need to craft diverse and precise policies, such as imposing recycling collection responsibilities on battery manufacturers and stimulating job creation within this sector.

In the realm of long-duration BESS policy, numerous countries are studying solutions to overcome the limitations of current lithium-ion batteries, with particular attention directed towards VRFB research. However, at this early stage, a notable drawback is the predominant allocation of development costs towards VRFB research, despite its potential. As policy development progresses beyond the 2^{nd} phase and enters the 3^{rd} phase, there is a crucial necessity to activate investment policies that accelerate the development of various battery technologies, encompassing VRFB among others.

Regarding safety policies, it is observable that most international standards are adhered to, with slight adjustments to suit individual country contexts. Therefore, it is imperative for the International Standards Committee to anticipate trends in newly developed batteries and proactively devise safety regulations. This proactive stance ensures seamless policy announcements in the future, catering to the evolving landscape of battery technologies and their safety requirements.

Beyond the 1st phase, many countries have yet to establish specific documented policies. During the initial phase, the U. S. led the way, and subsequent advanced nations often mirror U. S. policies. However, as we move into the 2nd phase, each country is anticipated to engage in extensive research to take the lead in the BESS market.

In the Asian region, China is anticipated to outstrip the U.S. in scale within the BESS domain. This is evident from the planned implementation of recycling measures for BESS in China and its concentrated research endeavors focused on post-processing large-scale BESS. Similarly, Japan is allocating its attention towards both recycling BESS and innovating new BESS technologies, particularly for their advanced automotive sector. Meanwhile, Republic of Korea is intensifying technological research efforts in collaboration with renowned battery manufacturers, emphasizing advancements in the field.

Europe has taken a leading stance by establishing benchmarks for BESS recycling. Extensive research in several European countries has resulted in substantial investments in developing new BESS integrated with large-scale new and renewable energy initiatives.

In the U.S., efforts are concentrated on maintaining leadership within the current BESS market. This is being pursued through significant investments and a robust workforce, particularly notable in California, where intensive research on new and renewable energy is underway. Additionally, policy recommendations for BESS recycling are being formulated, aiming to establish a pivotal role in global long-term energy storage. This involves the advancement of technologies, such as VRFB and zinc hybrid cathode batteries, expanding the scope beyond the existing lithium-ion batteries.

Besides, the following is the background and future direction to the policies discussed in previous sections.

A. Policies for Economic Support and Subsidies

To stimulate the initial BESS market and support the adoption of renewable energy, some countries have established policies for economic support and subsidy. These policies aim to make BESS more affordable for consumers and businesses, thereby promoting the integration of renewable energy into the power grid. The current policy framework, which encourages the installation of BESS, has been instrumental in promoting the adoption of clean energy technologies and enhancing grid stability. However, it is essential to recognize that the subsidy levels for BESS installations may need to be adjusted in the future as the market matures and reaches certain saturation levels. Key considerations for future policy adjustments are as follows.

1) Optimal BESS Capacity

Beyond a certain point, connecting too many BESS units to the power grid may provide diminishing returns in terms of grid stability and overall system efficiency. It is crucial to conduct research and analysis to determine the optimal BESS capacity that best balances grid needs with cost-effectiveness. Typically, methods involve solving a specific optimization algorithm or addressing an optimal power flow (OPF) problem. The objective function is chosen to minimize both the price and capacity of the BESS, while adhering to constraints that ensure the power system operates without issues at the selected capacity.

2) Market Maturity

As the BESS market matures and technologies improve, the cost of BESS components and installations may decrease. This reduced cost may warrant a reevaluation of subsidy levels to ensure that they remain aligned with market dynamics.

3) Demand and Grid Requirements

Policy adjustments should be based on the evolving demand for BESS and the changing requirements of the power grid. Periodic assessments of grid stability and the role of BESS in meeting those needs are essential for informed policymaking.

4) Long-term Viability

Sustainability and long-term viability should be key considerations in subsidy policies. Policy makers should explore ways to encourage the adoption of BESS technologies that provide lasting benefits and align with broader environmental and energy goals.

In summary, the future of BESS subsidy policies should involve a strategic and data-driven method. Policymakers should continuously assess the impact of BESS installations, analyze grid needs, and consider evolving market conditions to determine the most effective subsidy levels. By doing so, countries can ensure that their policies remain efficient, supportive, and responsive to the changing landscape of renewable energy and energy storage.

B. Development Policies of Long-duration BESS

Initially, BESS primarily serves to respond to instantaneous frequency changes in the power system and maintain real-time supply and demand balance as short-duration BESS. However, as the integration of renewable energy sources has increased, long-duration BESS solutions have emerged to address oversupply and load leveling. Policies have shifted focus to support new technologies for long-duration BESS, moving beyond traditional lithium-based systems. Especially, VRFB has gained significant attention due to their potential for LDES. Many countries are investing in VRFB technology as part of their BESS policies.

Furthermore, the development trajectory of long-duration BESS not only encompasses research into battery materials but also emphasizes the critical importance of controller design. Techniques such as adjusting the output power of controllable power generation devices through stochastic optimization [100] and optimizing the placement and capacity of BESS to enhance lifespan [101] are employed. Thus, each country should conduct a comprehensive investigation and analysis of the technological status of BESS with long-term viability and formulate the development policies accordingly.

For developing a long-duration BESS from an existing short-duration BESS, the following policies must be established.

1) Technological Advancements

Policy frameworks should remain flexible to accommodate advancements in BESS technology. Long-duration

BESS development is an evolving field, and policies should encourage research and development to improve energy density, cycle life, and safety while reducing costs.

2) Grid Services

Long-duration BESS can provide a wide range of grid services, including frequency regulation, peak shaving, and voltage support. Policies should define clear market mechanisms and compensation schemes for these services to incentivize BESS deployment.

3) Market Access and Fair Competition

Policies should promote fair market access for long-duration BESS providers and avoid creating barriers to entry. Competitive markets can drive innovation and lower costs.

4) Monitoring and Reporting

Monitoring and reporting requirements are implemented to track the performance, safety, and environmental impact of long-duration BESS installations.

By carefully considering these aspects, policymakers can develop comprehensive and effective long-duration BESS development policies that contribute to a more sustainable and resilient energy system.

C. BESS Recycling Policies

The increased adoption of BESS necessitates preparations for recycling and disposing of end-of-life batteries. Recycling policies for BESS are beginning to be explored as a response to the growing number of consumed and discarded BESS units. However, in order to expand the BESS recycling market, the following policies must be additionally established.

1) Collection Infrastructure

Developing a robust collection infrastructure for used batteries is crucial. This involves setting up collection centers and networks for consumers, businesses, and utilities to easily return their old batteries for recycling.

2) Circular Economy Integration

BESS recycling policies are integrated into broader circular economy initiatives, aiming to minimize waste, maximize resource efficiency, and reduce the environmental footprint of batteries.

3) Technological Tracking

Tracking systems are implemented to trace the lifecycle of batteries, from production to disposal, to ensure they are properly managed and recycled.

4) Consideration of Long-duration BESS

The consideration should be given to the environmental impact of production, operation, and disposal of long-duration BESS. Policies should encourage the use of sustainable materials, recycling practices, and environmentally responsible disposal methods.

These considerations will likely evolve as technology and environmental priorities change, so it is important for policymakers, industry stakeholders, and environmental organizations to stay informed and adapt their recycling policies accordingly to address emerging challenges and opportunities in BESS recycling.

D. Safety Policies

Safety is a critical concern for large-scale BESS deployments. Policies and regulations are being introduced to mitigate the risk of fires, which is a significant obstacle to widespread BESS adoption. Investigation committees in various countries are analyzing the factors contributing to BESS-related fires and developing safety policies to prevent such incidents. As technology evolves and the use of BESS becomes more widespread, safety policies should continue to adapt to address emerging challenges. Here are important considerations for BESS safety policies in the future.

1) Standardization and Codes

Safety standards and codes specific to BESS should be developed and updated, which should include input from experts, industry stakeholders, and regulatory bodies to ensure that safety measures are current and effective.

2) Cybersecurity

BESS systems should be protected from cybersecurity threats and unauthorized access. Cybersecurity standards and best practices should be developed to safeguard against potential attacks that could compromise system safety [58].

3) Liability and Insurance

Liability and insurance considerations associated with BESS should be addressed. Responsibilities and liabilities in the event of accidents or failures should be defined to ensure that appropriate insurance coverage is in place.

4) Data Collection and Reporting

Mechanisms for collecting and reporting safety-related data and incidents should be established. This information can be valuable for continuous improvement in safety policies and practices.

Safety should always be a top priority in the deployment and operation of BESS. As technology advances and new challenges emerge, it is essential to adapt safety policies to ensure the continued safe and responsible use of energy storage systems.

VIII. CONCLUSION

In this paper, we have summarized the roles of BESS and the policies associated with BESS in each country. The increasing integration of BESS into power system is a result of diverse economic support policies implemented in various countries. We have also examined policies aimed at addressing potential challenges arising from the growing deployment of BESS. Furthermore, based on the findings from various policies, we have considered the directions in which policies for each category should be established in the future. This analysis provides valuable insights into the evolving landscape of BESS adoption and the necessary policy adjustments to support its continued growth and effective integration into energy systems.

BESS technology is advancing rapidly, driven by numerous research institutes and companies globally. However, without supportive policies, these technologies may remain theoretical and not be implemented in practice. Hence, nations worldwide need to proactively anticipate the future development of BESS technology and formulate policies that facilitate the practical implementation of each technological advancement.

While this paper has limitations, specifically focusing on

BESS policies within individual countries, it can serve as a helpful guide for many countries seeking to introduce large-scale BESS based on its findings. Additionally, by delineating the previously unclear policy development process into three distinct stages, it can serve as a milestone for flexible policy development, even considering future ESS advancements.

In addition, future research will investigate the gap between the development of currently developing BESS technology and current policies and examine the development direction of each policy in detail.

References

[1] J. S. Kim, C. H. Kim, Y. S. Oh *et al*., "An islanding detection method for multi-RES systems using the graph search method," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 4, pp. 2722-2731, Oct. 2020.

[2] G. J. Cho, C. H. Kim, Y. S. Oh *et al*., "Planning for the future: optimization-based distribution planning strategies for integrating distributed energy resources," *IEEE Power and Energy Magazine*, vol. 16, no. 6, pp. 77-87, Nov. 2018.

[3] G. J. Cho, Y. S. Oh, M. S. Kim *et al*., "Optimal capacitor bank capacity and placement in distribution systems with high distributed solar power penetration," in *Proceedings of 2017 IEEE PES General Meeting*, Chicago, USA, Jul. 2017, pp. 1-10.

[4] S. J. Lee, J. H. Kim, C. H. Kim *et al*., "Coordinated control algorithm for distributed battery energy storage systems for mitigating voltage and frequency deviations," *IEEE Transactions on Smart Grid*, vol. 7, no. 3, pp. 1713-1722, May 2016.

[5] T. Gush, C. H. Kim, S. Admasie *et al*., "Optimal smart inverter control for PV and BESS to improve PV hosting capacity of distribution networks using slime mould algorithm," *IEEE Access*, vol. 9, pp. 52164-52176, Mar. 2021.

[6] K. M. Hazazi, K. Khalid Mehmood, G. J. Cho *et al*., "Optimal planning of distributed generators for loss reduction and voltage profile enhancement considering the integration of electric vehicles," in *Proceedings of 2018 IEEE Region 10 Conference*, Jeju, Korea (South), Oct. 2018, pp. 1-11.

[7] J. C. Bastidas, K. K. Mehmood, M. S. Zaman *et al*., "EMS strategy for accommodation of high solar intermittency in PV plants with EV parking lot and VRB in hybrid storage configuration," in *Proceedings of 2018 IEEE Region 10 Conference*, Jeju, Korea (South), Oct. 2018, pp. 1-8.

[8] Z. Zhang, C. Dou, D. Yue *et al*., "Regional coordinated voltage regulation in active distribution networks with PV-BESS," *IEEE Transactions on Circuits and Systems II*: *Express Briefs*, vol. 70, no. 2, pp. 596-600, Feb. 2023.

[9] S. Chen, T. Zhang, H. B. Gooi *et al*., "Penetration rate and effectiveness studies of aggregated BESS for frequency regulation," *IEEE Transactions on Smart Grid*, vol. 7, no. 1, pp. 167-177, Jan. 2016.

[10] S. M. Mohseni-Bonab, I. Kamwa, A. Moeini *et al*., "Voltage security constrained stochastic programming model for day-ahead BESS schedule in co-optimization of T&D systems," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 1, pp. 391-404, Jan. 2020.

[11] S. B. Sani, P. Celvakumaran, V. K. Ramachandaramurthy *et al*., "Energy storage system policies: way forward and opportunities for emerging economies," *Journal of Energy Storage*, vol. 32, p. 101902, Dec. 2020.

[12] S. Chen, T. Zhang, H. B. Gooi *et al*., "Penetration rate and effectiveness studies of aggregated BESS for frequency regulation," *IEEE Transactions on Smart Grid*, vol. 7, no. 1, pp. 167-177, Jan. 2016.

[13] Z. Yang, L. Xia, and X. Guan, "Fluctuation reduction of wind power and sizing of battery energy storage systems in microgrids," *IEEE Transactions on Automation Science and Engineering*, vol. 17, no. 3, pp. 1-13, Mar. 2020.

[14] X. Li, R. Ma, W. Gan *et al*., "Optimal dispatch for battery energy storage station in distribution network considering voltage distribution improvement and peak load shifting," *Journal of Modern Power Systems and Clean Energy*, vol. 10, no. 1, pp. 131-139, Jan. 2022.

[15] A. Khalid, A. Stevenson, and A. I. Sarwat, "Overview of technical specifications for grid-connected microgrid battery energy storage systems," *IEEE Access*, vol. 9, pp. 163554-163593, Dec. 2021.

[16] G. Wang, G. Konstantinou, C. D. Townsend *et al*., "A review of power electronics for grid connection of utility-scale battery energy storage systems," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 4, pp. 1778-1790, Oct. 2016.

[17] M. Stecca, L. R. Elizondo, T. B. Soeiro *et al*., "A comprehensive review of the integration of battery energy storage systems into distribution networks," *IEEE Open Journal of the Industrial Electronics Society*, vol. 1, pp. 46-65, Mar. 2020.

[18] M. A. Hannan, S. B. Wali, P. J. Ker *et al*., "Battery energy-storage system: a review of technologies, optimization objectives, constraints, approaches, and outstanding issues," *Journal of Energy Storage*, vol. 42, p. 103023, Oct. 2021.

[19] J. Wüllner, N. Reiners, L. Millet *et al*., "Review of stationary energy storage systems applications, their placement, and techno-economic potential," *Renewable Energy Reports*, vol. 8, no. 4, pp. 263-273, Dec. 2021.

[20] BloombergNEF. (2023, Mar.). 1H 2023 energy storage market outlook. [Online]. Available: https://about. bnef. com/blog/1h-2023-energy-storage-market-outlook/

[21] BloombergNEF. (2023, Jan.). 1H 2023 energy storage market outlook. [Online]. Available: https://about. bnef. com/blog/top-10-energy-storage-trends-in-2023/

[22] BloombergNEF. (2022, Oct.). Global energy storage market to grow 15-fold by 2030. [Online]. Available: https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/

[23] PV Magazine. (2022, Feb.). State Grid of China unveils plans for 100 GW battery fleet. [Online]. Available: https://www. pv-magazine. com/2022/02/25/state-grid-of-china-unveils-plans-for-100gw-battery-fleet/

[24] China Briefing. (2022, Jul.). China's energy storage sector: policies and investment opportunities. [Online]. Available: https://www. china-briefing. com/news/chinas-energy-storage-sector-policies-and-investment-opportunities/

[25] APCO Worldwide. (2023, Nov.). China's booming energy storage: a policy-driven and highly concentrated market. [Online]. Available: https://apcoworldwide. com/blog/chinas-booming-energy-storage-a-policy-driven-and-highly-concentrated-market/

[26] Mobility Transition in China. (2020, Nov.). Policy briefing & translation: NEV development plan 2035. [Online]. Available: https://transition-china. org/mobilityposts/policy-briefing-translation-nev-development-plan-2035/

[27] China Briefing. (2022, Jul.). China's energy storage sector: policies and investment opportunities. [Online]. Available: https://www. china-briefing.com/news/chinas-energy-storage-sector-policies-and-investment-opportunities/

[28] D. Jarrett, M. Niunoya, K. Masaki *et al*. *Battery Storage Subsidies in Japan*. Tokyo: Atsumi & Sakai, 2023.

[29] KEPCO. "Implementation rules for basic supply terms and conditions," KEPCO Rules, 2023.

[30] HM Revenue & Customs. (2022, Mar.). Changes to the VAT treatment of the installation of energy saving materials in in Great Britain. [Online]. Available: https://www. gov. uk/government/publications/changes-to-the-vat-treatment-of-the-installation-of-energy-saving-materials-in-in-great-britain

[31] Federal Ministires for Economics and Climate Protection for Housingm Urban Development and Construction, and Finance in Germany. (2022, May). Federal subsidy for efficient buildings (BEG) by KfW. [Online]. Available: https://www.iea.org/policies/14957-federal-subsidy-for-efficient-buildings-beg-by-kfw.

[32] SDG21. (2018, Dec.). State of Baden-Württemberg modifies storage subsidy. [Online]. Available: https://sdg21.eu/en/blog/land-baden-wuerttemberg-modified-storage-promotion.

[33] SDG21. (2020, Jan.). EnergiespeicherPLUS – Berlin funding programme for electricity storage goes online. [Online]. Available: https://sdg21. eu/en/blog/energiespeicherplus-berliner-foerderprogramm-fuer-stromspeicher-geht-online.

[34] *Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action*, 2nd ed, The White House, Washington D.C., 2023.

[35] *Self-generation Incentive Program Handbook: Provides financial incentives for installing clean, efficient, on-site distributed generation*, California Public Utilities Commission, San Francisco, CA, Nov. 2022.

[36] New York State Energy Research and Development Authority. (2023, Apr.). NY-SUN Con edison program manual. [Online]. Available: https://www.nyserda.ny.gov/All-Programs/NY-Sun/Contractors/Resources-for-Contractors/

[37] Hawaiian Electric. (2023, Aug.). Battery bonus: receive cash incentives for adding new energy storage to a rooftop solar system. [Online]. Available: https://www. hawaiianelectric. com/products-and-servic-

es/customer-incentive-programs/battery-bonus.
[38] R. DAgostino, L. Baumann, A. Damiano *et al*., "A vanadium-redox-flow-battery model for evaluation of distributed storage implementation in residential energy systems," *IEEE Transactions on Energy Conversion*, vol. 30, no. 2, pp. 421-430, Jun. 2015.
[39] M. Jafari, A. Sakti, and A. Botterud, "Optimization of electrolyte rebalancing in vanadium redox flow batteries," *IEEE Transactions on Energy* Conversion, vol. 37, no. 1, pp. 748-751, Mar. 2022.
[40] I. A. Khan, H. Mokhlis, N. N. Mansor *et al*., "Load frequency control using golden eagle optimization for multi-area power system connected through AC/HVDC transmission and supported with hybrid energy storage devices," *IEEE Access*, vol. 11, pp. 44672-44695, May 2023.
[41] The State Council. (2022, Mar.). New energy storage to see large-scale development by 2025. [Online]. Available: http://english. www. gov. cn/ statecouncil/ ministries/202203/02/content_WS621ec4bbc6d09c94e48a5bab.html
[42] Sumitomo Electric. (2023, Aug.). Redox flow battery. [Online]. Available: https://sumitomoelectric.com/products/redox.
[43] *10th Power Supply Basic Plan*, MOTIE, Seoul, Republic of Korea, 2023.
[44] *Longer Duration Energy Storage Demonstration Programme, Stream 1 Phase 1: Details of Successful Projects*, Department for Energy Security and Net Zero, London, U.K., Apr. 2023.
[45] I. Aramendia, U. Fernandez-Gamiz, A. Martinez-San-Vicente *et al*., "Vanadium redox flow batteries: a review oriented to fluid-dynamic optimization," *Energies*, vol. 14, no. 1, p. 176, Dec. 2020.
[46] U.S. Department of Energy. (2021, Sept.). Long duration storage shot. [Online]. Available: https://www. energy. gov/eere/long-duration-storage-shot.
[47] U. S. Department of Energy. (2022, Aug.). 2022 grid energy storage technology cost and performance assessment. [Online]. Available: https://www. energy. gov/eere/analysis/2022-grid-energy-storage-technology-cost-and-performance-assessment/
[48] R. Bird, Z. J. Baum, X. Yu *et al*., "The regulatory environment for lithium-ion battery recycling," *ACS Energy Letters*, vol. 7, no. 2, pp. 736-740, Feb. 2022.
[49] D. Wang, "Research on policies of power batteries recycle in China from the perspective of life cycle," *Journal of Environmental Engineering and Landscape Management*, vol. 29, no. 2, pp. 135-149, May 2021.
[50] T. Zhou, J. Gosens, and F. Jotzo. (2023, Jun.). China's EV plans: domestic market and policy developments & Australia-China links in decarbonization. [Online]. Available: https://iceds. anu. edu. au/files/Policy%20brief%20-%20EV%202023-04-06.pdf/
[51] M Ministry of Economy, Trade and Industry. (2021, Nov.). Subsidies for promoting the introduction of clean energy vehicles and infrastructure in the FY2021 supplementary budget. [Online]. Available: https:// www. meti. go. jp/english/policy/external_economy/investment/pdf/0324_001f.pdf/
[52] Nippon Recycle Center Corporation. (2023, Mar.). Business overview. [Online]. Available: https://www.recycle21.co.jp/recycle-e/service/detail.html
[53] *Strategy for Industrial New Growth Through the Activation of the Circular Economy*, MOEF, Seoul, Republic of Korea, 2023.
[54] S.-P. Lee, J.-S. Yeo, Y.-J. Jo *et al*. (2022, Aug.). An activation plan of ecosystem in used EV batteries industry. [Online]. Avvailable: https:// www.dbpia.co.kr/pdf/pdfView.do?nodeId=NODE11532787/
[55] Council of the European Union. (2019, Jul.). Regulation of the European parliament and of the council: concerning batteries and waste batteries. [Online]. Available: efaidnbmnnnibpcajpcglclefindmkaj/https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542 3/
[56] T. L. Curtis, L. Smith, and H. Buchanan, "A circular economy for lithium-ion batteries used in mobile and stationary energy storage: drivers, barriers, enablers, and U. S. policy considerations," NREL, Denver, CO, Tech. Rep. NREL/TP-6A20-77035, Mar. 2021.
[57] United States Environmental Protection Agency. (2023, Oct.). Improving recycling and management of renewable energy wastes: universal waste regulations for solar panels and lithium batteries. [Online]. Available: https://www.epa.gov/hw/improving-recycling-and-management-renewable-energy-wastes-universal-waste-regulations-solar
[58] K. Dehghanpour, Z. Wang, J. Wang *et al*., "A survey on state estimation techniques and challenges in smart distribution systems," *IEEE Transactions on Smart Grid*, vol. 10, no. 2, pp. 2312-2322, Mar. 2019.
[59] *Lithiumion Traction Battery Pack and System for Electric Vehicles – Part 3: Safety Requirements and Test Methods*, GB/T 31467.3, 2015.
[60] *Degrees of Protection Provided by Enclosure*, GB 4208, 2017.
[61] *Electrically Propelled Road Vehicles – Safety Specifications – Part 1: On-board Rechargeable Energy Storage System (REESS)*, GB/T 18384.1, 2015.
[62] *Electrically Propelled Road Vehicles – Safety Specifications – Part 3: Protection of Persons Against Electric Shock*, GB/T 18384.3, 2015.
[63] *Terminology of Electric Vehicles*, GB/T 19596, 2017.
[64] *Road Vehicles – Environmental Conditions and Testing for Electrical and Electronic Equipment – Part 1:General*, GB/T 28046.1, 2011.
[65] *Lithiumion Traction Battery Pack and System for Electric Vehicles – Part 1: Test Specification for High Power Applications*, GB/T 31467.1, 2015.
[66] *Lithiumion Traction Battery Pack and System for Electric Vehicles – Part 2: Test Specification for High Energy Applications*, GB/T 31467.2, 2015.
[67] *Safety Tests for Portable Lithium-ion Secondary Cells and Batteries for Use in Portable Electronic Applications*, JIS C 8714, 2007.
[68] *Audio, Video and Similar Electronic Apparatus – Safety Requirements*, JIS C 6065, 2016.
[69] *Information Technology Equipment – Safety – Part 1: General Requirements*, JIS C 6950, 2016.
[70] *Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from Them, for Use in Portable Applications*, JIS C 8712, 2015.
[71] *Rubber, Vulcanized or Thermoplastic – Determination of Hardness – Part 1: General Guidance*, JIS K 6253, 2012.
[72] *Technical Regulations for Electrical and Telecommunication Products and Components*, KS 62619, 2019.
[73] *Safety Aspects – Guidelines for Their Inclusion in Standards*, KS A ISO/IEC Guide 51, 2022.
[74] *Safety Testing for Lithium-ion Batteries*, KS C IEC 62133, 2005.
[75] *Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes – Secondary Lithium Cells and Batteries for Use in Industrial Applications*, KS C IEC 62620, 2015.
[76] *Secondary Lithium-ion Battery System for Battery Energy Storage Systems – Performance and Safety Requirements*, SPS-C KBIA-10104-03-7312, 2018.
[77] *Requirements for Electrical Installations*, BS 7671, 2022.
[78] *Requirements for the Connection of Fully Type Tested Micro-generators in Parallel with Public Low Voltage Distribution Networks on or After 27 April 2019*, G98/1, 2019
[79] *Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes – Safety Requirements for Secondary Lithium Cells and Batteries, for Use in Industrial Applications*, BS EN 62619, 2017.
[80] *Safety of Power Converters for Use in Photovoltaic Power Systems – General Requirements*, BS EN 62109-1, 2011.
[81] *Safety of Power Converters for Use in Photovoltaic Power Systems Particular Requirements for Inverters*, BS EN 62109-2, 2011.
[82] *Safety Requirements for Power Electronic Converter Systems and Equipment*, BS EN 62477-1, 2012.
[83] *Audio/video, Information and Communication Technology Equipment Part 1: Safety Requirements*, BS EN 62368-1, 2020.
[84] *Electromagnetic Compatibility (EMC) – Part 6-3: Generic Standards-Emission Standard for Residential, Commercial and Light-industrial Environments*, BS EN 61000-6-3, 2012.
[85] *Electromagnetic Compatibility (EMC) – Part 6-1: Generic Standards-immunity for Residential, Commercial and Light-industrial Environments*, BS EN 61000-6-3, 2007.
[86] *Transportation Testing for Lithium Batteries and Cells*, UN 38.3, 2009.
[87] *Lithium (Secondary Batteries in General) Focuses on Safety Aspects of Lithium-ion (Li-ion) Batteries*, DKE/AK 371.0.5, 2007.
[88] *Planning and Integration of Energy Storage Systems in Energy Building Systems – Electrical Storage*, VDI 4657, 2023.
[89] *Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes – Safety Requirements for Secondary Lithium Cells and Batteries, for Use in Industrial Applications*, DIN EN 62619, Aug. 2023.
[90] *Safety Requirements for Secondary Batteries and Battery Installations – Part 1: General Safety Information*, DIN IEC 62485-1, 2019.
[91] *Flow Battery Energy Systems for Stationary Applications – Part 1: Terminology and General Aspects*, DIN EN 62932-1, 2021.
[92] *Stationary Electrical Energy Storage Systems Intended for Connection to the Low Voltage Grid*, VDE-ARE 2510-2, 2021.
[93] *American National Standard for Portable Lithium Primary Cells and Batteries – Safety Standard*, ANSI C18, 2021.
[94] *UL Standard for Safety Lithium Batteries Standard*, UL 1642, 1995.
[95] *UL Standard for Safety for Household and Commercial Batteries*, UL 2054, 2005.
[96] *UL Standard for Safety General Requirements for Battery – Powered*

Appliances, UL 2595, 2015.

[97] K. Chaudhari, A. Ukil, K. N. Kumar *et al.*, "Hybrid optimization for economic deployment of ESS in PV-integrated EV charging stations," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 1, pp. 106-116, Jan. 2018.

[98] B. Li, Q. Yang, L. Duan *et al.*, "Operator-as-a-consumer: a novel energy storage sharing approach under demand charge," *IEEE Transactions on Cybernetics*, vol. 53, no. 2, pp. 941-953, Feb. 2023.

[99] Y.-Y. Hong and M.-Y. Wu, "Markov model-based energy storage system planning in power systems," *IEEE Systems Journal*, vol. 13, no. 4, pp. 4313-4323, Mar. 2019.

[100] Y. Qin, H. Hua, and J. Cao, "Stochastic optimal control scheme for battery lifetime extension in islanded microgrid via a novel modeling approach," *IEEE Transactions on Smart Grid*, vol. 10, no. 4, pp. 4467-4475, Jul. 2019.

[101] M. Stecca, L. R. Elizondo, T. B. Soeiro *et al.*, "A comprehensive review of the integration of battery energy storage systems into distribution networks," *IEEE Open Journal of the Industrial Electronics Society*, vol. 1, pp. 46-65, Jan. 2020.

Ji-Soo Kim received the B.S. and Ph.D degrees from the College of Information and Communication Engineering, Sungkyunkwan University, Suwon, Republic of Korea, in 2016 and 2022, respectively. In 2016, he was an Internship Graduated Student at the National Renewable Energy Laboratory, Denver, U.S. He is working as a Postdoctoral Researcher at Polytechnique Montreal, Montréal, Canada, since 2022. His research interests include wind power generation modeling.

Jin-Sol Song received the B.S. degree from the College of Information and Communication Engineering, Sungkyunkwan University, Suwon, Republic of Korea, in 2017. At present, he is enrolled in the combined master's and doctorate program. His research interests include power system transients, wind power generation, and distributed energy resource.

Chul-Hwan Kim received the B.S., M.S., and Ph.D. degrees in electrical engineering from Sungkyunkwan University, Suwon, Republic of Korea, in 1982, 1984, and 1990, respectively. In 1990, he joined Cheju National University, Cheju, Republic of Korea, as a Full-time Lecturer. He was a Visiting Academic with the University of Bath, Bath, U.K., in 1996, 1998, and 1999. He has been a Professor with the College of Information and Communication Engineering, Sungkyunkwan University, since 1992, where he is currently the Director of the Center for Power Information Technology. His current research interests include power system protection, artificial intelligence applications for protection and control, modeling/protection of underground cable, and electromagnetic transient program software.

Jean Mahseredjian received the M.A.Sc. and Ph.D. degrees from Polytechnique Montréal, Montréal, Canada, in 1985 and 1991, respectively. From 1987 to 2004, he was with IREQ (Hydro-Quebec), Canada. In 2004, he joined the Faculty of Electrical Engineering with Polytechnique Montréal, where he is currently a Professor. His research interests include simulation and analysis of electromagnetic transients.

Seung-Ho Kim received the B.S. degree from the Department of Electrical Engineering, Seoul National University of Technology, Seoul, Republic of Korea, in 2013, and the Ph.D. degree from the Department of Electrical and Electronics Engineering, Korea University of Technology and Education, Republic of Korea, in 2018. He started working in the UPS Development Department of Ewha Electric from 1981 and worked in the UPS field for more than 40 years. He is working as a Director of Research Institute of Global Electricity since 2000. His research interests include power conversion system and energy storage system fire safety.