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Challenges and Opportunities of Flywheel Energy Storage Systems in the Philippines

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ABSTRACT

Energy companies in the Philippines are beginning to look to energy storage systems to provide stability to the country's electric grids and to improve the viability of renewable energy. Several innovative energy storage solutions have been developed and made available in the market and one of them is flywheel technology. One of the pioneers of the flywheel industry in the Philippines is Amber Kinetics, a manufacturer of grid-scale kinetic energy storage systems that made breakthroughs in flywheel technology with its revolutionary M32 Flywheel. In this paper, the different factors that this technology must address are presented in order to compete against other energy storage systems in the country which includes characterization and cost projection. Furthermore, the paper explains how the landscape and geography of the country affect the logistics of flywheel installation, how flywheels can support renewable energy generation and off-grid areas of the country, and the leverages flywheel technology has over other systems already installed in the Philippines.

Key words: energy storage systems, flywheel, levelized cost of storage, Li-ion battery, renewable energy

1. INTRODUCTION

Renewable energy sources have gained a significant worldwide growth that responds to the increasing need and demands of the consumers. These sources are decentralized which indicate greater network load stability problems and require energy storage systems (ESS) as a potential solution. Lead- and lithium-ion based batteries are the primary options, but they lack the cycling sustainability especially for larger volumes of energy [1]. Thus, an innovative solution is needed venturing on the other forms of structure (e.g. mechanical) which, in this paper, highlights the flywheel energy storage systems (FESS).

1.1 Overview of Amber Kinetics

Countries all over the world have begun decarbonizing their grids and are utilizing renewable energy systems which are steadily penetrating the market with their low-cost feature and operations sustainability. However, the variability of renewable energy and electricity demand means that the generation of electricity may not match the load [2]. This has led to the growth of the global energy storage market as energy storage can compensate for the intermittency of renewable energy generation. Amber Kinetics was founded in 2009 to meet the challenges of the energy market and to develop different clean energy technologies for a safer future. Based in Union City, California, the company is now the industry-leader in the development of grid-scale kinetic energy storage systems and is the only manufacturer of long-duration flywheel energy storage systems. Their flywheels have been installed in California, Boston, Tibet, New Taipei, Hawaii, and in Laguna, Philippines through their academe and industry partnership with De La Salle University in order to further strengthen research and development of this technology in the local setting.

1.2 Overview of Energy Storage Systems

Energy storage systems refer to technology that is supplied with electrical energy, converts it into another form of energy, stores it, and converts it back into electrical energy when needed [3]; indicative of its application to support the fluctuating energy demands in a rural and urban setting [4]. Flywheel energy systems also provide frequency regulation and voltage support, deferral of upgrades to the network, improvement of distribution asset use, and decrease power supply costs [5].
There are several classifications of energy storage systems. Electrochemical energy storage systems convert the chemical energy in the active material into electrical energy [6] and they include redox flow batteries and battery energy storage systems [7]. Chemical storage systems like hydrogen fuel cell storage systems store energy in atoms and molecules and release it through electron transfer reactions [7]. Electrical storage systems store energy by modifying the electrical or

magnetic fields with the help of capacitors or superconducting magnets [8] and include supercapacitor storage systems and super magnetic energy storage systems. Thermal energy storage systems store energy by turning it into heat or ice and consist of low temperature and high temperature thermal options [9]. Mechanical energy storage systems store energy through mechanical processes which include flywheel mechanisms, compressed air storages, gravity energy-based, and pumped hydro storage systems [10].

1.3 Description of the M32 Flywheel

Flywheels are energy storage systems that store electricity in kinetic form by using the electricity to rotate a massive cylinder in incredibly high speeds. This stored kinetic energy can then be converted back to electrical energy by the motor-generator that rotates the cylinder and discharged when needed. As an energy storage system, flywheels can provide frequency and voltage regulation [11], voltage sag control [12], and stabilizing of renewable energy generation [13]. Flywheels can also help avoid costly Transmission and Distribution (T&D) upgrades and investments.

Amber Kinetics adopted flywheel technology as they believe that its low environmental impact will play a significant role in decreasing carbon-emissions in the energy sector. However, flywheels at the time were limited in their discharge duration, thus their use in the energy sector was overshadowed by other systems. In response to this, the company improved flywheel technology by applying a vacuum and magnetically levitating the flywheel, reducing losses that would have been caused by friction from air and mechanical bearings [14]. Lastly, the flywheel uses a steel rotor as it is the most cost-effective and readily obtainable material, making the flywheel easily recyclable. These improvements resulted in the M32 Flywheel, the first long-duration flywheel energy storage system.

The M32 can store 32 kWh of energy and delivering 8kW of power as well as having a 4-hour discharge duration and a roundtrip efficiency of more than 86%. Its durable design requires little to no maintenance, resists varying environmental temperatures, and eliminates the need for a HVAC which allows the flywheel to operate in almost any climate and location. The use of steel, absence of hazardous chemicals in the flywheel's operation, and low operating temperature also means that there is a minimal risk of a chemical fire. It can be cycled multiple times a day without suffering a degradation in its performance and can last more than 20 years without being replaced.

1.4 Scope and Significance

This study will focus on the factors that will determine the M32 Flywheel's viability in the Philippines. This includes applications, performance and cost of other energy storage systems. The considerations taken to assess the feasibility of an installation site is examined as well as the logistics of installing the flywheels in the local sites. Lastly, the possible applications of the M32 in the energy sector of the Philippines is determined.

This initial paper provides an information based on comparative study between M32 Flywheel and existing energy storage systems in the country that can support the development of their flywheels and allow them to continuously meet the demands of the Philippine energy sector. This study presents the energy issues that the M32 flywheel can address based on the energy trends in the Philippines as well as identify benefits using the M32 over other energy storage systems.

2. CHALLENGES IN THE ENERGY SECTOR

2.1 Energy Storage Systems in the Philippines

While there are several energy storage options available, research indicates that battery energy storage systems have been gaining attention in the country's energy sector and have already been installed to support the grid of several locations. The AES Corporation have installed the Masinloc Advancion TM Energy Storage Array in Masinloc, Zambales which aims to provide fast response ancillary services and a 10MW power capacity to the Luzon grid as well as a 40 MW battery energy storage system in Kabankalan, Negros Occidental which aims to improve the Visayas grid's ability to accommodate solar power available in the region [15, 16]. In 2019, Meralco and Hitachi unveiled a grid-scale distribution-connected Li-ion battery storage system in San Rafael, Bulacan that can deliver 2MW in capacity and will give Meralco a better understanding on the integration of battery energy storage systems with renewable energy [17].

Other local energy players will also begin installing battery energy storages to support different power plants as the Department of Energy (DoE) has approved forty-two battery energy storage system projects in the year 2019 [18]. A $28-million battery energy storage system will be built by the SN Aboitiz Power Group (SNAP) this 2020 in its Magat Hydro Electric Power Plant that would improve ancillary services and serve "as a giant power bank". [19]. The construction of a new battery energy storage system facility was announced in the same year when Siemens Gamesa began a 6MW hybrid energy project in Puerto Galera. This is in conjunction with the existing 16MW wind power facility which will provide a good supply of electricity to an area with a weak connection to the grid, thus reducing its dependency on diesel [20].

The number of battery energy storage installations in the country indicates that battery storage technologies are increasing in popularity and it is gaining interest from the local companies and investors in the Philippines as they will be a new source of ancillary frequency controllers according to the Energy Regulatory Commission [21]. Battery-based lithium-ion energy storage systems are known to be advantageous in terms of being a well-developed technology as its increased application in electronic devices, laptops, and electric cars [22] prompted an increase in production and development, leading to a reduction in costs and improved performance. Battery energy storage systems can support the generation, transmission, and distribution of electrical energy [23]. Battery storage can also be integrated with renewable energy which help address the issues of variability.

2.2 Li-ion Battery Characteristics and Economics

Lithium-based batteries are often found as power supplies for mobiles and laptops [24], but when used as energy storage, they provide peak load shaving, power curve smoothing and voltage regulation [25]. They are also capable of providing short-duration power, grid stabilization, frequency response, spinning reserves, transmission deferment, and demand response [26].

Li-ion batteries have the highest energy density amongst other battery energy storage systems [23]. The battery cells can be recharged repeatedly, are more than 90% efficient, and are expected to cost less as time goes on [27] They also have a very fast response time (milliseconds) but a short discharge time compared to other battery storage technologies [7].

The Levelized Cost of Storage (LCOS) is a good metric in determining the viability of different energy storage options and is defined as the total lifetime cost of the system divided by the accumulated discharged energy [28]. It is similar to Levelized Cost of Energy (LCOE) but considers energy storage characteristics instead of electricity generation characteristics and is calculated by using the formula in (1) [29].

$$LCOS = \Sigma\, (C_t + OM_t + F_t)\, (1+r)_{-t}]\, [\Sigma\, (E_t)\, (1+r)_{-t}]^{-1} \quad (1)$$

where:

- C_t - capital expenditures covered in year t
- OM_t - costs of operation and maintenance in year t
- F_t - charging cost in year t
- E_t - discharged electricity (in MWh) in year t
- $(1+r)_{-t}$ - discount factor for year t

Li-ion battery LCOS in 2030 will decrease by one-third of their LCOS in 2015, with costs ranging from as low as \$100/MWh for energy arbitrage and primary response applications to as high as \$12,000/MWh for black start applications, where the battery energy storage system is used to restart power plant operations without requiring an external power supply following a network outage [30]. The largest proportion of the LCOS is occupied by investment costs. Charging costs cover the second largest proportion with 7% to 25%. The LCOS projections for Li-ion batteries presented in this paper disregards potential improvements and are only based on future investment cost reductions, and assumes that the lithium ion energy storage technology is likely considered as the most cost-efficient in a majority of applications by the year 2030.

2.2 Geographical Constraints

Another challenge for the M32 is the feasibility of the installation sites. The country is composed of more than 7,000 islands with varying topographies and areas could be densely populated which may logistics and installation of flywheel storage systems.

The route to the installation site as well as the site itself must be planned and surveyed before the flywheel is shipped to ensure its safety. Remote areas like islands have more limitations compared to highly accessible areas and will require both land and sea transportation like trucks and cargo ships. Organizing the logistics of the installation also entails heavy equipment required such as forklifts and cranes and whether they will be available for use. The installation site should be free of obstructions, so M32 flywheel arrays may be difficult to install inside highly urbanized areas.

The M32 weighs 5,000 kg and is 52 inches high and 54 inches wide. Therefore, it must be loaded and unloaded onto the transport by forklifts and should be properly secured during transportation to ensure its safety. In the installation site, all obstructions should be cleared, and a pit must be made before the construction of the underground capsule, where cranes are used to lower the M32 inside. The forklifts and the cranes must be of the appropriate tonnage to lift the flywheels safely. applications by the year 2030.

2.3 Avoided Costs

Battery-based energy storage systems are the common choice of energy storage system in the country with its readily available technical support and services. The onshore wind and utility-scale PV LCOE in the global scene has fallen in 2019 to \$44.00 and \$50/MWh, respectively, and the average LCOE for coal-fired plants is \$35/MWh [31]. Li-ion battery LCOS is expected to go down throughout the years which makes them a more attractive option to integrate with renewables or fossil fuel-based power plants in the country. Therefore, flywheels must be priced in such a way that when it is integrated with any power generation technology, the

LCOS of flywheels combined with the LCOE results in a lower cost than batteries or other alternatives.

3. OPPORTUNITIES

3.1 Flywheel Integration with Renewable Energy Sources

The country's demand for power will increase as the population is expected to continuously increase from around 109,581,000 people in the year 2020 [32] to 115,377,992 people in the year 2025 [33]. Companies are investing in renewable energy to reduce the cost of electricity in the Philippines over time as it is considerably high [34], reaching around P9.716 per kWh in 2019 [35]. The country is also decarbonizing because its energy sector suffered an increase in carbon intensity despite a decrease in per capita energy consumption by 7% between 2000 and 2014, [36].

The National Renewable Energy Program (NREP) was launched to address this issue, aiming to maximize cheaper renewable technologies like run-of-river hydro and biomass, manage more expensive renewable energy resources, and increase renewable energy capacities to around 15,000 MW by 2030 [37]. By the year 2020, the country should have added 7311.5 MW to the installed capacities of renewable energy, increasing the total installed capacity of 5,438 MW in 2010 to 12,749.5 MW [37]. However, data provided by the Department of Energy (DOE) shows that the installed capacities for renewable energy were only 7,399 MW in 2019 [38]. The slow addition was caused by certain delays in the issuance of support mechanisms, energy portfolios, and marketing programs though the NREP will be updated and the DOE will focus instead on renewable energy's share in the total generation of power [39].

Renewable energy is divided into two types: dispatchable renewables and non-dispatchable renewables. Dispatchability refers to a source's ability to be turned on or off on demand and to be adjusted depending on the amount required by customers [40]. Therefore, dispatchable renewables are those that are readily available for electricity generation such as hydro, geothermal, and biomass power plants [41]. Non-dispatchable renewables, also known as variable renewables, are those whose availability is not consistent like solar power and wind power [2,52].

The M32 can alleviate the variability and uncertainty of a solar or wind power plant's energy output by storing energy and then delivering it when the energy output drops. The M32 can also perform the same way during times that solar and wind energy is plentiful but in low demand. The M32 can deliver the stored energy longer than other flywheels because of its 4-hour discharge duration.

The Philippines has numerous power plants that rely on dispatchable renewable energy such as biomass, hydropower, and geothermal energy which is very advantageous as the country has an abundance of supply. The agricultural nature of the country as well as its forests gives it access to plenty of biomass resources [42]. The country has numerous sources of water which allow several hydropower plants to be constructed [37]. The number of geothermal plants is small but are planned to have the second largest renewable energy based on-grid installed capacity by 2030 [37]. The M32 can supplement the power generated by these plants to make them more reliable and efficient, as well as storing excess power during non-peak hours.

3.2 Support for Off-Grid Areas

The Philippines is an archipelago and one of the problems faced by the many islands and remote areas in the country is getting reliable power from the grid. The solution these areas use is to operate off-grid systems that provide their power separate from the main grid. There are more than 280 small island grids [43, 44] and they are powered by diesel generators [44, 45]. Among these small islands, only 36% of them are supplied with electricity for 24 hours [43, 44], but projects like USAID AMORE project, Household (Sitio) Electrification Program, and the Philippine Rural Electrification Service Project were successful in providing electricity to some off-grid areas [46]. Flywheels, along with renewable energy, can provide a more stable and economical supply of electricity in these areas by increasing the efficiency of their grids and reducing their reliance on diesel.

3.3 Leverages of Flywheel over Li-ion Batteries

Amber Kinetics has taken advantage of research that improves the performance of flywheel technology and their development of the M32 has opened more energy storage applications to flywheels, allowing it to be more easily compared to Li-ion batteries when it comes to supporting electric grids.

Table 1: Comparison of M32 Flywheel vs. Li-ion Batteries

Parameter	M32 Flywheel	Li-ion Batteries
Modularization and Scalability	✓	✓
Efficiency	✓	✓
Temperature - resistant	✓	
Recyclability	✓	
Long-Term Performance	✓	
Low Environmental impact	✓	
Lifespan	✓	

The M32 flywheel has many advantages over the li-ion batteries. Li-ion batteries require a protection circuit to prevent the battery catching fire [23], whereas the M32's use of a steel rotor to store energy means that fires are unlikely. The use of steel in its rotor also means the system is more recyclable, whereas there are several complex methods of recycling lithium-ion batteries as improper disposal may lead to fires [47]. Batteries used for grid storage are also more difficult to prepare for recycling and not all Li-ion batteries are collected for recycling in most countries [48]. Furthermore, steel reduces the environmental impact of the M32, whereas the acquisition of the materials necessary for the assembly of a lithium-ion battery has strong effects on the environment due to resource consumption and depletion, potential contribution to global warming, ecological toxicity and waste mismanagement, and prompt impacts to human health [49,51]. Lastly, the M32's performance doesn't degrade overtime, whereas Li-ion batteries suffer from ageing, which is the degradation of its storage capability with an increase in impedance due to either calendar and cyclic ageing caused by storage temperature or SOC level [50].

4. CONCLUSION

The landscape of energy generation, transmission, consumption, and storage has changed in the recent years. In the local setting, the Philippines is in the transition stage of going "green" or turning towards sustainable renewable energy and environment friendly transmission and storage systems. From the chemical nature of lithium-ion based batteries, flywheel energy storage systems with its mechanical structure has the potential to break through the market with its advantages over chemical-based storage systems. Hence, a 7.4% increase is projected between 2020 to 2027 in the global setting. Amber Kinetics currently has grid-scale FESS but with advances in technology, the possibility of developing a community or residential-scale platforms are foreseen in the next decade.

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