ISSN 2347 - 3983
Volume 10. No.6, June 2022
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter041062022.pdf
https://doi.org/10.30534/ijeter/2022/041062022

The Landscape of Flywheel Energy Technology in the Philippines

Roy Francis Navea[1], Marco Angelo Satiada[2], William Kyle Deveza[3], Portia Marie Mercado[4], Dino Dominic Ligutan[5], Samuel Mabanta[6]
[1]De La Salle University, Philippines, roy.navea@dlsu.edu.ph
[2]De La Salle University, Philippines, marco.satiada@dlsu.edu.ph
[3]De La Salle University, Philippines, william.deveza@dlsu.edu.ph
[4]De La Salle University, Philippines, portia.mercado@dlsu.edu.ph
[5]De La Salle University, Philippines, dino.ligutan@dlsu.edu.ph
[6]Amber Kinetics Philippines, Philippines, smabanta@amberkinetics.com

Received Date : May 2 , 2022 Accepted Date : May 29, 2022 Published Date : June 07, 2022

ABSTRACT

A 20-year Philippine energy roadmap was released by the Department of Energy that covers national renewable energy program, and a framework of energy storage systems. The energy plan entails increasing the share of renewable energy sources in the power mix and the use of energy storage systems to further increase efficiency and effectiveness of electric power delivery in the country. A flywheel-based energy storage system is emerging in the country and in this paper, the landscape of flywheel energy technology is discussed which includes the components of the flywheel system, other energy storage systems, development, and innovations in the local energy sector, as well as the opportunities and impact of flywheel energy technology in the Philippine economy. Moreover, flywheel technology implementation poses challenges in terms of research and development towards reaching its full potential and growth in fabrication, manufacturability, deployment, quality assurance, data analytics, and systems integration.

Key words: energy storage systems, flywheel, power, renewable energy

1. INTRODUCTION

Renewable energy is gaining grounds in the market leaving a decreasing utilization gap discrepancy with fossil-based resources. A 3% increase in the consumption of renewable energy is projected each year between 2018 and 2050 as it will replace coal in regions worldwide [1]. The Philippines intends to increase its capacities in the utilization of multiple renewable energy sources which includes wind- and solar-based systems. With the Philippine Renewable Energy Act of 2008, implementing rules and regulations were in-placed to quicken the development of renewable energy sources in the country and to expedite its adoption [2]. In addition, the National Renewable Energy Program (NREP) demonstrated strategies to meet the goals stated in the Renewable Energy Act of 2008 [3]. However, generation from wind and solar energy is intermittent due to the variability of the sources. Therefore, the instability of wind and solar energy introduces challenges in managing a reliable energy supply [4], [5].

Energy storage systems (ESS) are needed to solve the reliability problems of wind and solar energy generation [6], [7]. ESS technologies transform electrical energy from a grid to another form of energy for storage. The stored energy is converted to electrical energy when necessary [7]. Moreover, the form of the stored energy determines the classification of the ESS. Hence, an ESS can be chemical, electrical, electrochemical, mechanical, or thermal in nature.

One of the most common mechanical ESS is the flywheel energy storage system (FESS) [8]. The flywheel is one of the oldest mechanical devices. It stores kinetic energy using a rotating cylinder, or rotor, supported on a stator by bearings housed by a container [9], [10]. Flywheels are noted to have a long calendar life and cycle life, offering other numerous benefits which include high charging and discharging rates, quick response, and high round trip efficiency. In addition, the technology takes advantage about high energy efficiency, higher power densities, and low detrimental effects on the environment [11].

This paper aims to present the flywheel technology, current energy storage systems in the Philippines, challenges, and opportunities with the flywheel in the electricity sector of the country, and the economic impact of the flywheel technology in the next decade. Particularly, the paper shall describe and assess the capacity of the flywheel energy storage system in the Philippines.

1.1 Description of the Flywheel

The FESS is one of the numerous kinds of ESS. It is an electrical machine composed of a rotor, motor-generator, bearings, interface for the electronics, and a capsule housing.Figure1 shows the mechanical components of a flywheel energy storage device [11].

1.1.1 Rotor

Energy stored in flywheel is kinetic in nature. The stored energy is equivalent to half of the product of the moment of inertia and the square of the rotational speed of the rotor. Mathematically,

$$E = \frac{1}{2}J\omega^2 \quad (1)$$

where E represents kinetic energy, J is the moment of inertia and $\omega$is the rotational speed [12].

The maximum energy density depends on the shape factor, mass density, and themaximum flywheel stress. In equation form, it is:

$$e_m = K(\frac{\sigma_{\theta \cdot u}}{\rho}) \quad (2)$$

where e_m is the energy density per unit mass, K is the flywheel's shape factor, the σ maximum flywheel stress, and ρ is the mass density [12].

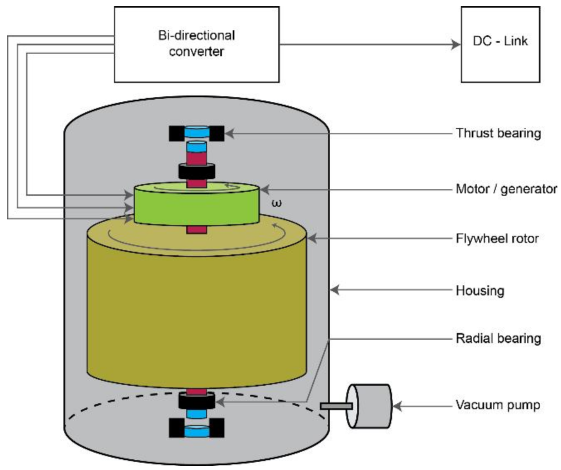

Figure 1: Structure and Components of a Flywheel Energy Storage Device [11]

1.1.2 Motor-Generator

The motor-generator is in-charge of the energy conversion task and handles the charging and discharging of the flywheel. When the machine works as a motor, it charges the flywheel and stores kinetic energy. Operating as a generator, it discharges the flywheel and converts the kinetic energy back to electrical energy [11], [12]. It is typically a high-speed permanent magnet machine It has an electromagnet where the field winding current is being adjusted to have full control and regulation of the motor voltage generated [13].

1.1.3 Rotor Bearing

The low-maintenance bearings support the rotor at a very minimal friction. These bearings come in a mechanical and in a magnetic assembly. Magnetic bearings are composed of permanent,and active magnetic bearings, and a superconducting magnetic bearing [11], [12]. Mechanical bearings are typically used for speeds under 20,000 rpm while magnetic bearings are favored for over 40,000 rpm [14].

1.1.4 Power Electronics Interface

The power electronics interface is essential for energy conversion and control. Aside from the motor/generator, a power controller and a variable-speed power electronics converter are parts of the power electronics interface. The power controller controls the system variables, and the converter is typically in a back-to-back configuration [11], [13].

An important function of the power electronics interface is to transform AC generator voltage to DC voltage. This DC voltage as a result of rectification gets fed to the inverter that converts it to usable AC voltage which is synchronized to the grid thus having full control over the power drawn from the flywheel. The process gets reversed once the flywheel starts in the charging mode facilitated by the bi-directional power flow feature of the power converter circuit [14].

1.1.5 Housing

Flywheels are housed for safety and optimal performance. The housing provides the flywheel with an environment with low gas drag and restricts the rotor in a case of a failure. It is usually made from high-strength materials like thick steel to contain flying projectiles when the rotor breaks. [11], [15]. Housing designs can be equipped with a vacuum enclosure for the reduction of windage loss of high-speed flywheels [16].

2. OVERVIEW OF ENERGY STORAGE SYSTEMS

As mentioned previously, there are other kinds of ESS aside from the FESS. An overview of the technologies of ESS, their benefits, and further descriptions according to their classification are reviewed.

ESS technologies can store a specific kind of energy, which is converted from electrical energy. The stored energy in the ESS can be transformed back to electrical energy when there is a need for it [7]. Therefore, ESS technologies can improve reliability of systems with renewable energy sources that produce intermittent supply and can support a faster adoption of renewable energy [15]. ESS is useful for peak shaving and load leveling functions[6]. With ESS, a continuous and flexible power supply can be maintained; thus, ensuring power quality during times of variations in demand. When voltage sags or power network failures occur, ESS can provide power to consumers, and it can alleviate congestion in the power grid [8]. The power generated from renewable energy sources is more efficient and can be more widely used as an alternative to the grid and consumers may pay lesser electricity cost. Installing ESS delays the need to upgrade transmission and distribution capacity [6] thus, diminishing harmful impacts on the environment [17].

2.1 Types of Energy Storage Systems

The diverse ESS technologies keep energy in distinct forms. Accordingly, ESS can be classified as electrical, chemical, electrochemical, thermal, or mechanical. Figure 2 illustrates the common types of ESS [8].

The efficiency of a Hydrogen chemical energy storage system is lower than both pumped hydro storage (PHS) and lithium-ion electrochemical storage. However, chemical energy storage can store energy in the TWh range for greater time periods [8].

Electrochemical energy storage systems include the use of secondary batteries or flow batteries which could be one of the following types: metal-air, lead-acid, nickel-metal hydride, nickel cadmium, lithium-ion,sodium nickel chloride, and sodium-sulfur cells. Meanwhile, flow batteries consist of redox and hybrid flow batteries. Secondary batteries make use of electrodes to charge and discharge energy, and flow batteries operate by dissolving electroactive species in liquid electrolytes [8].

The double-layer capacitor (DLC) used in electrical storage systems performs fast charging and discharging capabilities with high capacitance ratings. It also has nearly unlimited cycle stability and high-power capability. However, DLCs have high discharge rates and investment costs, making them unsuitable for long-term storage. Superconducting magnetic coils, the other technology used in electrical storage, have a high round trip efficiency and a very quick response time [8].

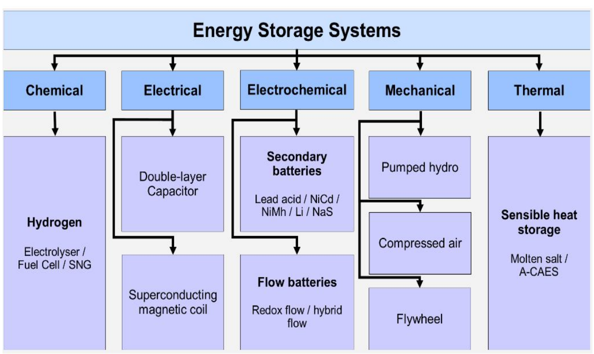

Figure 2: Classification of Electrical Energy Storage Systems according to the Form of Stored Energy [8]

PHS, compressed air energy storage (CAES), and FESS are the three kinds of mechanical energy storage systems. PHS has two water reservoirs that are in different altitudes to pump water from the lower reservoir to the upper during off-peak hours. This is the charging phase. The PHS discharges by letting the water flow into the lower reservoir and pass through a turbine that makes a generator produce electricity. A CAES system utilizes electricity to compress and store air in a system of pipes. Natural gas is combined with compressed air when necessary. This mixture is subjected to heat and expanded in a gas turbine. FESS uses a rotating cylinder to store kinetic energy [8].

Lastly, thermal energy storage systems use latent heat to supplement power to the load with renewable energy sources. Thermal energy is contained by a change in the temperature of the storage medium [8].

2.2 Energy Industries in the Philippines

ESS is penetrating global markets due to its significant benefits in different forms of technologies. In this section, the paper focuses specifically on the state of the ESS technologies in the Philippines and its prospects for the future in the country.

The Philippines through its Department of Energy (DOE) devised a framework for ESS in the electric power industry. In their framework, ESS technologies are recognized as a key element in the proposed Smart Grid Roadmap for the Philippines. The DOE lists the purposes of an ESS as a provision of ancillary services, managing the dawn of renewable energy in the country, deferring transmission and distribution facilities upgrade, mitigating transmission congestion, managing end-user demand, managing distribution utility demand, and forming a microgrid [18].

In the Philippines, numerous Battery ESS (BESS) have been installed in conjunction with the construction of renewable-energy power plants. Specifically, Fluence has commissioned two 20 MW / 20 MWh BESS for SMC Global Power Holdings Corp. Likewise, Fluence and SMC Global Power Holdings Corp. also deployed a 10 MW / 10 MWh ESS at a coal power plant in Zambales, the first in the country [19]. Furthermore, Aboitiz Power Corp., with partners Wärtsilä and Aboitiz Construction, has begun installing its first BESS in Davao de Oro [20]. Solar Philippines installed a 2 MWh Powerpack ESS from Tesla on a microgrid utilizing solar energy and a diesel generator as a backup [21]. A 2 MW / 2 MWh BESS was installed in Luzon by Meralco and Hitachi and is to be connected to the power grid of Meralco through a substation linked to a solar farm [22], [23].

SMC Global Power Holdings Corp. has partnered with ABB to install two 20 MW sites and a 40 MW site [24]. Aboitiz Power Corp. has planned to develop twelve BESS projects in the next ten years [20]. The Philippines is also set to host the first floating ESS in Southeast Asia. The floating ESS will be installed beside the 100 MW thermal power plant in the municipality of Maco in Davao de Oro and is a project of Therma Marine Inc. and Wärtsilä [25].

A pumped-storage project in Pantabangan, Nueva Ecija is planned by First Gen Hydro Power Corp. It is planned to have a maximum capacity of 120 MW from two 60 MW turbines [26].

2.3 FESS in the Philippines

The country is in its initial phase of adopting other storage systems aside from lithium-based batteries. A US-based company, Amber Kinetics, is spearheading this initiative by expanding its influence on the energy stakeholders, technology developers, innovators, and researchers.

Amber Kinetics installed the first long-duration FESS in the world. In the local scene, Amber Kinetics Philippines (AKP) established partnerships with De La Salle University and was able to build a facility inside its campus in Biñan, Laguna [27]. Figure 3 shows the flywheel innovation hub inside the campus vicinity as part of their academe-industry collaboration efforts. The company launched its product, the M32, a two-ton rotor made of steel for storing energy of up to 32kWh which can be utilized for microgrid, utility grid, and industrial applications [28].

As part of its policies to reinforce energy storage technologies, the Department of Energy (DoE) had recently engaged with Amber Kinetics to help realize the goal of clean energy transition through their energy storage solutions such as the flywheel technology [29]. The Development Bank of the Philippines (DPB) had granted a 750 million pesos loan to Amber Kinetics Philippines to aid in further development of its novel flywheel technology as well as to support its operational requirements for domestic and export sales. This aims to position the country as a leading development center for mechanical energy storage systems [30].

Figure 3: Flywheel Innovation Hub in De La Salle University-Laguna Campus

3. OPPORTUNITIES WITH FLYWHEEL TECHNOLOGY

In this section, the opportunities to implement the flywheel technology in the Philippines are presented. Moreover, the benefits of FESS are discussed, and different studies are cited as proof of the efficiency of FESS.

3.1 Philippines Energy Outlook and Current Situations

As part of the energy plan of the DoE of the Philippines, access to basic electricity for all Filipinos is aimed at the year 2022. Additionally, the DoE wants to improve the reliability of the power supply to match demand by 2040. Total electricity consumption in the country is expected to quadruple in 2040. Specifically, the grid at Luzon demands a total additional of 45,740 MW, the grid at Visayas needs an additional capacity of 8,564 MW, and the Mindanao grid needs 13,041 MW in 2040. Renewable energy is forecasted to be fifty percent of the total capacity mix in 2040 with a capacity of at least 20,000 MW [31].

The NREP targets a capacity of renewable energy in the Philippines to more than 30,000 MW by 2040 by increasing the capacity of hydropower, geothermal, wind, biomass,solar systems, and installing an ocean energy facility. Moreover, the NREP 2020-2040 focuses on the integration of storage systems with the development of renewable energy facilities. [31].

Currently, the Philippines, an archipelago, has multiple small islands that are powered by just diesel generators. The grids on the small islands experience power outages and blackouts regularly. Bertheau wrote in his research that solely relying on diesel generators is not feasible for the mentioned islands and hinders the aim to have universal electrification of the country by 2022. Consequently, he suggests that renewable energy sources with ESS must be utilized on the small islands [32]. In another study, Ahmed and Logarta proposed that integrating renewable energy and ESS with the installed diesel generators would stabilize the power supply at the small islands [33].

The paper has established that the renewable energy sources and ESS are expected to grow in the Philippines alongside myriad projects and investments done by local corporations. The FESS can be installed in the Philippines in-line with the framework and energy plan of the DoE as an alternative, matching the growing power demand in the country and providing reliable energy to consumers even in small island grids.

3.2 Advantages of FESS over other ESS

Table 1shows the characteristics of the different ESS technologies, particularly those mentioned in the framework of DOE and the previously discussed ESS technologies. The flywheel has a faster response time than both PHS and CAES. It also has a range of high efficiency scores of 80 % to 90 %, with Chen, Cong, Yang, Tan, Li, and Ding stating an efficiency range from 90 % to 95 % [7]. Furthermore, it has the highest typical cycle lifetime, besting other technologies by a factor of hundreds or thousands [8], [18].

The paper has demonstrated that the flywheel gives many benefits and is advantageous over its alternative technologies. Consequently, the flywheel is an efficient alternative to integrate with renewable energy sources as the growth of the latter is targeted by the Philippines. In the succeeding paragraphs, the paper cites different works by authors worldwide further demonstrating advantages and applications of the flywheel.

Table 1: Comparison of ESS Technologies [8]

ENERGYSTORAGESYSTEM	**PHS**	**CAES**	**FLYWHEEL**	**Li-ion**	**DLC**
RESPONSE TIME	minutes	minutes	less than seconds	less than seconds	less than seconds
ENERGY DENSITY (Wh / kg)	0.2 - 2	-	5 - 30	60 - 200	1 - 15
TYPICAL DISCHARGE TIME	hours	hours	seconds	hours	seconds
ENERGY-EFFICIENCY ηWh (%)	70 - 80	41 - 75	80 - 90	85 - 98	75 - 80
TYP. CYCLE LIFETIME (cycles)	> 15,000	> 10,000	2 x 10^4 - 10^7	500 - 10^4	10^4 - 10^5

The flywheel was commonly used for bridging the shift from one power supply to another and has an efficiency from 90 % to 95 %. Thus, the FESS can be integrated with hybrid power supplies [7]. In addition to having a high efficiency, flywheels have a long life and can have full charge-discharge cycles up to the thousands as noted by Bender [34]. FESS has notable advantages versusrechargeable batteries. To name a few, these include high power density, independently designed content of power and energy, multiple charge and discharge cycles, precise state of charge, and temperature independence [35]. The FESS was noted to have a rapid response, small contribution of hazardous waste, and longer life than rechargeable batteries [36]. It is estimated to have at least twenty-years of lifetime without performance decline [13]. In a critical review of the technology, applications and prospects of FESS done by Choudhury, it was highlighted that FESS technology holds many merits compared to other ESS technologies such as modularity, recyclability, quick response, ability to deliver large peak power, highly efficient, high-energy density, and long-life cycle [37].

Installing FESS to a wind-diesel hybrid power system smoothens the transient period of switching power sources and reduces diesel consumption. Whenever the wind generator could not meet the demand, the FESS would discharge [38]. The FESS can handle the peak load in microgrids [39]. The installation of FESS in Yamanashi prefecture in Japan contributed to the stabilization of the fluctuation of the output of a 1 MW photovoltaic plant [36]. Frequency control is one of the parameters in assessing FESS. It was found that the FESS has a very quick response and ramp rate, and that the FESS life is not shortened because of constant charge and discharge, unlike a battery [40].

Philippine-published literature about the flywheel in the context of the electricity sector is scarce as of the moment as this technology is just in its dawn in the local market. Flywheels could be integrated with renewable energy sources in the Philippines. Similar to Bertheau [32] and Ahmed and Logarta [33], the article mentioned that the flywheel can be used at off-grid areas and in the small islands of the Philippines [41]. The Amber Kinetics M32 was noted in [28], [41] to have key advantages over chemical batteries. Specifically, the product has a lower operation and maintenance costs, an round trip efficiency in DC configurations of 86%, unlimited daily cycling, and almost zero degradation in its lifetime, a fast response time in milliseconds, been designed to have a 30-year calendar life [28], lesser detrimental effects on the environment, and a longer lifespan than batteries [41].

4. ECONOMICS

The paper has discussed the opportunities of the flywheel in the Philippines along with the advantages and different applications of the flywheel. In this section, the economics regarding the flywheel is discussed. Generally, ESS can potentially reduce the operational expenses in managing the power grid. Likewise, the expense for regulating frequency may also be reduced [17].

In [42], projections regarding the future levelized cost of electricity storage technologies is discussed. Equation (3) was used to determine this costin USD per Megawatt hour and to predict the total lifetime cost of an energy storage system. The operation and maintenance cost appears as $O\ \&\ M\ cost$whilecharging cost and the end-of-life cost are also considered in the equation. The costs are assumed to start in the first year,n, with an investment cost, i, until the end of life of the energy storage system, N that is discounted by the discount rate r .

$$LCOS = \frac{i + \sum_n^N \frac{O\ \&\ M cost}{(1+r)^n} + \sum_n^N \frac{charging\ cost}{(1+r)^n} + \frac{end-of-life\ cost}{(1+r)^{N+1}}}{\sum_n^N \frac{Elec_{discharged}}{(1+r)^n}} \quad (3)$$

It was noted that the flywheel had the lowest LCOS among nine ESS technologies. Additionally, it found that the FESS was a competitive technology because of its low power-specific cost and better cycle life. FESS is expected to be one of the most used ESS technologies in discharge and frequency combinations along with PHS and batteries [42].

The levelized cost of electricity was used to compare the flywheel and battery considering the total system energy cost during the project duration [43]. It is mathematically given as:

$$LCOE = \frac{\left[\frac{i(1+i)^{t_s}}{(1+i)^{t_{s-1}}}\right][C_{NPC,total}]}{E_{served}} \tag{4}$$

where $LCOE$ stands for the levelized cost of electricity, inflation rate(i), the project duration(t_s), the total net present cost($C_{NPC,total}$), and the amount of electricity served to the load (E_{served}).

Different configurations of energy systems were simulated as a microgrid at Busuanga Island, Philippines. The configuration consisting of a solar photovoltaic, diesel, and a flywheel yielded a lower LCOE than the solar photovoltaic, diesel, and battery configuration. Similarly, it is also evident that a solar photovoltaic and flywheel setup has a lower LCOE than the corresponding solar photovoltaic and lithium-ion battery setup [43]. Table 2details the findings of the study.

Zakeri and Syri considered in their study the LCOE coming from ESS and the life cycle costs (LCC) of different ESS including PHS, CAES, FESS, electrochemical batteries, flow batteries, and supercapacitors. In addition, uncertainties were weighed by utilizing the Monte Carlo method. In their findings, the flywheel had the highest capital cost but had the lowest annualized LCC as depicted in Figure 4from [44]. Hence, the flywheel was concluded as the most economical ESS technology with lower operational costs in the power quality and frequency regulation applications when compared with the lithium-ion and lead-acid batteries.

Table 2: Island-based Optimal Energy System Configuration

SYSTEM CONFIGURATION	LCOE [USD / kWh]
Diesel	0.434
Solar photovoltaic / diesel	0.371
solar photovoltaic / diesel / lithium-ion battery	0.349
solar photovoltaic / diesel / flywheel	0.345
solar photovoltaic / lithium-ion battery	0.467
solar photovoltaic / flywheel	0.492

While the previous studies mentioned the LCOS and the LCOE of the flywheel, a bottom-up cost model for evaluating the levelized cost of the FESS is also available. In this study, the equipment design and sizing hugely influence the cost of the FESS. Results identified that a steel rotor has a cheaper capital cost and lower LCOS than a composite rotor for frequency regulation [42]. However, a rotor made from a combination of 70 % graphite whisker/epoxy material had a higher strength under constant stress of a factor of 17.6 over steel [46].

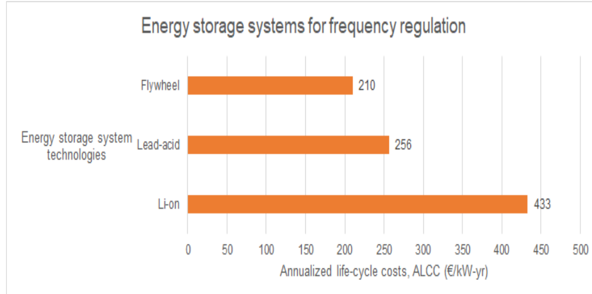

Figure 4: Annualized LLC for ESS systems in frequency regulation and power quality applications [44]

The flywheel offers economic benefits in addition to its competitive advantages over other ESS technologies. Thus, integrating flywheels to the utility grid, renewable energy sources, and hybrid systems in the Philippines is an economical alternative for reaching the goals of the energy plan of the country.

5. CONCLUSION

The world is expected to shift to renewable energy sources in the future. However, with renewable energy sources, power generation is unreliable and intermittent. Thus, ESS is required for improving the reliability of renewable energy. The flywheel is one kind of ESS. ESS generally can be utilized for peak shaving and load leveling, providing power during voltage sags or grid failures, and freeing congestion in grids. It, renewable energy power plants, and universal electrification are part of the energy plan of the DoE in the Philippines. Yet, the Philippines has many small islands that are powered exclusively by diesel generators, a hindrance to the universal electrification in the country. To solve the rising power demands and provide reliable electricity nationwide, the opportunity arises for the flywheel technology. The flywheel has been researched to be extremely efficient, scoring 90 % to 95 % values. Also, it has been used to control frequency, reduce transient periods, and supply power during peak demands. ESS typically reduces operating costs of the utility grid and the expense for regulating frequency. Specifically, the flywheel has low LCOS, competitive, and is the most economical technology for frequency regulation and power quality regulation.

ACKNOWLEDGEMENT

Grateful appreciation to the support of the Department of Science and Technology (DOST), Republic of the Philippines through its Philippine Council for Industry, Energy, and Emerging Technology Research and Development - Collaborative Research and Development to Leverage Philippine Economy (PCIEERD - CRADLE) program.

REFERENCES

1. **International Energy Outlook**. Available: https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf on May 2021, 2019.
2. **Republic Act. No. 9513**.Available:https://www.doe.gov.ph/national-renewable-energy-program?q=renewable-energy/republic-act-no-9513 on June 2021.
3. **National Renewable Energy Program**. Available: https://www.doe.gov.ph/national-renewable-energy-program on June 2021.
4. G. Notton, ML.Nivet, C.Voyant,C. Paoli,C. Darras,F.Motte, and A. Fouilloy.**Intermittent and stochastic character of renewable energy sources: Consequences, cost of intermittence and benefit of forecasting**, *Renewable and Sustainable Energy Reviews*,Vol. 87, pp. 96-105, May 2018.
5. D.Peralta, C.Canizares, and K.Bhattacharya. **Practical modeling of flywheel energy storage for primary frequency control in power grids**, in *2018 IEEE Power & Energy Society General Meeting*. Portland, Oregon, USA, 2018,pp. 1-5.
6. P.Medina,A.W. Bizuayehu, J.P.S. Catalão, E.M.G.Rodriguez, and J.Contreras.**Electrical energy storage systems: Technologies' state-of-the-art, techno-economic benefits and applications analysis,** in*2017 47th Hawaii International Conference on System Sciences*, Waikoloa, Hawaii, USA, 2017, pp. 2295-2304.
7. H. Chen,TN. Cong,W. Yang,C. Tan,Y.Li,andY. Ding.**Progress in electrical energy storage system: A critical review,***Progress in Natural Science*,Vol. 19, no. 3, pp. 291-312, March 2009.
8. **Electrical Energy Storage**.Available: https://www.iec.ch/basecamp/electrical-energy-storageon May 2021.
9. G. Genta.***Kinetic energy storage: Theory and practice of advanced flywheel systems.***Heinemann, London, UK: Butterworth, 1985.
10. D.Y.Goswami and F. Kreith.***Energy conversion.*** Boca Raton: CRC Press, 2007.
11. Amiryar, M.E., &Pullen, K.R.**A review of flywheel energy storage system technologies and their applications,** *Applied Sciences*, Vol. 7, no. 3, p. 286., March 2017.
12. S.M.Mousavi,F.Faraji,A.Majazi, and K. Al-Haddad.**A comprehensive review of flywheel energy storage system technology,** *Renewable and Sustainable Energy Reviews*,Vol.67, pp. 477-490, January 2017.
13. I.Hadjipaschalis,A.Poullikkas, and V. Efthimiou. **Overview of current and future energy storage technologies for electric power applications,** *Renewable and Sustainable Energy Reviews*, Vol. 13, no. 6-7, pp. 1513-1522, August 2009.
14. R. Östergård.**Flywheel energy storage: A conceptual study**, Uppsala University, Uppsala, Sweden, 2011.
15. A.S.A. Awad, T.H.M.El-Fouly,and M.M.A. Salama. **Optimal ESS allocation and load shedding for improving distribution system reliability**, *IEEE Transactions on Smart Grid*, Vol. 5, no. 5, pp. 2339-2349, September 2014.
16. X.Liand A.Palazzolo.**A review of flywheel energy storage systems: state of the art and opportunities,** *Journal of Energy Storage*, Vol. 46, p. 103576, February 2022.
17. **Benefits of Energy Storage**. Available:https://energystorage.org/why-energy-storage/benefits/ on May 2021.
18. **Providing a framework for energy storage system in the electric power industry**.Available:https://www.doe.gov.ph/sites/default/files/pdf/announcements/proposed-dc-providing-framework-for-ess-in-electric-power-industry.pdf on May 2021.
19. A. Colthorpe. **Fluence completes first projects in 470MW / 470MWh Philippines battery order.**Available:https://www.energy-storage.news/news/fluence-completes-first-projects-in-470mw-470mwh-philippines-battery-order on May 2021, 2021.
20. R.W. Domingo. **Energy giants installing mega batteries across PH.** Available:https://business.inquirer.net/321819/energy-giants-installing-megabatteries-across-ph on May 2021, 2021.
21. A. Colthorpe.**'NO MORE BROWNOUTS!': Philippines town hails arrival of Tesla battery.** Available: https://www.energy-storage.news/news/no-more-brownouts-philippines-town-hails-arrival-of-tesla-batteryon May 2021, 2018.
22. C. Keating.**Meralco and Hitachi inaugurate 2MW / 2MWh BESS in Philippines.** Available:https://www.energy-storage.news/news/meralco-and-hitatchi-unveil-2mw-2mwh-bess-in-philippines on May 2021, 2019.
23. J.B. Lagare.**Meralco close to 100% electrification target.**Available:https://www.manilatimes.net/2021/05/26/business/corporate-news/meralco-close-to-100-electrification-target/1800689 on May 2021, 2021.
24. Manila Standard. **ABB supplies Southeast Asia's largest battery energy storage system.**Available:https://manilastandard.net/mobile/article/355996 on June 2021, 2021.
25. Nicholasnhede. **Philippines to host South East Asia's first floating energy storage solution.**Available:https://www.powerengineeringint.com/smart-grid-td/energy-storage/philippines-to-host-south-east-asias-first-floating-energy-storage-solution/ on May 2021, 2021.
26. B.SuryadiandR. Verniastika. **ASEAN to push utilisation of storage technologies.** Available:https://theaseanpost.com/article/asean-push-utilisation-storage-technologies on June 2021, 2021.
27. The Philippine Star.**Amber Kinetics introduces flywheel energy storage systems in Philippines.**Available:https://www.philstar.com/business/2021/03/23/2086227/amber-kinetics-introduces-

flywheel-energy-storage-systems-philippines on May 2021, 2021.

28. **Amber Kinetics M32.**Available:https://amberkinetics.com/wp-content/uploads/2020/05/Amber-Kinetics-DataSheet.pdf on June 2021.
29. Business Mirror. (2021). **DOE seeks new technologies, engages flywheel energy storage company Amber Kinetics.** Available: https://businessmirror.com.ph/2021/06/03/doe-seeks-new-technologies-engages-flywheel-energy-storage-company-amber-kinetics/ on August 2021.
30. Development Bank of the Philippines (2021). **DBP grants P750-million credit line to boost renewable energy storage.** Available: https://www.dbp.ph/newsroom/dbp-grants-p750-million-credit-line-to-boost-renewable-energy-storage/ on August 2021.
31. **Philippine Energy Plan 2018-2040**.Available:https://www.doe.gov.ph/pep on May 2021.
32. P.Bertheau.**Supplying not electrified islands with 100% renewable energy based micro grids: A geospatial and techno-economic analysis for the Philippines,** *Energy*, Vol. 202, p. 117670, July 2020.
33. S.J.Ahmed and J.D.Logarta.**IEEFA Report: Electricity-Sector Opportunity in the Philippines.**Available:https://ieefa.org/ieefa-report-electricity-sector-opportunity-philippines/ on May 2021, 2017.
34. D.Bender. **Flywheels,** In*Energy Storage*, G.M. Crawley, Ed. Singapore: World Scientific,2017, ch. 7, pp. 249-289.
35. A.Buchroithner,A. Haan,R.Preßmair, M. Bader,B. Schweighofer,H.Wegleiter, and H.Edtmayer. **Decentralized low-cost flywheel energy storage for photovoltaic systems,**in *Proceeding of the 2016 International Conference on Sustainable Energy Engineering and Application*, Jakarta, Indonesia, 2016, pp. 41-49.
36. S.Mukoyama, et al. **Development of Superconducting Magnetic Bearing for 300 kW Flywheel Energy Storage System.***IEEE Transactions on Applied Superconductivity*,Vol. 27, no. 4, pp 1-4, June 2017.
37. S. Choudhury.**Flywheel energy storage systems: A critical review on technologies, applications, and future prospects.***International Transactions on Electrical Energy Systems*, Vol. 31, no. 9, e13024, July 2021.
38. S.SujithandV.Ramesh.**Reducing the transient active power from diesel generator using flywheel energy storage system in isolated wind-diesel hybrid power system,**in *Proceeding of the 2015 International Conference on Power, Instrumentation, Control and Computing*, Thrissur, India, 2015, pp. 1-4.
39. W. Su,T.Jin, and S.Wang.**Modeling and simulation of short-term energy storage: Flywheel,**in *2010 International Conference on Advances in Energy Engineering*, Beijing, China, 2010, pp. 9-12.
40. D. Peralta,C.Cañizares, and K.Bhattacharya. **Practical modeling of flywheel energy storage for primary frequency control in power grids,**in*2018 IEEE Power & Energy Society General Meeting*, Portland, Oregon, USA, 2018, p. 1-5.
41. I.K. Naco,X. Broncano,A. Go,R.F.Navea, and G.N. Santos.**Challenges and opportunities of flywheel energy storage systems in the Philippines,***International Journal of Emerging Trends in Engineering Research*,Vol. 8, no. 10, pp. 7047-7053, October 2020.
42. O. Schmidt,S. Melchior,A.Hawkes,and I.Staffell. **Projecting the future levelized cost of electricity storage technologies,** *Joule*,Vol. 3, no. 1, pp. 81-100, January 2019.
43. E.A.Esparcia Jr.,M.T. Castro,R.E.Buendia, andJ.D. Ocon.**Long-discharge flywheel versus battery energy storage for microgrids: A techno-economic comparison,***Chemical Engineering Transactions*, Vol. 76, pp. 949-954, October 2019.
44. B.Zakeriand S. Syri.**Electrical energy storage systems: A comparative life cycle cost analysis,***Renewable and Sustainable Energy Review*,Vol.42, pp. 569-596, February 2015.
45. Md.M. Rahman,E. Gemechu,A.O.Oni,andA. Kumar.**The development of a techno-economic model for the assessment of the cost of flywheel energy storage systems for utility-scale stationary applications,***Sustainable Energy Technologies and Assessments*,Vol. 47, p. 101382, October 2021.
46. M.A.Conteh and E.C. Nsofor.**Composite flywheel material design for high-speed energy storage,** *Journal of Applied Research and technology*, Vol. 14, no. 3, pp. 184-190, June 2016.