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Techno Economy Comparison of Conventional Generating Unit and Lithium Battery Energy Storage as a Primary Frequency Regulation of Variable Renewable Energy Penetrated Grid System, Case Study: Southern Sulawesi of Indonesia

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ABSTRACT

Integrating higher shares energy mix of variable renewable energy (VRE) technologies, such as wind and solar PV, in the energy transition process presents many challenges in its operation. One of the required services needed in this activity is the Primary Frequency Regulation (PFR). Many studies have studied various ways to provide PFR services, such as using the Conventional Generating Unit (CGU) and Lithium Battery Energy Storage (LiBESS). This paper presents several battery sizing methods used for comparison between the Levelized Cost of Electricity (LCOE) of a CGU and the Levelized Cost of Storage (LCOS) of a LiBESS, which used as PFR of a VRE penetrated grid system in a case study: the grid of southern Sulawesi, Indonesia. The results show that the LCOE of LiBESS is still below the LCOE of the CGU, but for projections in 2030, the LCOS LiBESS shows a competitive number compared to the LCOE of CGU.

1. Introduction

Many countries have started preparing infrastructure to accommodate various renewable energy types that currently exist to be applied in their country. That can be seen from the massive development of renewable energy. The proportion of world renewable energy has recently reached 18% in 2010 and is projected to increase by 26% in 2030 (Ferroukhi et al., 2015). One renewable energy that is most considered effective and efficient to reduce fossil fuels, carbon emissions, and increasing energy demand is solar and wind energy (Nehrir et al., 2011). With these advantages, it is also supported by the possibility of reducing costs in 2025, which will reach 43% for solar PV and 26% for onshore wind energy (IRENA, 2016).

Despite those advantages, solar and wind energy tends to be unstable due to the effect of wind speed and weather determined by natural conditions (Abbey & Joos, 2007). Because of their fluctuated output, wind farms tend to affect the grid voltage and frequency, furthermore generating technical issues including interconnection problems, power quality, reliability, protection, delivery, and generation control (Teleke et al., 2009). The electricity power provider will face many challenges because of massive VRE penetration, especially wind power (Abbey & Joos, 2007).

The Southern Sulawesi grid of Indonesia managed by PT PLN (Persero) also tries to anticipate the penetration of Jeneponto/Tolo WPP (Wind Power Plant) and Sidrap WPP in their grid system. The most common method to solve this problem is to use conventional power plants that have a fast response feature as a reserve (Liu & Tomsovic, 2012) and use energy storage systems such as batteries as wind power buffers (Spahic & Balzer, 2006).

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As one of the developing countries, Indonesia has committed to the Paris Agreement (COP21, 2015) through its energy policy sets a target of renewable energy in the National energy mix of 23% of the total national energy mix in 2025 and 31% in 2050. One of them is the Wind Power Plant (WPP) penetration in the southern Sulawesi grid.
The southern Sulawesi grid is home to WPP Sidrap (70 MW) and WPP Tolo (72 MW), with a total VRE penetration of 130 MW. The southern Sulawesi grid has an installed power of 2107.4 MW and a peak load of 1391.2 MW (PLN, 2019). With that condition, several impacts will arise. One of them is a decrease in the quality of the frequency distribution. The electricity power provider is trying to overcome this problem by providing a large spinning reserve for frequency regulation and causing cost improvement.
This paper will focus on the comparison between the LCOE of the CGU as PFR compared to the LCOS of a LiBESS for the same service. Besides, it discussed the sizing method from various references as input for battery LCOS calculations.

2. Methods

Determination of the LCOS is obtained through several steps, including calculating the battery power capacity required for the grid with three methods, using the percentage of the droop governor, the percentage of VRE installed in the grid, and based on the range of the PFR to be accommodated. A lithium battery is chosen in this paper because of the best performance among other types of batteries (Świerczyński et al., 2013).

2.1. PFR Service Requirements

Some specific requirements in PFR, for example, are described by UCTE (Union for the Co-ordination of Transmission of Electricity) in regulating the Transmission System Operator (TSO) as shown in Table 1.

Table 1.
UCTE PFR Service Requirement

Description	Requirement
Activation	Automatic joint action, locally
Start	3-5 Sec
Fully activated	<30 sec
End	> 15 min
Payment mechanism	Availability payment

Source:(UCTE, 2004)

Generally, there is no special requirement to provide PFR service except for a time duration set to a minimum of 15 minutes and power linearity where power must increase linearly in response to a frequency deviation. Furthermore, this requirement has been met by both CGU and LiBESS.

2.2. LiBESS Sizing Methods

2.2.1. Percentage of Governor Droop Method

Kim et al. (2018) aim to balance the grid frequency using three variables according to formula (1), including Frequency Gain, Governor Droop, and Frequency. The governor droop is a percentage value that states a power plant's sensitivity to respond to the system frequency. The smaller the value, the faster it responds, and vice versa. So that if there is a generator that has a slow response to frequencies, a large BESS capacity is required.

$$P_{BESS}\,(MW) = F_g\left(\frac{MW}{Hz}\right) \times G_d\,(\%) \times f\,(Hz) \qquad (1)$$

where: P_{BESS} is the BESS power capacity, F_g is the frequency gain, G_d is the Governor Droop, and f is the System Frequency.

2.2.2. Percentage of VRE Penetration Method

There are four references chosen to calculate the BESS capacity from many available reference sources based on WPP penetration as follows:

Table 2.

BESS Capacity Calculation Method form Reference

Calculation Method	Finding
Techno-Economic	Of the 100 MW WPP installed, 34MW and 40 MWh of BESS capacity are needed. (34%)
Technical indicator	Of the 50 MW WPP installed, 15-25% of the BESS capacity is required. (7.5-12.5 MW)
Technical indicators	From 34 MW of WPP installed, 4 MWh of BESS capacity is required. (35%, if DoD = 80% Eff = 95% duration= 15 minutes)
Techno-Economic	From 50 MW of WPP installed, 5,3MW and 3MWh BESS capacity required. (10,6% duration= 25 minutes)

Source: (Brekken et al., 2010); (Teleke et al., 2009); (Etherden & Bollen, 2013); (Johnston et al., 2015)

Based on Table 2, it can be averaged that the ratio of the BESS capacity to the installed WPP capacity is around 10-35%. So this value will be used to determine the BESS capacity on the southern Sulawesi Grid. Here is the formula:

$$P_{BESS}\,(MW) = 35\,\% * C_{WPP} \qquad (upper\ limit) \tag{2}$$
$$P_{BESS}\,(MW) = 10\,\% * C_{WPP} \qquad (lower\ limit) \tag{3}$$

where: $\boldsymbol{P_{BESS}}\,(\boldsymbol{MW})$ is the BESS power capacity and $\boldsymbol{C_{WPP}}$ is the WPP installed capacity.

2.2.3. Range of PFR Method

Based on the Southern Sulawesi grid code (MEMR, 2015), this grid has a system stiffness indicator at 79,92 MW/Hz at peak load and 65 MW/Hz outside peak load time. (PLN, 2019) Figure 1 shows that the normal frequency range on the southern Sulawesi Grid is 49.8-50.2 Hz. According to the grid code, the first stage Under Frequency Relay (UFR) is set to 49.0 Hz. There is a frequency range of 0.8 Hz from normal frequency conditions.

$$\boldsymbol{P_{BESS} = S_{Sys}\left(\frac{MW}{Hz}\right) \times f_{range}\,(Hz)} \tag{4}$$

where: P_{BESS} is the BESS power capacity, S_{Sys} is the System Stiffness, and f_{range} is the PFR frequency range.

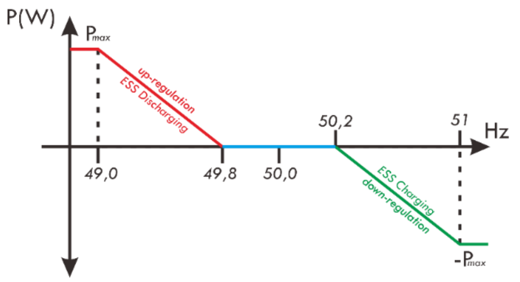


Fig. 1.

Typical PFR characteristic

2.3. Primary Frequency Control Operation Scheme

The PFR service operation scheme is determined based on the requirement for electrical energy (MWh), which is calculated from historical data of the frequency distribution in the Southern Sulawesi grid every day (PLN, 2019) according to equation 5 as follows:

$$W_{need} = \sum \Delta f_{req}(Hz) \times S_{sys}(\frac{MW}{Hz}) \times t_{req}(H) \quad (5)$$

where: W_{need} is the Daily energy needed, Δf_{req} is the deviation in operating frequency at the time of BESS discharge (49.0 - 49.8 Hz) with the frequency regulation target of 49.8 Hz, S_{sys} is system stiffness. In this calculation, using the most considerable value at peak load time as a safety factor, and t_{req} is the time interval between sampling frequencies, assumed that the frequency value is constant according to the last sampling results.

Furthermore, determining the annual energy requirements is calculated using the most significant daily energy needs, where the number of days in a year was set at 365 days.

2.4. CGU Capacity Calculation

In this study, a Natural Gas Open Cycle (NGOC) is chosen to compete with LiBESS to provide the PFR services for the Southern Sulawesi grid system. NGOC was chosen due to the gas turbine's response to rapid frequency changes (Undrill, 2018) and the Southern Sulawesi grid system has 315 MW of NGOC as both load follower and Baseload.

After determining the type of CGU, another thing that needs to be considered in determining the optimal NGOC capacity according to the required operating scheme. It also to be considered that determining the optimal capacity will affect the NGOC electricity production costs.

Based on the above considerations, the first step in determining NGOC capacity is to equate the NGOC capacity value with the battery capacity. The next step is to test the fairness of NGOC electricity production costs by calculating the NGOC capacity factor (CF) and comparing the results with the reference value (EIA, 2020) (Lazard, 2020a), which is NGOC CF as a peaker type generator. If the CF value is lower than the reference value, the NGOC capacity is recalculated based on the reference CF value. This needs to be done to obtain an economically reasonable NGOC cost and ensure an equal comparison between NGOC and LiBESS.

2.5. Financial Analysis

In this study, the cost of producing electricity from conventional fossil energy generators will be compared with lithium battery storage technology. The method of calculating the cost of electricity production used is the calculation of costs during the project cycle or LCOE for conventional fossil energy generation (Timilsina, 2020) and LCOS for lithium battery storage technology (Jülch, 2016).

The value of LCOE and LCOS is the sum of all investment and operating costs during the project cycle divided by the production of electricity generated. The approach used in this study is to use annuity calculations where the investment cost is averaged per year (Lai & McCulloch, 2016; Timilsina, 2020). Furthermore, it is assumed that operational costs do not change from year to year. Likewise, the value of electricity production is supposed to use the same value according to the field survey data. As for the technical and financial assumptions data used as input data in cost calculations, it is endeavored to use market data if possible or to use data from a literature study carried out.

According to equations 7 and 8, the LCOS calculation formula is a derivative of the previous research method (Jülch, 2016; Jülch et al., 2015). LCOS is the sum of the total CAPEX costs averaged per year, both the initial and additional investment value as well as the annual operating costs or A_t consisting of OPEX and charging costs reduced by the residual value divided by the energy output from the battery. The residual value or R_t in this study is assumed

not to remain at the end of the period. Maintenance costs or OPEX are a percentage of the total CAPEX. Meanwhile, the charge is the multiplication of the battery input energy or W_{in} with the electricity rate or C_{el}.
Battery input energy can be calculated using equation 3 by considering the output energy of the battery or W_{out} and the efficiency of the storage system, which consists of battery efficiency or η_{bat} and inverter efficiency or η_{inv} and monthly self-discharge energy, which is the multiplication of the self-discharge r_{sd} per C_r capacity. The method of calculating the NGOC generating capacity is according to equation 6 where the magnitude of the generating capacity depends on the energy requirements to fulfill the PFR service, and the CF value of the generator is multiplied by the operating hours a year (Borin et al., 2010).

$$LCOE/S_{Annuitzing} = \frac{Ann\ (Cost)}{Ave\ (Output)} = \frac{\left(\sum_{t=0}^{n} \frac{CAPEX}{(1+i)^n}\right)\left(\frac{r}{(1-(1+i)^{-n})}\right) + A_t}{W_{out}} \tag{7}$$

$$A_t = OPEX + C_{el}, W_{in} - R_t \tag{8}$$

$$W_{in} = \frac{W_{out}}{\eta_{bat}\eta_{inv}{}^2} + 12\frac{months}{a} \times C_r \times r_{sd} \tag{9}$$

2.5.1. LCOE & NGOC Model

The LCOE and LCOS calculations with the annuity approach (Lai & McCulloch, 2016; Timilsina, 2020) use the same formula as equation 1, but with a slight adjustment to the annual operating costs according to equation 10. The annual operating costs of conventional fossil energy generators or CGU consist of annual operating and maintenance costs or a percentage of the total CAPEX plus primary energy costs. The primary energy cost is the multiplication of primary energy consumption volume with the unit price of primary energy or. The amount of primary energy volume is determined from the heating value of primary energy or HHV, the efficiency of the CGU or generating engine, and the amount of electricity production or according to equation 11.

$$A_t = M_t + F_t \tag{10}$$

$$F_t = \frac{W_{out}}{HHV \times \eta_{NGOC}} \times F_c \tag{11}$$

2.5.2. Technical and Financial Data

The following is technical data (Table 3 and Table 4) and financial data (Table 5 and Table 6) which are used as input parameters for calculating the LCOS Lithium ION Battery and LCOE CGU:

Table 3 :Lithium ION battery technical data input

Technical Data	Symbol	Unit	Value
Inverter Efficiency	h_{inv}	%	95,00
Battery Efficiency	h_{bat}	%	95,00
Self Discharge Rate	r_{sd}	%	1,00
Depth of Discharge	DoD	%	80,00
Calendar Lifetime		years	20
Warranty @DoD		cycle	7.000

Source: (Jülch, 2016; Jülch et al., 2015)

Table 4: CGU technical data input

Technical Data	Symbol	Unit	Value
Life Time NGOC		Years	20
Efficiency	η_{NGOC}	%	36%
Heat rate	HHV	btu/ft3	950
MWh to MMBTU Conversion Factor		-	3,41

Source: (Handayani et al., 2019)

Table 5: Lithium ION battery financial data input

Financial Data	Symbol	Unit	Value
CAPEX Inverter	I_{Inv}	\$/kW	51,64,80
CAPEX Battery	I_{Batt}	\$/kWh	166,186,272
OPEX	M_{Inv}	\$/kW	2
Interest Rate	WACC	%	8
Electricity Tariff	Cel	Rp/kWh	996,74

Source: (Jülch, 2016; Lazard, 2020b; MEMR, 2020)

Table 6: CGU financial data input

Financial Data	Symbol	Unit	Value
CAPEX CGU	I_{NGOC}	US\$/kW	700
Fixed OM	FM	USD/kW	18,0
Variable OM	VM	USD/MWh	1,00
Interest Rate	WACC	%	8
Harga Satuan EP	Fc	USD/MMBTU	7

Source: (Handayani et al., 2019; Jülch, 2016)

2.5.3. The projection of LCOS in 2030

The projection of LCOS in 2030 is useful information for the battery's economic value in the future. The parameters used for calculating LCOS in 2030 are described in Table 7 and Table 8:

Table 7: Lithium ION battery technical data input in 2030

Technical Data	Symbol	Unit	Value
Depth of Discharge	DoD	%	100,00
Warranty @DoD		cycle	10.000

Source: (Jülch, 2016)

Table 8: Lithium ION battery financial data input in 2030

Financial Data	Symbol	Unit	Value
Learning Rate Battery	LR	%	19
CAPEX Inverter Decrease Ratio			0,75

Source: (Curry, 2017; Jülch, 2016)

Battery investment data in 2030 is calculated using a one-factor learning model according to equation 12 and 13 (Handayani et al., 2019):

$$K_t = K_0 \times \left(\frac{C_t}{C_0}\right)^{\beta} \tag{12}$$

$$\boldsymbol{Learning\ Rate\ (LR) = 1 - 2^{\beta}} \tag{13}$$

where: K_t is the investment cost in year t, and K_0 is the current investment cost, while b is the learning parameter index calculated from the value of the learning rate.

The inverter investment data is calculated using the inverter cost reduction ratio, which is calculated by comparing the current inverter price with the 2030 inverter price (Jülch, 2016).

3. Result and Discussion

3.1. BESS Capacity Calculation Results

The following is the calculation result of BESS capacity from several methods used:

Table 9: BESS Capacity Calculation Results

Method	Power BESS (MW)		Energy BESS (MWh)	
	Peak Hour	Off-Peak	Peak Hour	Off-Peak
Governor Drop (1)	199,8	162,5	65,72	53,45
15% VRE (2)	19,5		6,41	
30% VRE (3)	45,5		14,97	
PFR (4)	63,94	52	21,03	17,11

Table 9 shows the BESS power capacity and energy capacity from three calculation methods for the Southern Sulawesi grid system. Where the highest power capacity is 199.8 MW, and the lowest is 19.5 MW. In contrast, the highest battery energy capacity is 65.72 MWh, and the lowest is 6.41 MWh. The methods that produce the largest to low battery capacity are the Droop Governor, PFR, VRE 30%, and VRE 15%.

The C-Rate value of the battery is 0.25, so it can support a minimum PFR service requirement of 15 minutes. With a C-Rate value of 0.25, the battery used is classified as a high power type.

Furthermore, the battery capacity value that has been calculated in table 9 will be tested whether it can meet the energy needs of the PFR service in the Southern Sulawesi system.

3.2. Result of calculation of output energy for PFR service

The results of energy output are taken from the highest energy needs per day within 1 year, where the highest demand data in the southern Sulawesi grid system in 2019 occurred on 7 September 2019 with data as in Table 10.

Table 10: Frequency Distribution Data on 7 September 2019 And Energy Needs For PFR

No	frequency (Hz)	Number of Data (s)	Δ Freq (Hz)	Energi Equivalent (MWh)
1	49,5	36	0,3	0,24
2	49,52	39	0,28	0,24
3	49,54	59	0,26	0,34
4	49,56	75	0,24	0,40
5	49,58	46	0,22	0,22
6	49,6	155	0,2	0,69
7	49,62	205	0,18	0,82
8	49,64	363	0,16	1,29
9	49,66	588	0,14	1,83
10	49,68	537	0,12	1,43
11	49,7	736	0,1	1,63

12	49,72	924	0,08	1,64
13	49,74	572	0,06	0,76
14	49,76	1293	0,04	1,15
15	49,78	1673	0,02	0,74
16	49,8	2080	0	0,00
Daily energy requirements				13,43
Annual energy requirements				4901,8

Source: (PLN, 2019)

Table 10 shows the total energy demand per day for PFR is 13.43 MWh or 4901.8 MWh /year. This data will be used to determine the battery operation as a number of cycles per day and the NGOC operation as the CF value.

Table 11: Battery and NGOC Operation

Method	Capacity (MW)	Cycle per day	Lifetime (years)	CF NGOC (%)
Gov Peak Hour	199,8	0,27	20	0,28
Gov Off Peak	162,5	0,33	20	0,34
PFR WBP	63,9	0,84	20	0,88
PFR LWBP	52	1,03	19	1,08
VRE 15%	19,5	2,75	7	2,87
VRE 30%	45,5	1,18	16	1,23

3.3. NGOC Capacity Calculation Results

In Table 11, the battery cycle pattern varies from 0.27 to 2.75, where the largest battery capacity, the number of cycles per day, is getting smaller. Otherwise, the number of the smallest battery capacity cycles is getting bigger. The bigger the cycle means higher battery utilization, but it should also be considered because some manufacturers require a guaranteed guarantee if the number of cycles is not more than once a day. The number of cycles will also affect battery life, where higher cycles per day will lower the battery life.

The CF NGOC value in table 10 varies between 0.28-2.87%. The highest CF value for the lowest capacity (19.5 MW) is 2.87%. Then, The lowest CF value for the highest capacity (199.8 MW) is 0.28%. The greater the NGOC capacity, the lower the CF value, so that the generator utilization will be lower. The NGOC capacity, of course, will affect the economic value of NGOC. Unlike the Battery, CF NGOC is getting higher, which does not affect the NGOC's lifetime because the utilization value is not more excellent than 100%, or it is still in the NGOC operating range.

To calculate NGOC capacity, it takes a value of Power Capacity (MW) and energy consumption (MWh), which is equal to the Power Capacity and energy consumption of BESS. Based on the NGOC operating pattern calculation in Table 11 and with the same total energy requirement as BESS, which is 4901.8 MWh. The NGOC Capacity value can be calculated using equation 6 so that the NGOC capacity value is obtained in Table 12.

Table 12: NGOC Capacity

Method	NGOC Capacity (MW)	Throughput (MWh/yr)	CF NGOC (%)
Gov WBP	199,8	4902	0,28
Gov LWBP	162,5	4902	0,34
PFR WBP	63,9	4902	0,88
PFR LWBP	52	4902	1,08
VRE 15%	19,5	4902	2,87
VRE 30%	45,5	4902	1,23
Lazard	5,6	4902	10
IEA	4,95	4902	11,3

3.4. LCOS Calculation Result

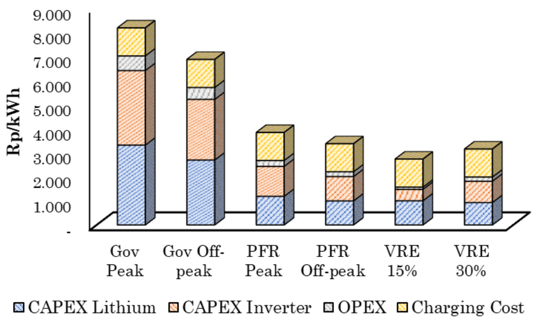
The main objective of this paper is to obtain the LCOS value. Then it will be compared with the LCOE CGU value in the South Sulawesi grid system. 6 results from 3 battery sizing methods were tested at this stage with technical data input and financial data and using equation 7 to get the LCOS value as in Table 13.

Table 13: LCOS Result

No	Description	Symbol	Unit	Method					
				Gov Peak	Gov Offpeak	PFR Peak	PFR Offpeak	VRE 15%	VRE 30%
1	Calendar Life	calendar t_{batt}	years	20	20	20	20	20	20
2	Cycle Durability at DoD	DoD Cy	cycle	7.000	7.000	7.000	7.000	7.000	7.000
3	Annual Operation	Ann Cy	cycle	98	121	307	377	1.006	431
4	Lifetime Battery	t_{batt}	years	20	20	20	19	7	16
5	Storage Unit Capex	I_{batt}	ε/kWh	166	166	186	186	272	186
6	Discharging Unit Capex	I_{inv}	ε/kw	51	51	64	64	80	64
7	Discharging Unit Opex	M_{inv}	% of CAPEX /years	2	2	2	2	2	2
8	WACC	WACC	%	8	8	8	8	8	8
9	Rated Capacity	C_r	kWh	65.724	53.454	21.032	17.105	6.414	14.967
10	Annual Storage Unit CAPEX	Ann I_{batt}	ε	1.111.221	903.771	398.433	334.731	336.508	312.121
11	Rated Power	P_r	kW	199.800	162.500	63.936	52.000	19.500	45.500
12	Total Discharging Unit CAPEX	Ann I_{inv}	ε	1.037.854	844.100	416.769	338.964	158.889	296.594
13	Total OPEX annual	Ann M_{inv}	ε	203.796	165.750	81.838	66.560	31.200	58.240
14	Annual Energy Discharge	W_{out}	kWh	4.901.829	4.901.829	4.901.829	4.901.829	4.901.829	4.901.829
15	Charging Cost	$C_{charging}$	kWh	1.164	1.164	1.163	1.163	1.163	1.163
16	LCOS wo charging cost	$LCOS_{woc}$	ε/kWh	0,48	0,39	0,18	0,15	0,11	0,14
17	LCOS wo charging cost	$LCOS_{woc}$	Rp/kWh	7.008	5.700	2.672	2.205	1.568	1.987
18	LCOS	LCOS	Rp/kWh	8.172	6.864	3.835	3.368	2.731	3.149

Based on Table 13, the highest LCOS value is 8,176 Rp/kWh for a battery capacity of 199.8 MW, and the lowest is 2,731 Rp/kWh for a battery capacity of 19.5 MW. At the highest LCOS value, the lowest number of battery cycles per year was 98 times, while for the lowest LCOS value, the highest number of battery cycles was 1,006 times per year. So the higher the battery utility value, the lower the LCOS value. The battery's lifetime value is also inversely proportional to the utility, where the more often the battery is used, the faster battery replacement is required. For the highest and lowest utility LCOS values, the battery can be used up to 20 years, while for the lowest and highest utility LCOS values, the battery should be replaced after seven years. Based on Figure 2 and Table 13, it can be analyzed that the battery charging cost tends to be constant for all battery capacity values. The minor difference related to charging charges is due to the insignificant effect of battery self-discharge.

Fig. 2 Cost breakdown LCOS of LiBESS



Then, the decrease of LCOS is dominant because the annual CAPEX value decreases, which is influenced by the increased utility value. When the LCOS is lower, the charging cost portion will be more significant because its value tends to be constant. For the lowest LCOS value, the charging cost portion is close to 50% of the total cost. In this case, of course, if the charging cost value can be lowered, the effect on the decrease in LCOS will be significant. This opportunity is open to power companies that manage the system because battery charging can be managed using low-cost fuel generators or baseload generators. The electricity production costs are lower than the system costs, which are the average cost of all generators.

3.5. LCOE NGOC Calculation Result

Based on LCOE NGOC capacity calculation, the NGOC power plant's utilization tends to be lower than the typical base practice, resulting in an unreasonable electricity production cost. Therefore in this research, it is assumed that the NGOC power plant also provides peak load service beside PFC. Hence, LCOE NGOC is calculated based on secondary data with 10% and 11,3% capacity factor.

The highest LCOE NGOC is 2.610 Rp/kWh for a 10% capacity factor, and the lowest is 2.439 Rp/kWh for an 11,3% capacity factor. Moreover, from the cost breakdown of LCOE NGOC as per figure 3, besides the investment cost, the fuel cost significantly contributes to the increase in the total cost.

Table 14: LCOE NGOC

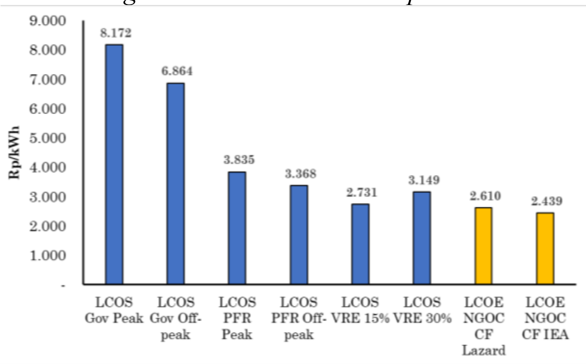
Description	Symbol	Unit	Lazard	IEA
Plant Capacity	C_{NGOC}	MWe	5,60	4,95
Capacity Factor	CF	%	10,00%	11,30%
Fuel Consumption	V_{NGOC}	MMBTU	48.906	48.906
Total Capex	Total I_{NGOC}	Mill USD	3,92	3,47
Annual Fuel Cost per kWh	Ann C_{fuel}	Rp/kWh	1.107	1.107
LCOE	LCOE	Rp/kWh	2.610	2.439

3.6. LCOS LiBESS and LCOE NGOC comparison

Figure 4 show a comparison of LCOS LiBESS and LCOE NGOC calculation result. The lowest LCOS of LiBESS is higher than the highest LCOE NGOC. Therefore, NGOC is more economical than LiBESS. Interestingly the lowest cost of LiBESS is close to the highest NGOC, which is 2.731 Rp/kWh compare to 2.610 Rp/kWh. The LiBESS charging cost depends on the electricity tariff that is above the electricity grid production cost and economic baseload power plant.

Nevertheless, NGOC's capacity is calculated to be 5,6 MW and 4,95 MW, which is lower than the smallest LiBESS. From the technical aspect view, the LiBESS is more robust than NGOC since if there is a large frequency dropping, LiBESS with larger capacity will smoothly handle the system compare to the NGOC power plant. Furthermore, LiBESS also can provide PFR service at a higher frequency (more than 50 Hz) with charging capability.

Fig 3. LCOS dan LCOE comparison



3.7. LCOS projection in 2030

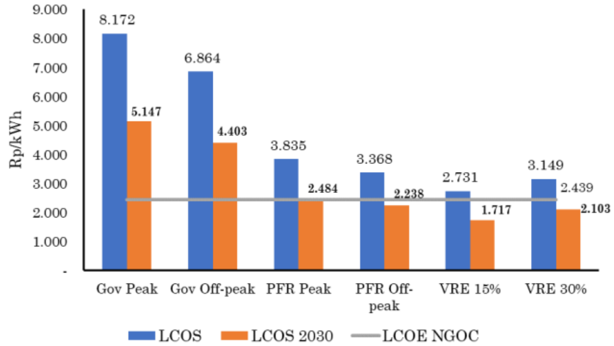
The investment projection cost uses equations 12 and 13, with a 19% learning rate. The LiBESS investment expenditure currently at 166-272 USD/kWh and will be lower to 75,83-124,25 USD/KWh in 2030. This investment projection data will be used as input data to calculate LCOS projection in 2030 besides the technical data such as DoD and Warranty Cycle as per table 7. DoD data increase from 80% to 100%, and the warranty cycle increase from 7000 to 10.000 cycle for LCOS projection calculation.

Tabel 16: LiBESS Investment Expenditure Projection 2030

Methods	CAPEX Battery (USD/kWh)	CAPEX Battery 2030 (USD/kWh)	D %
Gov Peak	166,00	75,83	-54,32
Gov Offpeak	166,00	75,83	-54,32
PFR Peak	186,00	84,96	-54,32
PFR Offpeak	186,00	84,96	-54,32
VRE 15%	272,00	124,25	-54,32
VRE 30%	186,00	84,96	-54,32

Figure 6 shows The LiBESS LCOS projection calculation result. From all LiBESS alternatives, the LCOS projection calculation result shows that 3 LiBESS options with PFR LWBP, VRE 30%, dan VRE 15% method are lower than the lowest LCOE of NGOC. Therefore, in 2030 LiBESS is already economically competitive from a financial aspect view.

Fig 6. Currently and Projection LCOS of LiBESS with the lowest LCOE of NGOC comparison



4. Conclusion

This research mainly focused on comparing LCOS of LiBESS and LCOE of CGU for providing PFR service in Southern Celebes Grid that is integrated with the wind farm. There are six different methods used to determine LiBESS capacity. LiBESS LCOS calculation for all capacity options shows that the lowest LCOS currently at 2.735 Rp/kWh compare to the highest LCOE NGOC at 2.610 Rp/kWh. The cost difference between LiBESS and NGOC is 125/kWh. Therefore, NGOC is more economical than LiBESS.

By 2030 the investment expenditure of LiBESS will be lower than 50% compare to the current price and further affect the LCOS from 3 of 6 different sizing methods of LiBESS lower than the lowest cost of currently LCOE of NGOC. Therefore by 2030, LiBESS is more economical than the NGOC. Besides that, LiBESS will be more attractive since fossil fuel price is also predicted to increase in the future. The calculation results also show that the most dominant factor affecting the LCOS of LiBESS is charging cost. The change of the tariff scheme can be a key to lower the LCOS of LiBESS below the LCOE of NGOC.

Currently, NGOC can still be an option for the Southern Celebes grid system. However, in the future, LiBESS may shift the role of NGOC to provide PFR service for the grid even though it competes with NGOC with a high Capacity Factor.

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