Contribution of Energy Storage Technologies in Load Frequency Control - A Review

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Abstract- Due to increased population and the continuous efforts through the global residents to lessen the impact of environmental change have caused the prompt usage of renewable based energy plants such as wind power plant and solar centred power generation units. The usage of such power generating unit is purely dependent upon nature. Additionally, integration of renewable unit to power system causes instability. The frequency stability is one of the important aspects and depends on balance between generation and demand. To restore the frequency deviation back to its normal condition, an effective control strategy called Load Frequency Control is adopted. To improve the performance of the control scheme different energy storage technologies can be considered. The storage technology not only has distinctive features of fast response and high energy density but also helps in load levelling, peak shaving and black start support. In this paper, comprehensive survey of diverse energy storage technology, its current market scenario and utilization in frequency regulation services are presented by collecting, reviewing and interrupting numerous research articles. Furthermore, current scenario of energy storage management in different parts of the world is included. Application and control strategies of energy storage system in frequency regulation is also presented for research scholars. In the paper, all the control structures are discussed theatrically also the pros and cons of each is addressed from technical point of view.

Keywords: Energy Storage Technology, Load Frequency Control, Battery Storage, Load Scale System, Grid Scale System.

1. Introduction

In an interconnected power system, the equilibrium among the generation and load demand must be conserved for smooth and stable operation. The equilibrium is directly proportional to frequency deviation and change in inter area power called tie line power at scheduled level in respective control areas. On the other hand, if balance is not maintained, then there is a severe deviation of frequency as well as tie line power, which challenges the stability and sustainability of the overall power structure [1-2]. The balance of generation and load demand is not sustained due to either one or more numbers of generation units are tripped (known as generation side) or abruptly change of connecting loads (known as load side). Such type scenario may happen any time of the day and cannot be forecasted well before time by the method of short time load forecasting [3-5].

In recent years, the portion of power generation from the renewable based power plant is increasing and reaching at greater level, which in turn challenges the generation-demand balance [6]. Hence to maintain this equilibrium, three distinct control schemes (i.e. primary, secondary, and tertiary schemes) are applied in the power structure. According to North American Electric Reliability Corporation (NERC), the control vector is termed as ‘balancing authority’. The control schemes which are applied to power system have a specific time frame as presented in the Fig.1 [7]. Among three control schemes, secondary control also termed as load frequency control (LFC) is the most effective one whose prime objective is to restrict the frequency fluctuation and tie line power in the respective control area under prescribed limit and maintains the steady power flow. Normally, LFC is symbolized as the “minute-to-minute” control that applied in the system to restrict the frequency under the nominal value followed by any disturbances [8]. In traditional LFC control, diverse power plant is controlled and coordinated which are operated with the grid synchronously that delivers the power to load fully or partially. In that process, a term is involved named as Area Control Error (ACE) which is the summation of frequency fluctuation and incremental change in tie line power [2, 9]. The ACE signal coming from automatic generation controller is fed to the power generation unit. The power plant will be operated in such a fashion that the control error will converge to zero. However, in that process LFC faces certain economical as well as practical challenges such as high operational and maintenance cost and the reduction of efficiency due to partial loading operation [10-
12]. Additionally, LFC takes 1-10 minutes to operate as various mechanical linkages are linked in the process, which is found to be not sufficient to counteract the challenges discussed above. Hence, researches suggested various control schemes to enhance the LFC, to effectively operate under the sudden mismatch of power generation and demand.

2. Storage Technology

2.1. Pumped hydroelectric storage System (PHSS)

Pumped hydroelectric storage is one of the prominent technologies in the field of energy storage applications and has a characteristic of a massive storage of energy for prolong duration of time [13-15]. The presence of PHSS is found across the globe but mostly set up in the countries like Japan (24.6GW) followed by USA (21.8 GW), and least in European peninsula, particularly in Spain (5.3 GW). Generally, PHSS are installed either in over ground (known as conventional) and underground. Among them few are operated as pump back and rest are normal PHSS. In normal PHSS system, two reservoirs are created and head is maintained in between the two reservoirs so that the potential energy of the water gets converted to kinetic energy and turbine is rotated. But in case of the pump back system, the water which is used to run the turbine is pumped back again to main reservoirs in the off peak hours[16-18].

Generally, pump back system is the augmentation of the conventional hydro-electric station. Hence with the use of a pump back system with conventional hydro system, the efficiency of the overall unit gets improved [19]. PHSS has lots of advantages such as longer life span, quick starting time, highly reliable and efficient under up-down regulation of power and frequency operation. Unfortunately, PHSS involves high capital cost with longer construction time and prolonged payback period. However, with support from government as well as other organization, PHSS certainly become profitable and at the same time can be used for flood control and irrigation purpose [20].

2.2. Compressed air energy storage (CAES)

CAES is one of the mature technologies for large scale energy storage and can be used as either a short or long duration. It involves three stages named as compression, storage and expansion [22, 23]. Researchers are trying to improve the efficiency of the system by modifying only one stage or multiple stages. For small scale application (i.e. up to 100 kW/KW), pressurized air is stored in closed container but for large scale applications air is kept in underground caverns like salt caves, abandoned natural gas wells, hard rock/limestone mines, surface/buried air tanks [24]. Hence, the geographical topology of the storage site plays a vital role in the quantity of storage.

In some cases, CAES is operated with gas power plant to maximize efficiency [25]. Even re-searchers are developing advance technology to use CAES in cryogenic mode so that more power can be derived without wasting energy. It has come with lots of ad-antages similar to PHSS like high reliability, high efficiency and long life etc. Moreover, from Table 1, it can be inferred that CAES has high volumetric, mass energy and power delivered rate compared to PHSS [21]. Despite the various benefits of this storage, very few profitable executions have been appreciated in the recent scenario. Thus commercial feasibility remains a big question [26].
Table 1. General Specification of Pumped Hydro, Compressed Air and Flywheel storage System

<table>
<thead>
<tr>
<th>Metric</th>
<th>Pumped Hydro</th>
<th>Compressed Air</th>
<th>Flywheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy [Wh/kg]</td>
<td>0.3-1.33</td>
<td>3.200-60</td>
<td>5-200</td>
</tr>
<tr>
<td>Energy Density [kWh/m³]</td>
<td>0.5-1.33</td>
<td>0.4-20</td>
<td>0.25-424</td>
</tr>
<tr>
<td>Specific Power [W/kg]</td>
<td>0.01-0.12</td>
<td>2.2-24</td>
<td>400-30,000</td>
</tr>
<tr>
<td>Power Density [kW/m³]</td>
<td>0.01-0.12</td>
<td>0.04-10</td>
<td>40-2,000</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>65-87</td>
<td>57-89</td>
<td>70-96</td>
</tr>
<tr>
<td>Lifespan [yrs]</td>
<td>20-80</td>
<td>20-40</td>
<td>15-20</td>
</tr>
<tr>
<td>Self-Discharge Rate [%/day]</td>
<td>0</td>
<td>0</td>
<td>24-100</td>
</tr>
<tr>
<td>Scale [MW]</td>
<td>10-8,000</td>
<td>0.01-3,000</td>
<td>0.001-10</td>
</tr>
<tr>
<td>Energy Capital Cost [US$/kWh]</td>
<td>1-291.2</td>
<td>1-140</td>
<td>200-150,000</td>
</tr>
<tr>
<td>Power Capital Cost [US$/kW]</td>
<td>300-5,288</td>
<td>400-2,250</td>
<td>30.28-700</td>
</tr>
<tr>
<td>Application</td>
<td>Higher Scale Energy Management</td>
<td>Higher Scale Energy Management</td>
<td>Medium Scale Power Quality</td>
</tr>
<tr>
<td>Technical Maturity</td>
<td>Highly Mature/ Fully Commercialized</td>
<td>Proven/Commercializing</td>
<td>Mature/Commercializing</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>High/Medium</td>
<td>Medium/Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 2. General Specification of diverse thermal energy storages

<table>
<thead>
<tr>
<th>Metric</th>
<th>Sensible Heat</th>
<th>Latent Heat</th>
<th>Reaction Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy [Wh/kg]</td>
<td>10-120</td>
<td>150-250</td>
<td>250</td>
</tr>
<tr>
<td>Energy Density [kWh/m³]</td>
<td>25-120</td>
<td>100.00-370</td>
<td>300</td>
</tr>
<tr>
<td>Specific Power [W/kg]</td>
<td>-</td>
<td>10-30</td>
<td>-</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>7-90</td>
<td>75-90</td>
<td>75-100</td>
</tr>
<tr>
<td>Lifespan [yrs]</td>
<td>10-20</td>
<td>20-40</td>
<td>-</td>
</tr>
<tr>
<td>Self-Discharge Rate [%/day]</td>
<td>0.5</td>
<td>0.5-1</td>
<td>-</td>
</tr>
<tr>
<td>Scale [MW]</td>
<td>0.001-10</td>
<td>0.001-300</td>
<td>0.01-1</td>
</tr>
<tr>
<td>Energy Capital Cost [US$/kWh]</td>
<td>0.04-50</td>
<td>3-88.73</td>
<td>10.9-137</td>
</tr>
<tr>
<td>Power Capital Cost [US$/kW]</td>
<td>2,500-7,900</td>
<td>200.00-300.00</td>
<td>-</td>
</tr>
<tr>
<td>Application</td>
<td>Medium Scale, Bridging Power</td>
<td>Medium/Large Scale, Energy Management</td>
<td>Small/Medium Scale, Energy Management</td>
</tr>
<tr>
<td>Technical Maturity</td>
<td>Mature/Commercializing</td>
<td>Proven/Commercializing</td>
<td>Proven/Developing</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Low</td>
<td>Low/Uncertain</td>
<td>Low/Uncertain</td>
</tr>
</tbody>
</table>

2.3. Flywheel energy storage unit (FESU)

FESU is one of the oldest technologies of energy storage which stores energy in the form of rotational motion. Generally, FESU is used for short duration energy storage and virtually independent of normal temperature at the time of discharging [27-28]. A recent study suggested that its efficiency can be improved by modernizing the sub-system associated with FESU. A 2.2 MWh fly wheel coupled with a 400MW/1MWh generator is used in the study at Fusion.
Institute of JAEA (Japan Atomic Energy Agency) [29]. Through modular design centred on 2 MW units, a low power and high energy (20MW/5MWh) commercial flywheel energy storage is achieved for grid connected application [30, 31]. However, for grid connected mode, the design of FESU is still under development. Hence its commercial feasibility remains in doubt. FESU is now used in regenerative breaking system of locomotive in which electricity is generated when brake is applied [32]. It can be observed from Table 1, FESU has large number of benefits such as high power and energy density, fast operating time, long life span, invariant to temperature and require less maintenance. There are certain constraints in FESU like contamination problem and gyroscopic effect due to earth rotational motion [33, 34].

2.4. Thermal energy storage

Its application can be found in solar power tower for time shifting in grid applications [35-37]. Time shifting refers to extending the energy conversion rate in thermal alternator and its associated energy conversion device [38]. It is highly effective in grid management system due to its efficient mechanism, high power/energy density and slow rate of discharge as shown in following Table 2 [21].

2.5. Battery Energy Storage Unit (BESU)

The most effective and widely used device in the field of energy storage is chemical battery. Table-3 as well as Table-4, demonstrates the diverse features and physical constraints with appropriate application of selective range of battery such as Zinc Silver Oxide, Alkaline, Lead Acid and Lithium Ion [21, 39-41]. Generally, battery is constituents of three main components namely the electrode at the positive and negative side, the electrolyte and separating medium as separator. In a conventional battery, the efficiency is strongly dependent upon the materials used in the electrodes. However, cycle life and lifespan of the battery is calculated based on the composition of used electrolyte and its stability. Hence most of the battery is affected by the temperature variation, environment condition and the charging-discharging regime. One of the batteries, known as Zink Silver Oxide (ZnAg), has characteristics of flat discharging rate, low temperature and climate effect and high durability [42]. Though its performance is superior over other batteries, the cost linked with electrode material (Zinc) is high. Thus it does not fit in large scale of storage applications, so presence of ZnAg battery is restricted to small storage application such as hearing aids devices and timepieces [43]. Alkaline zinc manganese dioxide (ZnMn) batteries are the most used storage technology across the globe [44]. Although it’s operated under low/ high temperature condition, its internal resistance is low so that it provides low/high current drain performance, but increased demand creates the problem of soil contamination as low recovery rate of its materials (Zinc, Manganese, and Steel) from soil [45]. In a stationary energy storage application, the selection of an opposite energy storage unit is vital. Hence in these cases, redox flow battery (RFB) is one of the deserving storage devices [46]. RFB is electrochemical energy conversion devices that exhibit redox processes of types in mixed solution of liquid form, deposited in the external containers, and when needed, the solution is introduced in the process [47]. Moreover, its working mechanism is similar to that of polymer electrolyte membrane fuel cell (PEMFC) [48]. It has some remarkable characteristics such as stability, size is free from power and energy application, flexibility, reduced impact on environment, high depth of dis-charge, etc., making it ideal for supporting the electricity production from non-conventional power sources. In recent years, the use of lithium ion (Li-Ion) batteries is increased multiple times owing to advantages like low costs, excellent charge retention time, high cell voltages, superior performance under low temperature, long life cycle [49, 50]. Furthermore, researchers are shifting the focus toward the storage management in Plug in hybrid vehicle (PEV) by the help of (Li-Ion) battery [52]. But, in certain cases, nickel metal hydride (NiMH) batteries are used in PEV storage management system [51]. A comparative assessment of Diverse Flow batteries are presented in Table 4.

Table 3. General Specification of the diverse battery storage system

<table>
<thead>
<tr>
<th>Metric</th>
<th>Zinc Silver Oxide</th>
<th>Alkaline</th>
<th>Lead Acid</th>
<th>Lithium Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy [Wh/kg]</td>
<td>81-276</td>
<td>80-175</td>
<td>10-50</td>
<td>30–300</td>
</tr>
<tr>
<td>Energy Density [kWh/m³]</td>
<td>4.2-957</td>
<td>360-400</td>
<td>25-90</td>
<td>94–500</td>
</tr>
<tr>
<td>Specific Power [W/kg]</td>
<td>0.09-330</td>
<td>4.35-35</td>
<td>25-415</td>
<td>8–2,000</td>
</tr>
<tr>
<td>Power Density [kW/m³]</td>
<td>0.36-610</td>
<td>12.35-101.7</td>
<td>10-400</td>
<td>56.8–800</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>20-100</td>
<td>36-94</td>
<td>63-90</td>
<td>70–100</td>
</tr>
<tr>
<td>Lifespan [yrs]</td>
<td>2-10</td>
<td>2.5-10</td>
<td>3-20</td>
<td>2–20</td>
</tr>
<tr>
<td>Cycle Life [cycles]</td>
<td>1-1,500</td>
<td>1-200</td>
<td>100-2,000</td>
<td>250–10,000</td>
</tr>
<tr>
<td>Self-Discharge Rate [%/day]</td>
<td>0.01-0.25</td>
<td>0.008-0.011</td>
<td>0.033-1.1</td>
<td>0.03–0.33</td>
</tr>
<tr>
<td>Scale [MW]</td>
<td>0-0.25</td>
<td>0-0.001</td>
<td>0-50</td>
<td>0–3</td>
</tr>
<tr>
<td>Energy Capital Cost [US$/kWh]</td>
<td>3,167-20,000</td>
<td>100-1,000</td>
<td>50-1,100</td>
<td>200–4,000</td>
</tr>
<tr>
<td>Power Capital Cost [US$/kW]</td>
<td>7,140,620-741,935</td>
<td>1,000-11,900</td>
<td>175-900</td>
<td>175–4,000</td>
</tr>
</tbody>
</table>
producing high intensity magnetic fields in magnetic devices is to deliver a relatively high quality of power for the short duration [55]. As it is observed that, maximum numbers of grid failure is due to sag and outages, which lasts for less than one second. In SMES unit, super conductors are achieved through cryogenic process and mainly used for producing high intensity magnetic fields in magnetic resonance imaging devices and laboratory re-search setup [56]. In view of grid application, SMES are much effective for faster operations and power quality issues. Additionally, SMES are aimed for managing the sag compensation and quality of power ranging from 10 to 1000 MW, expected to be seen by 2030-40 [57].

Super capacitor sometimes called as electric double layer capacitor, is generally used as a secondary system with a primary system usually in hybrid electric vehicles [58]. In recent years, Shanghai municipal corporation tested an electric bus (capa buses) operated by super capacitor. It has high rate efficiency, faster charging time and low internal losses [59]. As a result, it is used in grid operation mainly for

<table>
<thead>
<tr>
<th>Application</th>
<th>Small Scale Energy Management</th>
<th>Small Scale Energy Management</th>
<th>Small/Medium Scale Energy Management</th>
<th>Small/Medium Scale Energy Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Maturity</td>
<td>Highly Mature/Fully Commercialized</td>
<td>Highly Mature/Fully Commercialized</td>
<td>Highly Mature/Fully Commercialized</td>
<td>Mature/Commercialized</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High/Medium</td>
</tr>
</tbody>
</table>

Table 4. General Specification of flow battery storage system

<table>
<thead>
<tr>
<th>Metric</th>
<th>Vanadium Redox</th>
<th>Zinc Bromine</th>
<th>Polysulphide Bromine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy [Wh/kg]</td>
<td>10–50</td>
<td>11.1–90</td>
<td>10–50</td>
</tr>
<tr>
<td>Energy Density [kWh/m³]</td>
<td>10–33</td>
<td>5.17–70</td>
<td>10.8–60</td>
</tr>
<tr>
<td>Specific Power [W/kg]</td>
<td>31.3–166</td>
<td>5.50–110</td>
<td>-</td>
</tr>
<tr>
<td>Power Density [kW/m³]</td>
<td>2.50–33.42</td>
<td>2.58–8.5</td>
<td>1.35–4.16</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>60–88</td>
<td>60–85</td>
<td>57–83</td>
</tr>
<tr>
<td>Lifespan [yrs]</td>
<td>2–20</td>
<td>5–20</td>
<td>10–15</td>
</tr>
<tr>
<td>Cycle Life [cycles]</td>
<td>800–16,000</td>
<td>800–5,000</td>
<td>800–4,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metric</th>
<th>SMES</th>
<th>Super capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy [W/kg]</td>
<td>0.27–75</td>
<td>0.07–85.6</td>
</tr>
<tr>
<td>Energy Density [kWh/m³]</td>
<td>0.2–13.8</td>
<td>1–35</td>
</tr>
<tr>
<td>Specific Power [W/kg]</td>
<td>500–15,000</td>
<td>5.44–100,000</td>
</tr>
<tr>
<td>Power Density [kW/m³]</td>
<td>300–4,000</td>
<td>15–4,500</td>
</tr>
<tr>
<td>Efficiency [%]</td>
<td>80–99</td>
<td>65–99</td>
</tr>
<tr>
<td>Lifespan [yrs]</td>
<td>20–30</td>
<td>5–20</td>
</tr>
<tr>
<td>Cycle Life [cycles]</td>
<td>10,000–100,000</td>
<td>10,000–1,000,000</td>
</tr>
<tr>
<td>Self-Discharge Rate [%/day]</td>
<td>1–15</td>
<td>0.46–40</td>
</tr>
<tr>
<td>Scale [MW]</td>
<td>0.01–200</td>
<td>0–5</td>
</tr>
<tr>
<td>Energy Capital Cost [US$/kWh]</td>
<td>500–1,080,000</td>
<td>100.00–94,000</td>
</tr>
<tr>
<td>Power Capital Cost [US$/kW]</td>
<td>196–10,000</td>
<td>100–800</td>
</tr>
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<table>
<thead>
<tr>
<th>Metric</th>
<th>SMES</th>
<th>Super capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Medium/Large Scale Power Quality</td>
<td>Small/Medium Scale Power Quality</td>
</tr>
<tr>
<td>Technical Maturity</td>
<td>Proven/Commercializing</td>
<td>Proven/Commercializing</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Low</td>
<td>Too Low</td>
</tr>
</tbody>
</table>

2.6. Super conducting magnetic energy storage and Super Capacitor

Superconductors are vastly used in generation and storage applications such as fly-wheel storage system and synchronous generator [53-54]. Moreover, using the property of superconductor, super conducting magnetic energy storage (SMES) is build-up. The main use of such a device is to deliver a relatively high quality of power for the shorter duration [55]. As it is observed that, maximum numbers of grid failure is due to sag and outages, which lasts for less than one second. In SMES unit, super conductors are achieved through cryogenic process and mainly used for producing high intensity magnetic fields in magnetic
sag compensation. Although SMES and super capacitor are much costly, but super capacitor is virtually maintenance free. The technical specification of both SMES and super capacitor is depicted in Table 5. With multiple manufactures entering in to market, it is expected that cost of super capacitor will gradually decrease [60].

3. Storage Scenario Across the World

3.1. United States of America

The United States of America is one of the most developed countries that have matured technology of energy storage technology [61-62]. The first battery was developed by Volta hence called as Volta’s cell in 1800, and the first energy storage system located in Rocky River Pumped Storage plant in Housatonic River in Connecticut, which is founded in 1929. It is estimated that 25.2 GW rated power over 1082 GW total power is installed. It is calculated that 2.5 % power which is used comes from storage or recycled. As of 2018, 1361 numbers of projects are under operation [61]. In US, 41% of projects were functional, and 33% are under construction. California is the topmost state, which has 220 functional projects of total 4.2GW power followed by Virginia and South Carolina comes. Energy storage is growing at faster rate in USA at 174% from 2013 to 2018 due to various steps taken by government as well as local agency [63]. From the literatures, it is found that the maximum amount (94%) of energy storage is the PHES, which is of 23.68 GW followed by BES (0.75 GW), CAES (0.114 GW) and FESU (0.058 GW) as of June 2018 [61-62].

3.2. Japan

The battery storage system of Japan holds commanding lead with comparison of world stage largely [64]. Due to ongoing research, Japan provides an effective and efficient mechanism; hence it becomes the world leader in battery energy storing technology and applications. Japan has 277 MW of functional energy storage projects and 59 projects are under construction as per 2012 report. It is noteworthy that, the figure is not only the best but also surpasses the data of other developed countries like US and China [65]. Though the USA presently has the biggest supplementary battery storage system under construction, Japan is still the world leader in terms of battery storage capacity. Moreover, Japan’s ambitious plan is to capture half of the world’s battery storage market by end of 2020. From 1990 onwards, NaS battery installation increases at a faster rate as the data is revelling. In 1998, the rating was only 10 MW but in 2009 the rating becomes 300 MW/2000 MWh and in next year 350MW storage is achieved. The recent study suggests that, Japan dominates the manufacturing of NaS across worldwide. In 2012, NGK installed a sodium sulphur based energy system of 450 MW. In the meantime, Japan becomes second largest manufactures of lead-acid battery after the USA. In the future, the rating of storage system will rapidly reach at the ultimate level with support of new policy and incentive schemes introduced by the government [66].

3.3. China

Advancement of energy storage in China is growing at a faster rate due to continuous growth of ancillary services as well as sustainable investment towards the grid with realization of smart grid [67, 68]. China’s current storage market size is $700 million and expected to be reached at a record of $6 billion by 2024. The decrease of technology costs and emerging of new technology in the existing system will further boost the storage market. In recent times, it is witnessed that the cost of lithium ion battery is reduced up to 50% as compared to past. The world’s first and China’s largest electromechanical energy storage station with virtual synchronous generator is started its operation in JinJiang, Fujian Province in 2019 [69]. This plant has 100 MWh battery energy storage with integrated 400 MW of wind energy, 200 MW of PV, and 50 MW of concentrated Photovoltaic plant. In subsequent stage the rating of system will increased up to 1000 MWh. Government reforms favour the development of storage system across the country, which will further enhance the system capacity [70].

3.4. India

The storage sector in India is just started blooming after much-awaited reforms and encouragement done by the government [71]. As per the study conducted by Indian Energy Storage Alliance (IESA), energy storage system alone for renewable energy will be 6000MW by 2020 [72, 73]. It is expected that the new range for energy storage will be much higher than the existing unit as the government targeted to increase the renewable power generation up to 175 GW by 2022. Apart from this, the Ministry of New and Renewable Energy (MNRE) has a plan to include 10,000 micro-grid/500 MW of micro and mini-grids in the existing system [74]. In 2019, Solar Energy Corporation of India (SECI) asked to install 3.6 GWh of storage that should make a couple to 1.2 GW of solar on India’s interstate grid transmission, the largest battery realization in the country to come yet [75]. Hence it is suggested that lots of additional opportunities can be seen in storage system if it fulfils the above said target.

4. Overview and Application of Energy Storage in LFC

Energy storage battery technologies have been in operation in power system applications since the early 1900s. In reference [28], the authors discussed the use of batteries as an equalizer and carried out the tests on the distribution substations supplied by Indiana’s Union Traction Company in 1902. BESU systems can be used in a wide range of grid support applications, including generation, transmission, distribution, and end-user services, due to their rapid response to sudden power fluctuations [77, 78]. For example, the use of energy storage could be 2-3 times more effective than the addition of a combustion generation unit to the system [79] for frequency regulations. For example, BESU is found in numerous applications such as peak shaving [80, 81], load levelling [82, 83], black start support [84, 85], frequency regulation [86, 87], and voltage support [88, 89]. Figure 2 provides a hierarchical summary of the use of energy...
storage in power systems. One of these applications is the load frequency control, and BESS has now been used for decades. The provision of BESU in LFC is being discussed by researchers since the mid-1980s after Kunisch et al. [90] proposed the first effective BESU demonstration facility as an approach to improve the performance of LFC control in Germany-1986 [90-92]. During periods, when the frequency goes above the scheduled value, the battery is charged known as charging mode. Similarly, when the frequency drops below the scheduled value under such circumstances, BESU provides energy to the grid called dis-charging mode. Until now, researchers have been considered as inspiring, particularly given the recent extension of the concept of intelligent grid systems [93, 94]. The strategy of controlling LFC using energy storage technology has been described in Fig. 3 [95]. Two types of strategies are introduced depending on the amount of energy storage, its location and possession in the power system, quality and its behaviour with independent dispatching centre [96]. The two different types are known as Load Scale System and Grid Scale System.

![Flow diagram showing the application of energy storage in power system](image)

**Fig. 2.** Flow diagram showing the application of energy storage in power system

**4.1. Grid Scale System**

In this type, centralized battery systems are being controlled using LFC and modern reheat type was taken into consideration. In 2001, the authors Aditya and Das have observed the usage of BESU for LFC with reheat thermal plant in two interconnected power systems. As per the simulation result, enhancement in the system response has been noticed at a 1% step increase in demand. Moreover, the BESU performance for LFC in two area interconnected system has been simulated in MATLAB simulation environment by [96-97]. In case of isolated power grids, a small amount of spinning reserve problem arises. So, in this case, reliable system frequency regulation is necessary [92]. By the author’s in reference [98], BESU is utilized to improve the LFC performance of the system. In an isolated power system, the impact of BESU on LFC was performed and optimal sizing of BES was taken into account by Mercier et al. [99]. Using MATLAB, the result of BESU was inspected for one month of operation. It is observed that 0.98% (scheduled 50Hz) frequency deviation occurs without BESU while this deviation was only 0.26% using BESU.

![Line diagram showing the LFC Coordination in single area system](image)

**Fig. 3.** Line diagram showing the LFC Coordination in single area system

The idea of integrating distributed BESU in microgrid system can be accepted in multi microgrid system [100]. It is observed a multi microgrid with two microgrids that are interconnected with each other. For frequency control of a multi microgrid two ACEs, the frequency control is used in this purpose. But in case of isolation systems, the control signal is the frequency response of the system [101]. The equipment of an isolated system are the wind turbine generator, battery backup and hydro plants. The characteristics of LFC was tested by using and without using energy storage element. In system frequency variation a considerable amount of attenuation was achieved. Later Mohammadi et al. proposed an advanced LFC strategy having a synchronous generator, battery storage, PV units and loads [102]. The aim was splitting of microgrid into several virtual areas that are interconnected with virtual tie line. By this tie line LFC signal was obtained, which is used to control the frequency and power deviation. In the result
section the characteristics of LFC was described. For controlling the frequency, how the energy capacity of BESU was affected by the power ramp rate of thermal units has been discussed by the authors [103]. It is observed that the power rate of the BESU reduces to 53%. The type of Grid Scale System is revised by deliberating the following characteristics.

4.1.1. LFC Control Techniques

The techniques of LFC are important in terms of future study. In Automatic Generation Control (AGC), LFC control techniques are used inevitably. We can use different types of control strategies to integrate the AGC controller. The function of a controller is to initiate the control signal to the units contributing to the LFC, depending on the requirement of the system. For more information regarding LFC control techniques, refer to [104]. Umrao et al. [105] has classified the LFC controllers into two types.

- Classic control technique: Proportional, integral derivative by linear quadratic regulators.
- Artificial intelligence (AI) control technique: It includes fuzzy, genetic, neural, hybrid optimization technique.

A battery energy system can be implemented in all types of control methods to offer an improved BESU in LFC technique. In this case, the function of the controller is to deliver signals to the aided BESU and LFC units. The authors Kalyani et al. and Sen et al. have described about Integral, Proportional Integral, Proportional Integral Derivative control techniques [96, 97]. From the literature survey, it is also found that multi stage controller, fractional order controller and cascaded controller are recently used in LFC study [188, 189]. The authors in reference [106-110] examined a robust control method namely H-infinity by replacing regular PI controller. The authors considered problems like uncertainty in parameters and propagation delay which are presented in control channels and treated them. The control system introduced by them was examined by New England 39-bus network on an LFC of two area. It infers from the result that the stability and robustness provided by H-infinity controller was better than PI controller. Though it is categorized into load scale system, the work done by the authors are Janfeshan et al. [111]. They have presented a control method based on decentralized fuzzy logic by considering BESU used in electric vehicles. The idea of manipulating electric vehicles by regulating the frequency has been described more briefly in the subsequent sections.

4.1.2. BESS Characteristics

Usually, three basic modules are present in a battery storage system [112]:

- Battery pack: A group of battery cells arranged in series or parallel configuration.
- Power conditioning module: For tie-up BES with the grid, power electronic converters are used.
- Control as well as protection: It keeps track of state of charge (SOC) and confirms that the capability of battery power for applications regulates the charging-discharging of battery with respect to the control variable of the system, used for safety and protection purposes.

In BES various types of batteries are used. The authors in reference [113] observed various kinds of batteries, their merits, and demerits in various applications. Battery characteristics like efficiency of the battery, discharge rate, rate of charging and discharging, life-time restriction, SOC limitation differ for different kinds of batteries and perform a vital role in the LFC performance [76, 114]. Generally, in power system two kinds of secondary batteries are used:

- Conventional battery: It comprises Sodium Sulphur, Lithium ion, Nickel Cadmium, Lead Acid.
- Flow battery: Characterized by vanadium redox.

The most efficient battery technology that is mostly adopted in the grid system is Sodium Sulphur [115]. Nevertheless, the production cost of Lithium batteries is high as compared to other types of batteries. The reason behind the high cost is that additional protection units are required as Lithium batteries are more vulnerable towards overheating and overcharging conditions. Using the protection system, the cost increases by 25% and weight up to 50% [116]. The most common NiMH battery technology is practiced in electric vehicle technologies. By considering safety, cost, life cycle and high energy density, this battery technology can play a vital role [117]. Currently, a new NiMH battery technology research is going on by the inventor of NiMH battery technology, the world leader of chemical industry [118] by which the energy capacity of the battery can be increased to eight times as well as the price of the kWh will be reduced to $146 [116]. Both the categories as described above are used in the LFC application. Shibasaki et al. presented the application of Sodium Sulphur battery system [119]. A controlling method has been developed, which uses H-infinity controller. Using two area system, it is observed that the fluctuations in generation greatly reduces by using Sodium Sulphur battery system. In utility systems Flow batteries are reliable among various rechargeable batteries. Flow batteries are used extensively in LFC applications because of durability, fast response, and high power capability and no self-discharge. But the disadvantages of redox batteries are complicacy, costly, low energy density as compared to conventional batteries [113, 120]. Sasaki et al. performed load frequency control using redox flow battery [120]. The authors examined performance of Redox Flow batteries; its advantages by doing simulation of two area inter connected systems. Both the interconnected systems have hydroelectric and thermal generation units with Redox.
Flow batteries. In transmitting the LFC signal, the variation of the response speed between thermal units and RF units were taken into consideration. The results from the simulation shows in LFC application the RFB batteries are very effective as they have overload ability and fast response. The effectiveness of RFB batteries was discussed in [121] for LFC of the deregulated system. In the above-mentioned works, the authors have explained about LFC system using one kind of battery. But they have not discussed about the effects of various characteristics of different sets of BESU. In [122], the use of various sets of BESU has been discussed. Taking charge and discharge characteristics, the authors invented advanced SOC based control techniques. Two sets of Sodium Sulphur and Nickel Metal Hydride batteries with different capacities were taken into account and examined for this study. From the simulation results, it is obtained that the performance of the LFC system has been improved by the proposed control techniques in spite of the variation in the charging-discharging rate of the used battery.

4.1.3. Optimum Size of BESU

One of the main problems is the positioning of BESU in the utility system is the price of the BESU system. Cook et al. stated that “before discussing the price of BES, we have to consider the size of BESU system” [123]. Therefore, by optimizing the size of BESU, a great profitability can be achieved in the system [124]. Moreover, the size of batteries is primarily selected in such a way that it can meet the LFC power and energy requirement. Hence, the optimal sizing of BESU should be realized. Authors in reference [125-126] have worked in this field. Before deciding the size of the battery, the variations in speed of response among the batteries and LFC units have to be taken into account. In order to restrict the required size of BESU, Amano et al. invented a new technology for ACE to the LFC and BESU units [127]. This proposed method allocates low frequency ACE signal to LFC units and high frequencies are transmitted towards BESS. A similar strategy has been proposed by Leitermann et al. regarding the reduction of ramp rate of thermal units and the vital capacity of BESU [129]. A strategy of LFC by implementing BESU by considering reduced BES capacity has been discussed in [129]. By dividing the LFC duty, the authors observed a difference in response speed of thermal units and BESU. BESU units regulate the frequency of the system while thermal units take care of the load flow. Thus, fast BESU is associated with small charge and discharge and does not abolish thermal units. In this way, BESU energy capacity is reduced to a great extent [130-131]. The aim is to obtain LFC signals from tie line power deviation with battery storage output. This can be useful in the case where the output of the thermal unit does not rely on BESU. It is shown that BESU capacity has been reduced to 30%. The authors in reference [99] proposed a method using Net Present Value formula to optimize the BESU size for maximizing the operating revenue.

4.1.4. Grid Scale Systems in a Nutshell

All the work review in this category is based mainly on grid connected BESU in large scale systems and utilizing generation side control [132-134]. This method is most popular in the power system. The practical challenge encountered by it has been described below:

- The installation cost is high in large scale BESU systems.
- High efficiency is required in BESU systems.
- Between thermal units, system operators and BES units, correlative dispatch of LFC signal is required because of time scale variance between generation units and BESU units.

Now a day, more attention is given towards demand side control utilizing loads to take part in frequency regulation and distribute the burden with generation side control. In reference [132], the authors stated that the loads having battery storage can effectively reduce the capacity of BESU to a greater extent. In the upcoming section, different methods of LFC using BESU and local loads as controlled reserve are described.

4.2. Load Scale System

If the frequency deviation occurs in the generation, transmission, or distribution system, it can be identified instantly and can be measured by effective mechanism, which in turn affects the load generation balance [135]. Thus, loads play a vital role in controlling the frequency of the system instead of sitting idly in the grid [136-137]. Before discussing various LFC control techniques in this section, first the role of loads in regulation of frequency is discussed. In this area many research papers have been issued [138-140]. Loads like heat pump water heaters, refrigerators, resistive heaters are appropriate for this type of application because they can store thermal energy [141-143]. In references [144-146], thermal energy storage with heat pump water heaters were used for LFC support. This type of loads can be governed via switching ON-OFF to track the deviation in frequency for a short period of time. Zhao et al. have discussed some researches that have been implemented in load control techniques based on frequency [147]. Grid Friendly Controller of Pacific Northwest National Laboratory (Grid Friendly TM Controller Helps Balance Energy Supply and Demand) is one of them. This controller measures the line frequencies to regulate the appliances. When the frequency goes below standard value (50 Hz in India), the appliances are switched off from few seconds to few minutes by the controller for reduction of load.

On the other hand, this technique has some downsides of customer side disutility because appliances go to off state during overload period. In order to reduce the burden of customers, the disutility period must be controlled, or else this method might not be helpful towards the users [132]. In reference [147], the authors presented a technique of distributed load control with monitoring the frequency of the
system to reduce the disutility of load. In order to improve the accuracy in frequency measurement at different load periods, communication among loads is necessary. Thus, an adjustment must be made between modest communication and small disutility period. During over frequency period, this control method may not provide better regulation. To encounter this problem, a group of equipment should be arranged and dedicated to be turned ON when frequency goes beyond the standard value. Hence a controlling algorithm is required to develop for ON-OFF switching for appliances so that it does not interfere with the user’s choice. In reference [136], the authors proposed an ON-OFF technique for the equipment to permit main reserve in both directions, and three kinds of users’ choice were taken into account, namely conservative, optimistic, and probabilistic. The authors also developed a new theory stated as ‘electric spring’ [148-151]. These authors implemented a creative idea of ‘smart loads’ by using power electronic devices.

The above mentioned controlled techniques are outside of our scope of review as we discussed explicitly deployment of battery storage in frequency regulation. Hence demand side BESS is focused here. For the improvement of LFC control, customers load having battery storage can be used. According to our classification, it comes under load scale system category. In this type, distributed energy storages are in-stalled as secondary storages at the load side and also controlled in such a way that it is similar to the AGC of thermal generation depending on available data. Nowadays, electric vehicles are widely used and mostly discussed for this application purpose. There are different kinds of electrical vehicles categorized by U.S. DoE (‘Hybrid and Plug-In Electric Vehicles’). With the advancement of technology, diverse researchers proposed that these electric vehicles can be implemented in LFC as a mobile BESU unit [152-155]. According to the way of communication between power system units and controlled loads, the load scale system technique can be divided into two types: Coordinated Aggregate System and Non-Coordinated Individual System.

4.2.1. Coordinated Aggregate System

The aggregate system plays a vital role among all other load scale systems. Electric vehicles are the revolutionary appliances that are being researched to be used in this technique. Authors in [157,159] stated that other techniques of distributed battery energy storage like domestic battery banks or battery installed appliances can be easily used. According to this technique, a number of electric vehicles are linked to a central charging station, having coordinated system operators and electric vehicles using V2G mode of operation [159,160]. Guille et al. implemented an administrator and intermediate controller (which is known as aggregator), collects information about battery SOC, switch on and off time [162]. They also calculated the arrival and subsequent time of charging from smart interfaces of electric vehicles and interconnected with dispatching centre. Then LFC signals were transmitted to the electric vehicles using the aggregator [163, 164]. The author Shimizu et al. proposed an LFC technique which reduces the necessity of BES using Battery of EVs [152]. A control technique was developed which gives priority to its users considering SOC of electric vehicles battery. This SOC technique regulates only the plugged and fully charged electric vehicles in which SOC level is 80%-90% in order to provide satisfaction to its users. This proposed model contains 50000 electric vehicles dispersed in 500 local control centres that are interconnected with central load dispatch centre. The system was inspected using two conditions that are considering users expediency and not considering users expediency. It is observed from the result that the frequency response is better in case of considering user expediency than in the case where user’s expediency was not taken into account. In the second case the output of electric vehicles is controlled by using SOC limits. In [165], authors proposed a control method of LFC using the BESU of distributed plug in hybrid electric vehicles with thermostatically regulated loads. The authors invented an aggregation method by implementing in a management system which is known as aggregator based model predictive control method [166-168].

This aggregation method keeps a high level of management between the control loads, plug in hybrid electric vehicles, system operators and distribution through communication. The proposed model consists of a bunch of 40000 plug in hybrid electric vehicles, thermostatically regulated appliances, a CHP unit all linked to a network providing service to an urban community of 160000 populations. It is observed from the results that for the improvement of the system LFC such frequency control methods are effective. On the other hand, the author raises a question about the availability and sufficiency of the reserve quantity given by those loads for the practical application of the proposed system. Moreover, the performance of aggregation is discussed by considering fast communication condition and the consequence of delay in communication system was also not presented. In reference [169], authors discussed about the effects of data exchange and communication method between the grid and the loads controlled by LFC. With the help of numerical simulations, the authors examined the processing delay and network delay to transmit the LFC signal to the distributed battery storage system. In the end, the authors also neglected the network delay. The model was simulated under random variation of load 8000 MW and large influence of wind energy 1800 MW. They also proposed various processing delays and variation in the rate of installation of battery energy storage system. A control method known as cutoff control was also invented to keep coordination with the batteries having a slow response rate. A problem arises in this method which is the small use of BESU because in some operating situations, the slow batteries cannot be dispatched. Another problem is that to avoid over charging or over discharging of batteries SOC limits also considered [170, 171]. The authors have tackled the issues of SOC limits by building an energy control system utilizing Hierarchical Model Predictive Control to regulate the frequency of smart grid [172]. The proposed model consists of conventional generators, coordinated electric vehicles, and recurrent renewable energy sources. The proposed HiMPC method predicts and controls the SOC of electric
vehicles and keeps away from over charging and discharging [173]. A noteworthy enhancement in the performance of LFC was seen utilizing electric vehicles in comparison to the case where electric vehicles are not accessible for control [174, 175]. The author, Vachirasricirikul et al. discovered a new control technique using V2G scheme for frequency support [176]. The main objective is to manage the problems associated with system uncertainties, disturbances and to develop a simple and robust controller. To regulate the parameters of the frequency of the controller, both classical as well as intelligent control techniques were used where a particle swarm optimization method using the H2/H infinity control technique was implemented [177]. The frequency controller was used with a PI controller. Using SOC optimization strategy, the power output of the battery was regulated to sustain battery SOC within a predefined limit. From the results of the simulation of the two-area wind farm system, the efficacy and heftiness of the control technique were obtained. The author Huang et al. also observed the usefulness of electric vehicles in LFC system [178]. The publication list about the role of electric vehicles in frequency control is very long, but here the value of LFC control technique was highlighted and the readers can find more material in the literature about the vehicle to grid strategy. As per our discussion the following problems must be solved:

- The charge-discharge control method must give priority to the customer’s necessity and suitability.
- In order to achieve the above case, system operators should be able to control and keep track of a large number of loads. Therefore, intermediate control and aggregation units are required for dispatching LFC signals and in interconnection with the generation units.
- Without knowing the status of the entire system, the aggregator examines the required LFC services from the local operating systems. This is accomplished by metering, regulation and collection of real time statuses of the loads like battery SOC limit, frequency, electric vehicles plug in and out times as reported in [179].
- The interconnection between utility operators and aggregator requires seamless two-way communication method with high-speed protocols [180].

By implementing the above techniques, the installation and maintenance cost of the system increases. Hence, it is important to obtain top-notch trade-offs between control complexity, cost, the amount of communication and usefulness of frequency regulation so that the utility operators can adopt this load control technique.

4.2.2. Non-Coordinated aggregate Systems

Nowadays, vigorous development can be seen in the field of power electronics control techniques. According to the authors Ribeiro et al., and Ota et al. appliances having battery storage system can be implemented in interface circuits having capability to measure system frequency accurately and respond to deviation in power [135, 181]. The theory of non-regulated control of individual loads having battery energy storage to obtain load side control of frequency is still not implemented by anyone. In the coordinated aggregate system, electric vehicles play a vital role where decentralized regulation is obtained at electric vehicles end via battery chargers. Hence, smart interface circuits which control the bidirectional flow of power between the power line and battery and measures frequency are required. Rei et al. invented an improved smart interface circuit for electric vehicles [182]. In this model, a three-phase multilevel diode is used as a bidirectional AC/DC converter. According to the droop control methodology, this circuit uses voltage control services and auxiliary frequency. Using this technique, Ota et al. developed a single-phase Grid economic interface system to understand the V2G and smart charging concept [183].

The main objective behind the non-regulated discrete system is to distribute the cyber security and communication requirement between system operators and regulated loads for getting a more supple system as stated by the authors in reference [184]. The authors in reference [185] stated that this technique is similar to the frequency controlled load regulation and grid responsive controller. The charging-discharging process of load battery energy storage is regulated with droop control technique corresponding to the generator droop control, so that turning off the equipment during under frequency period is not required. Hence this strategy does not fall under the category of secondary control strategy. On the other hand, it comprehends the primary frequency regulation because no interconnection signals between the generation side and the battery storage is directed. The line frequency signal only represents the communication signal between the generation side and the battery side.

The charge controller, by sensing the frequency for electric vehicles is invented by Argonne National Laboratory. They proposed that using droop control technique and without taking any signals from the dispatching centre, the PEV of battery loads can be regulated automatically [188]. When the variation in the range of the frequency is between the range of 0.1Hz <Δf <0.5Hz, the controller decreases the charging rate to 50%. But when the frequency drops below the range of 59.5Hz, it finally stops charging. When it reaches 50%, the charging method is resumed where the power mismatch is recovered and the frequency range is 59.7%. Charging is continued at full rate when the frequency exceeds to 60Hz. This control method is known as V1G/smart charging. In this case, one-way power transfer is permitted from grid to vehicle and discharge of powers does not occur during under voltage period to maintain the utility grid as in the V2G technique. The authors in [135] presented a distributed and non-coordinated V2G control scheme by implementing a two-
way power transfer technique between the grid and the electric vehicle. However, V1G control method is also used to control the SOC level of the battery of the vehicle within the limit as required by users. The proposed control technique states that the power of the battery storage is modulated in proportional to the variation in the frequency.

The safe charging and discharging of the battery is maintained by the SOC algorithm and keeps its SOC value in the range of 10%–90%. The maximum amount of charging and discharging power is obtained at frequency variation between +0.025 Hz–0.025 Hz. By responding to the request of the driver, the control switches between V1G and V2G modes. The result of 250MW V2G power unit was examined under two-area of thermal system with the absence of coordination between the thermal generators, electric vehicles, system operators. A noticeable enhancement of frequency regulation of both the areas was realized by setting the SOC within its predefined limit of around 50%. To get another level of SOC, the parameters of SOC have to be modified in the algorithm. Liu et al. invented a SOC holding algorithm which controls the level of SOC according to the user’s choice without making any changes in the boundary limits of SOC [180]. For this type of control method, electric vehicles are used widely as storage battery installed appliances. Now a day, more focus is given towards the domestic batteries for the load side control strategy of Behind-the-Meter Energy Storage matching with the discovery of modern domestic batteries by battery companies like Powerwall of Tesla, xStorage of Nissan. In Rocky Mountain Institute, Fitzgerald et al. studied that except the meter energy storage, there are many challenges that keeps away it from supplying frequency control services and to the customer-oriented services [189]. This study explains about these problems, the necessary actions to avoid them, and the appliances that should follow these steps to permit this model of battery energy storage to work in the frequency control. The proposed study by the research community shows that it is necessary to capitalize efforts to build technical as well as economic strategies. In the literature, it is found that many attempts were made in this regard. The authors in reference [156] analysed the performance of domestic lithium ion battery. From the results obtained from the simulation, the energy efficiency and cycling capacity of the battery were evaluated. Different authors discussed about the decentralized control algorithm of domestic batteries [190,191]. The authors in references [192,193] explained the advantages of PEV as behind the meter energy storage unit in an advanced control technique for primary and secondary frequency regulation]. The distributed individual entities aim to give prioritize the user’s suitability considering the parameters of SOC and to safeguard their privacy by decreasing the rate of communication with the operator of the system.

5. Conclusion

Energy storage is found to be crucial for the enhancement of power quality also sag compensation, power smoothing, load levelling, and power balancing when multiple renewable energy sources are included in the power system. In addition to that, it also supports the stability of the system with significant technical and economic assistances. This Methodology can be realized with a large capacity of diverse storage units that should be operated by the utility in accord with LFC. Such type of scheme requires the highest level of accuracy and price control by the operator and utility. Much attention is needed by the demand side control as distributed energy storage can be connected to loads or placed in the customer’s home so that the size of centralized storage unit can be reduced. EVs do not only help the frequency regulation but also act as excellent energy storage. The utilization of battery storage can be achieved through efficient and advance batteries like Tesla’s Powerwall and Nissan’s xStorage. For power, the EVs, high energy density storage technology will play a vital role in the near future. With the advancement of energy technology, frequency regulation could be reasonable and also the commercial services obtainable by these smart-grid-oriented applications. It is expected that, all of us will experience a modern and matured storage technology with their corresponding roles in near future.

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