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Optimal Sizing of Battery Energy Storage System in Commercial Buildings Utilizing Techno-economic Analysis

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ABSTRACT

Finding the correct battery size is important to the project's financial success. Many studies utilize complicated simulations to identify the optimal battery size. It is also difficult to reuse the outcomes of such optimization in other projects. In this paper, by introducing the factor β as the energy to power ratio, a simple techno-economic model is proposed to allow a quick evaluation of the feasibility of a building-integrated battery energy storage system (BI-BESS) and can apply to all commercial buildings that use the same tariff structure and is independent on the building load profile. Because the battery's energy and power are coupled, defining β allows both metrics to be addressed, resulting in high accuracy. For validating the results, the load profile from a commercial building based on Malaysia's tariff structure is used, and the optimal size of the battery is obtained from the proposed techno-economic model with the help of a Benefit-cost ratio (BCR) and simple iterative model for peak shaving. The results reveal that after finding the optimal BCR=1.08, the optimal battery size is achieved at 66.84 kWh. However, considering the market interests in the payback period, the economic feasibility of installing BESS is evaluated at BCR= 1.7, which is higher than our results. Hence, the impact of battery cost reduction is assessed.

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NOMENCLATURE

$BESS$	battery energy storage system	RTE	Round trip efficiency of BESS
P_{BESS}	Required power for BESS (kW)	N_{days}	Number of working days per year
E_{BESS}	Required energy for BESS (kWh)	Deg	Degradation efficiency of the battery
ΔE	Shifted energy of peak shaving (kWh)	η_{inv}	Efficiency of the inverter
ΔP	Shaved power of peak shaving (kW)	P_{inv}	Power rating of the inverter (kW)
DoD	Depth of discharge	Δr	Peak to the off-peak cost difference
D_{rate}	Charging/discharging rate	C_{energy}	Energy cost of BESS
$P_{L,i}$	Load power (kW)	C_{power}	Power cost of BESS
$E_{D,i}$	Discharged energy of battery (kWh)	C_{tot}	Total cost of BESS
$E_{max,i}$	Maximum energy of battery (kWh)	C_{opex}	Operational cost of BESS
β	Energy to power ratio (kWh/kW)	BCR	Benefit-cost ratio
MD	Maximum demand charge (USD/kW)	PV_{rate}	total yearly revenue of the project
R	Revenue of the project	PP	Payback period
R_{kWh}	Revenue of load shifting	K	Proposed parameter for total battery storage costs
R_{MD}	Annual revenue of demand cost reduction		

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1. INTRODUCTION

The utilization of energy storage systems (ESS) is becoming an emerging trend in recent years mainly due to the increasing development of smart grids related technologies introduced by Hassan [1], Alhajj Hassan et al. [2] and Jain et al. [3]. For a long time, battery storage was mostly used for starting engines, a few emergencies backup, portable devices, etc. Lithium-based batteries revolutionized the landscape by providing improved energy efficiency and density, as well as longer shelf life, quick charge and discharge, and other benefits. Energy storage devices can assist lower consumer power costs, increasing grid flexibility, and promoting renewable energy integration [4, 5]. One of the most notable benefits of implementing a Battery Energy Storage System (BESS) in buildings is the ability to minimize bill expenses through peak shaving and load shifting strategies. However, when using BESS, determining the correct battery size is a key challenge. Since oversizing battery consideration can result in early investments that threaten the project's economic benefit, under-sizing can put greater strain on batteries and shorten the BESS's overall life. In this manner, Kumar and Biswas [6] have determined the optimal battery.

Many complicated strategies for optimal BESS size have been discussed in recent years. Lange et al. [7], and Chua, Lim, and Morris [8] identified the battery and algorithm parameters; the authors suggested a real-time peak shaving control technique and an optimization procedure. Englberger et al. [9] provided a two-step technique for developing the linear optimizer with extensive modelling of non-linear effects on the battery. Martins et al. [10] presented research on linear optimization in MATLAB using a dual simplex method for peak shaving in commercial buildings based on maximum yearly peaks while accounting for power costs, energy prices, and battery degradation costs. However, all of the discussed publications are restricted to improving storage systems based on historical data from certain commercial load patterns.

There has been a substantial amount of research dedicated to managing BESS charging/discharging in order to reduce total energy costs [11-13]. However, the high cost of BESS is frequently the limiting factor in such projects' financial feasibility, and BESS sizing is the first problem to be addressed in such projects.

The load profile and tariff structure will also need to be examined in terms of financial viability. Previously, researchers presented many iterative simulations or optimization tools to study the feasibility of building-integrated BESS. However, the building load profile and tariff structure vary from case to case, and there is a lack of consensus on the efficacy of BESS in lowering building energy expenditures.

Some articles examined the economic viability of energy storage projects using various metrics such as Payback Period (PP), Internal Rate of Return (IRR), and Net Present Value (NPV) by positioning the battery at the maximum point of peak in load profiles. Uddin et al. [14] used BESS and generators; they suggested a decision-tree-based peak shaving method for islanded microgrids. To determine the project's economic viability, the payback period and net profit are calculated. However, there is a lack of battery parameters considered for battery sizing. In recent research conducted by Tsai et al. [15], they determined the appropriate size of the battery using HOMER software's techno-economic simulation and assessed the project's viability using economic methods such as internal rate of return (IRR) and net present value (NPV). Several economic approaches may be used to assess the viability of adopting BI-BESS, but determining the most realistic method that does not require complex calculations has proven difficult.

There is a need to find a simpler solution to allow a quick preliminary evaluation of the feasibility of the BI-BESS project. Instead of relying on optimization; there should be some underlying relationship between the various design parameters for a BI-BESS project such that a techno-economic model can be built to better understand the feasibility of such project for the given constraints that are attempted in this project.

In this study, a techno-economic model is provided to assess the economic feasibility of a Building-Integrated Battery Energy Storage System (BI-BESS) in commercial projects. The practicality of a BI-BESS, especially in commercial buildings to lower bill costs, may be examined by specifying the energy to power ratio ($\beta = \Delta E/\Delta P$) as a single parameter in a techno-economic model, with the aid of a benefit-cost ratio (BCR) as an important economic tool, and a simple iterative model for battery sizing. The proposed approach is described and proven using MATLAB simulation based on a real-world building load profile. Finally, for checking the feasibility of the project based on market interests, the payback period calculation is considered to check the return of investments based on market interests. The main contributions of this study, which make this study original, are listed briefly in the following:

- Proposing a novel techno-economic model for checking the economic possibility of a BESS project in commercial buildings.
- Defining a new parameter ($\beta = \Delta E/\Delta P$) as a single parameter in the proposed model that coupled energy and power of the peak shaving.
- Using β in techno-economic analysis to find the effective parameters in optimal battery sizing.
- Applying the results on the actual load profile to validate the achievements from the proposed method.

- Considering the market interests in the results and assessing the importance of BESS cost reduction in different future scenarios.

In the following, the overview of BI-BESS and the related cost and revenue parameters will be discussed in section 2. In section 3, the proposed research method will be presented. In section 4, the results of implementing the proposed model in the actual commercial load profile will be assessed and finally, the conclusion would be stated in section 5.

2. BACKGROUND

In this section, basic concepts of using battery energy storage systems in buildings, as well as related cost and revenue considerations are briefly described.

2. 1. Building-integrated BESS Through peak shaving and load shifting, a building-integrated BI-BESS has the ability to minimize a building's energy consumption bill. However, the BESS size must be changed based on the load profile and the building's tariff system to guarantee that the BI-BESS project is economically viable. Figure 1 depicts the process of sizing BI-BESS for commercial load profiles while taking economic aspects into account.

2. 2. Load Shifting and Peak Shaving To reduce a business building's overall electricity bill, BI-BESS can perform two key purposes. The first is to minimize the building's highest consumption, which is known as peak shaving, and the second is to shift energy from peak to off-peak hours, which is known as load shifting. Peak shaving saves money on power bills by lowering maximum demand (MD) rates, but load shifting saves money by lowering peak-to-off peak kWh costs.

Figure 2 demonstrates the concept of peak shaving in a load of a typical building for peak shaving. A threshold power ($P_{threshold}$) is first specified. The BESS will subsequently discharge anytime the load exceeds the $P_{threshold}$ to reduce the higher load depicted by the shaded portion of the curve.

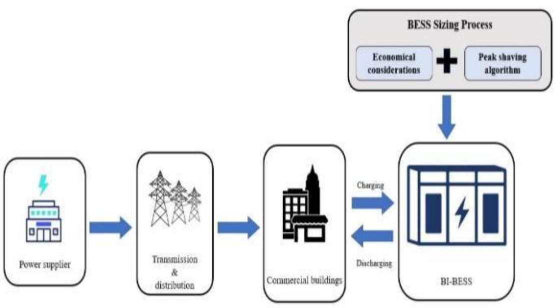

Figure 1. Schematic representation of BI-BESS sizing for commercial buildings

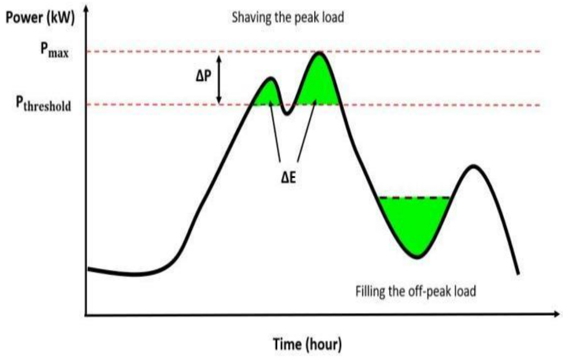

Figure 2. Typical building load profile with peak shaving and load shifting operations

The peak power shaved by the BESS is represented by ΔP, and the energy required to achieve the peak shaving is represented by ΔE. Because peak shaving typically occurs during peak hours, the energy ΔE will be subject to peak hour kWh price as well. Energy cost savings owing to load shifting can be realized if the BESS delays the recharging of this ΔE energy to the off-peak time. This means that load shifting will be an inherent feature of peak shaving, allowing for both a decrease in maximum demand (MD) charges and a reduction in peak to off-peak kWh costs to be achieved at the same time.

2. 3. Technical Considerations of BI-BESS The BESS must dispatch energy comparable to peak shaving energy ΔE to accomplish peak shaving. This peak shaving energy must then be restored by recharging the BESS before the next discharge round from the BESS is required. It is necessary to comprehend the BESS's authorized charging/discharging cycle each day as well as the depth of discharge (DoD). With the revenue from load shifting, the BESS should discharge only during peak hours and recharge only during off-peak hours. With 1 charging/discharging cycle per day assumed, the BESS energy capacity will be a function of ΔE and DoD as follows:

$$E_{BESS} \geq \frac{\Delta E}{DoD} \tag{1}$$

On the other hand, the required power of the BESS is determined by the peak shaving power (ΔP), hence the BESS should be configured to deliver equal or greater power than ΔP. The power of a BESS is limited by its energy capacity and discharge rate (D_{rate}). If the BESS's energy capacity is insufficient to compensate for the high power, the D_{rate} may be excessively high, damaging the battery and reducing its lifespan. The power constraint equation of the BESS can be rewritten for maximum D_{rate} as:

$$D_{rate} \times E_{BESS} \geq \Delta P \tag{2}$$

Then:

$$E_{BESS} \geq \frac{\Delta P}{D_{rate}} \quad (3)$$

By comparing Equations (1) and (3), it is possible to determine that the charge-discharge rate as well as the depth of discharge, will influence the size of the BESS. The total energy of the battery can be calculated by combining the energy and power limits stated as follows:

$$E_{BESS} = max\left(\frac{\Delta E}{DoD}, \frac{\Delta P}{D_{rate}}\right) \quad (4)$$

This means that for a particular peak shaving power and energy requirement, the BESS's minimum energy capacity should be chosen as the largest of the two battery size formulae generated from the two restrictions.

2. 4. Economic Considerations of BI-BESS The economic advantage of peak shaving divides into two categories: the first is the price savings by lowering maximum demand, and the second is load shifting. The annual income obtained by the lowering of MD charges may be computed over a period of 12 months as follows:

$$R_{MD} = \Delta P \times C_{MD} \times \text{Deg} \times \eta_{inv} \times 12 \left[\frac{USD}{kW.month}\right] \quad (5)$$

where ΔP is the peak power shaved in kW, C_{MD} are MD charges imposed by the utility in USD/kW, Deg is the degradation of BESS per unit, and η_{inv} is the efficiency of the BESS per unit. On the other hand, the annual revenue generated from kWh cost saving due to the peak-to-off peak load shifting, R_{kWh} can be calculated as follows:

$$R_{kWh} = \Delta E \times \Delta r \times RTE \times N_{days} \left[\frac{USD}{year}\right] \quad (6)$$

where ΔE is the energy shifted from peak to off-peak, RTE is round trip efficiency of the battery system, N_{days} is the number of days where the peak-to-off peak load shifting is performed in a year and Δr is the difference in price from the peak and off-peak hours. The total revenue from a BI-BESS project then be calculated as the sum of R_{MD} and R_{kWh}. The change in ΔP affects the benefit of maximum demand saving, while the change in ΔE affects the revenue for the arbitrage.

Operational expense is one of the cost elements that influence overall revenue. It is connected to the size of the battery and should be factored into overall income. This operating cost comprises insurance, system management, service contract, maintenance, and administrative charges, which are determined as follows:

$$C_{opex} = \Delta P \times C_{opex-unit} \left[\frac{USD}{year}\right] \quad (7)$$

where $C_{opex-unit}$ is the operational costs in USD/kW-year and C_{opex} is the total annual operating costs in USD/year. The total revenue based on ΔP and ΔE is defined as:

$$R_{tot} = \Delta P\left(C_{MD} \times Deg \times \eta_{inv} - C_{opex-unit}\right) + \Delta E\left(\Delta r \times RTE\right) \quad (8)$$

The battery and a bidirectional DC/AC inverter that serves as the interface between the DC battery and the AC grid are the two primary cost components of a BESS. The total cost of the BESS based on battery and inverter costs is as follows:

$$C_{tot} = \left(C_{energy} \times E_{BESS}\right) + \left(C_{power} \times P_{inv}\right) \quad (9)$$

where C_{tot} is the total cost of BESS, C_{energy} energy cost of BESS in USD/kWh, E_{batt} the size of BESS in kWh, C_{power} is power cost of BESS in USD/kW and P_{inv} is the power rating of the BESS in kW. As previously stated, the BESS's power is proportional to its energy and D_{rate}. The total cost of BI-BESS may be reduced to a simple function of BESS energy as follows:

$$C_{tot} = \left(C_{energy} + \left(D_{rate} \times C_{power}\right)\right) \times E_{BESS} \quad (10)$$

By defining K as:

$$K = C_{energy} + \left(D_{rate} \times C_{power}\right) \quad (11)$$

That means the total cost of the BI-BESS can be expressed as $K \times E_{BESS}$.

After replacing the E_{BESS} in the total cost equation, the total cost of BESS is presented as:

$$C_{tot} = K \times max\left(\frac{\Delta E}{DoD}, \frac{\Delta P}{D_{rate}}\right) \quad (12)$$

3. PROPOSED TECHNO-ECONOMIC METHOD

The proposed model is explained in this section based on the β variable. Since the battery's energy and power are linked, specifying this variable allows the sizing and economic calculation of the battery to be discussed using both parameters, resulting in more accurate conclusions at the end. The flowchart, as shown in Figure 3 is divided into three sections: economic analysis, peak shaving algorithm, and battery sizing. In terms of economic computation, the BCR is used after defining and adding basic parameters related to the tariff structure and a specific lithium Ion battery, and the BCR against the graph achieves the best result. The simple peak shaving using an iterative approach was presented to graph the ΔE against β with the help of the ratio of ΔE to ΔP. Finally, the optimal β can reveal the best battery size for the particular building by comparing the two graphs from an economic and peak shaving analysis.

3. 1. Energy to Power Ratio ΔP may be thought of as a design parameter, whereas ΔE is a function of ΔP and the load profile of the building. β variable is provided

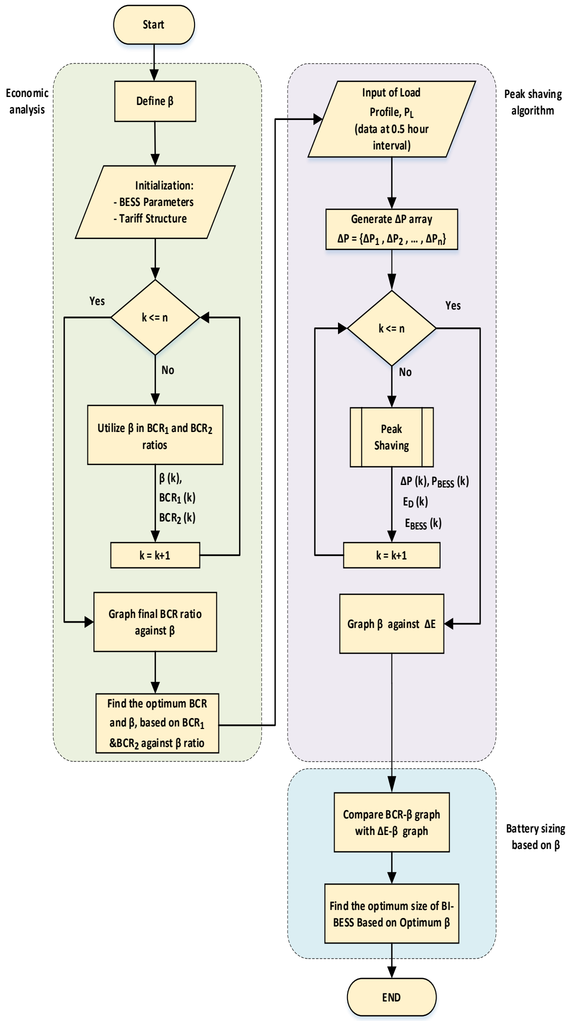

Figure 3. Proposed Techno-economic model for optimal battery sizing

here as a ratio of ΔE to ΔP to allow a techno-economic method to analyze the economic feasibility of the BI-BESS project as follows:

$$\Delta E = \beta \times \Delta P \tag{13}$$

A new formula for the total cost may be produced by substituting the specified ΔE equation into Equation (12):

$$C_{tot} = K \times [max\,(\frac{\beta}{DoD}, \frac{1}{D_{rate}}) \times \Delta P] \tag{14}$$

Similarly, by swapping ΔE into Equation (8), the total yearly revenue is redefined as follows:

$$R_{tot} = [(\beta \times \Delta r \times \mathrm{RTE}) + (C_{MD} \times \mathrm{Deg} \times \eta_{inv} - C_{opex-unit})] \times \Delta P \tag{15}$$

The β is the load profile characteristics, all other parameters are fixed values, and ΔP is the sole variable in these equations. When ΔP rises, the overall revenue rises as well. On the other side, the overall cost will increase as well. It follows that there should be an ideal value of ΔP at which the economic gain of the BI-BESS is maximized.

3. 2. Benefit-cost Ratio

The Benefit-cost ratio (BCR) is calculated by dividing the entire income by the total cost of the project defined by Cotter [16]. A BCR larger than one indicates that the project will be profitable, but a BCR less than one indicates that the project will result in a loss. The idea of BCR is used to analyze the BI-BESS project in this case. It is vital to highlight that the project's revenue is seen to be recurring yearly throughout the project's life, whilst the project's cost is thought to be spent at the start of the project. The yearly revenue and expense must be examined over a variety of time frames. It is necessary to determine the overall length of the project as well as the discount rate for each year to estimate the appropriate BCR. In this way, it is required to consider the discount rate parameter in the total benefit-cost ratio. The discount rate is the interest rate paid by commercial banks and other financial institutions on short-term loans obtained from the Federal Reserve Bank. The interest rate used in BCR analysis to assess the present value of future cash flows is referred to as the discount rate by Shively and Galopin [17]. For calculating the present value of annual revenue, the following multiplication factor can be utilized:

$$PV_{rate} = \left[\frac{1-(1+r)^{-n}}{r}\right] \tag{16}$$

where n is the total years of the project, r is the discount rate of a specific area based on the market, and PV_{rate} is the total yearly revenue during the life of the project. By adding the discount rate into the BCR, the ratio will change as:

$$BCR = \frac{Rtot \times PV_{rate}}{Ctot} \tag{17}$$

Based on the total cost equation that consists of two ratios, the BCR should be evaluated in BCR_1 and BCR_2, which means the BCR is considered based on power and energy constraints. By considering whole costs and revenue consideration in the formula above, the total benefit-cost ratio will be expressed as:

$$BCR_1 = \frac{(\beta \times \Delta r \times RTE \times N_{days}) \times PV_{rate}}{\frac{k \cdot \beta}{DoD}} + \frac{[(C_{MD} \times Deg \times \eta_{inv} \times 12) - C_{opex}] \times PV_{rate}}{\frac{k \cdot \beta}{DoD}} \tag{18}$$

and

$$BCR_2 = \frac{(\beta \times \Delta r \times RTE \times N_{days}) \times PV_{rate}}{\frac{k}{D_{rate}}} + \frac{[(C_{MD} \times Deg \times \eta_{inv} \times 12) - C_{opex}] \times PV_{rate}}{\frac{k}{D_{rate}}} \tag{19}$$

The minimum of the two equations above may be used to display BCR versus β graph. This is the BCR of a BI-BESS project based on a certain tariff structure and BESS technology, irrespective of the building load profile. The overall BCR for the BI-BESS should be the lowest of the two ratios:

$$BCR = \min(BCR_1, BCR_2) \quad (20)$$

Observing Equations (18) and (19), it is evident thatBCR_1 is an inverse function of β and BCR_2 is a linear function of β. As a result, a typical graph of both BCRs against β will look like Figure 4:

There exists an optimal β location where the total BCR is maximized, which is supplied by the intersection point of BCR_1 and BCR_2. By checking the two equations it is clear that there are two parameters that can affect the optimum point of β:

$$\beta_{opt} = \frac{DOD}{D_{rate}} \quad (21)$$

It's important to note that once the tariff structure and BESS technology are in place, the BCR-graph is no longer changeable. Because it is not affected by the load profile of the building, the same graph will apply to all buildings that employ the same tariff and BESS technology in the future. This tool may also be used to determine how specific elements, such as BESS cost reduction and MD fee revisions, influence the potential economic gain from a BI-BESS project.

3. 3. Iterative Model for Peak Shaving

The battery size graph of the techno-economic technique can be employed with the help of a peak shaving iterative model and a peak shaving iterative model. For this iterative model, the 1-day load profile data from a commercial building in Malaysia is modeled in MATLAB using the data from the commercial building. Based on the Malaysian electricity supplier[1], the MD is calculated every 30 minutes, then the load profile data should be given every 30 minutes intervals, resulting in i = 48 data points for the load profile in a single day. The peak shaving power will be iteratively varied to determine the battery size, and the corresponding battery size will be computed. This project employs 100 iterations.

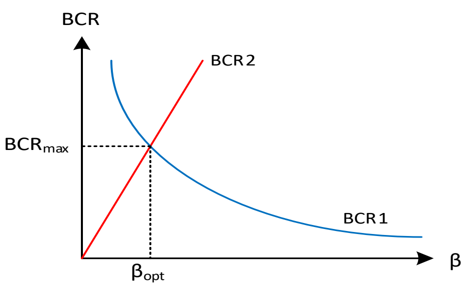

Figure 4. Typical BCR against β plot

After selecting a peak shaving power (ΔP_1), the appropriate threshold power ($P_{threshold1}$) can be determined. The simulation will then determine the operation of the BESS for each of the load profile data points from i = 1 to i = 48. The load profile data has been reorganized so that i=1 denotes the commencement of the peak hour when the BESS discharge procedure is expected to start. This means that data at i=48 will be the last point of the off-peak hour at which battery charging should stop. This captures the battery charging-discharging cycle inside the 48 data points, which is critical for confirming that the battery energy can be fully replenished during off-peak hours before the next discharging cycle begins.

At any point in (i), the algorithm will first determine if the point is in the peak or off-peak hour. If the data point falls during the peak hour, the peak shaving algorithm's "battery discharge" operation will be called; otherwise, the peak shaving algorithm's "battery charging" operation will be invoked. The size of the battery $E_{BESS(1)}$ required for the selected peak shaving power (ΔP_1) will be determined based on the results, and the related E_{BESS} will be calculated. The process is then repeated for the next peak shaving power (ΔP_k) with the $E_{BESS}(k)$ determined using the same technique described above for each iteration. The β to attain the ΔE can be plotted after k = n iterations.

"Battery Discharging" and "Battery Charging" are the two sections of the Peak Shaving algorithm used in the iterative approach. It will be necessary to request the former during peak hours, and it will be necessary to request the latter during off-peak hours. The load profile power $P_{L,i}$ is compared with the threshold power $P_{threshold,i}$. If the load power is higher than the threshold power, the battery will discharge at a power $P_{BESS,i} = P_{L,i} - P_{threshold,i}$.

$$P_{BESS,i} = P_{L,i} - P_{threshold,i} \quad (22)$$

Because the battery must be recharged during off-peak hours, it is necessary to determine the amount of energy that has been drained by the battery. The discharged energy at point-i should be updated in the following manner, assuming that both the charging and discharging efficiency of the battery stay constant.

$$E_{D,i+1} = E_{D,i} - \frac{0.5 * P_{BESS,i}}{\sqrt{RTE}} \quad (23)$$

Given that the BESS has the same charging and discharging power capabilities, the peak power required for recharging the battery will be equal to the peak shaving power (ΔP) required. The greatest amount of energy that may be acquired through this recharging power will be as follows for data points taken at 30-minute intervals:

$$E_{max,i} = \sqrt{RTE} * 0.5 * \Delta P \quad (24)$$

[1] https://www.tnb.com.my/commercial-industrial/pricing-tariffs1

If the drained energy for the battery at point-i exceeds the $E_{max,i}$, the battery shall recharge at full power. Otherwise, the battery should be recharged at a lower power level merely to help compensate for the lost energy. The battery power and discharge energy may be computed using the following conditions:

$if\ E_{D,i} < -E_{max,i}$
$then$
$P_{BESS,i} = \Delta P$
$E_{D,i+1} = E_{D,i} + E_{max,i}$
$else\ if\ E_{D,i} < 0\ then$
$P_{BESS,i} = \frac{-E_{D,i}}{0.5*\sqrt{RTE}}$
$E_{D,i+1} = 0$

The simulation will produce time-series data for battery power (P_{BESS}) and discharged energy (E_D), which will be used in further calculations. For battery size, it is necessary to guarantee that the energy discharged during peak hours can be adequately recharged during off-peak hours; otherwise, the BESS would have a net loss of energy after each charging-discharging cycle, making the operation unfeasible. i.e. E_D (48) = 0 can be verified as the final point of the discharged energy array by evaluating the final point of the discharged energy array and confirming that it is zero. Figure 5 shows the total process of battery charging/discharging in the proposed iterative method.

3. 4. Battery Sizing Utilizing Optimum β

Finding the maximum value of each time-series data allows for determining the maximum battery power and maximum drained energy. Finally, the energy constraint and power constraint may be used to calculate the minimal BESS size in kWh and BESS power as follows:

$$E_{BESS} = \max\left(\frac{\max(abs(E_D))}{DoD}, \frac{\Delta P}{D_{rate}}\right) \quad (25)$$

Note that the absolute value of E_D is considered here due to the negative value of discharged energy. Once the E_{BESS} is decided, the whole process is then repeated with a different peak shaving power ΔP(k+1) and so on, up to ΔP(N). This iterative process will generate the N numbers of ΔP value chosen. Finally, the curve of β against ΔE can be plotted. After plotting the β against ΔE and fixing the achieved value of optimum β from the economic calculation, the optimum size of the battery can be calculated.

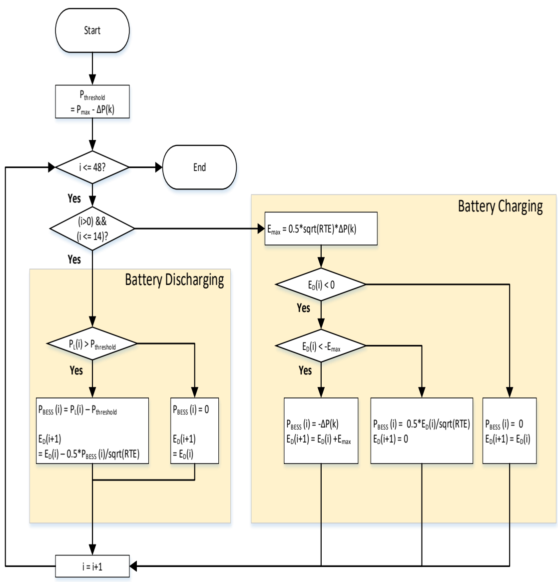

Figure 5. Battery charging/discharging process of the iterative method

4. RESULTS AND DISCUSSION

Here, the results of the techno-economic technique for commercial buildings are examined in detail, with the help of MATLAB program. In addition, the effective parameters of the techno-economic approach are addressed in greater detail. The results and outputs of the ratios are analyzed in the context of commercial buildings in Malaysia, and all cost estimations and tariff structures are based on the country's tariff system. Despite the fact that the cost of batteries and associated considerations would fluctuate over time, the interest rate for the first 10 years of the BESS project has been set at 3%, based on the market's interest in having an accurate layout. Final considerations are given to the influence of market interests on the payback duration of the project. Also, a detailed analysis of the cost reduction estimation and its impact on the entire profits of the project's overall benefits is included.

4. 1. Economic Considerations Utilizing β in Commercial Tariff Structure

To check the techno-economic model's applications, it must clarify parameters included in BCR1 and BCR2. The energy tariff structure summarized in Table 1; which is based on the tariff structured by Tenaga Nasional Berhad (TNB), the sole utility company in Peninsular Malaysia TNB 2021[1]. Tariff structures have been selected here for this study, based on the commercial medium-voltage C2 Tariff.

In terms of battery technology, Lithium-Ion batteries (LiB) with the following parameters mentioned in Table 2 have been selected Asian Development Bank [18, 19].

It should be noted that since the specific project is being evaluated in accordance with Malaysia's tariff system, the costs of BESS components are being obtained from vendors in Malaysian marketplaces due to the lack of battery manufacturers in the country. Some of the real prices are determined at a higher level than the manufacturer's price lists, taking into account shipping and other additional expenditures.

[1] https://www.tnb.com.my/commercial-industrial/pricing-tariffs1

TABLE 1. Electricity tariff rates for Commercial Buildings in Malaysia (C2 Tariff)

Parameters	Values
Maximum Demand Charge (C_{MD})	10.72 (USD/kW)
Peak Hour kWh Charges ($C_{rate\ peak}$)	0.09 (USD/kWh)
Off-Peak Hour kWh Charge ($C_{rate\ off-peak}$)	0.06 (USD/kWh)
Difference from off-peak hours to peak hours costs (Δr)	0.03 (USD/kWh)

TABLE 2. Techno-economic parameters of BESS

Parameters	Values
BESS Energy Cost (C_{energy})	363.37 (USD/kWh)
BESS Power Cost (C_{power})	242.25 (USD/kWh)
BESS Operational Costs (C_{opex})	12.11 (USD/kW-year)
Round-trip efficiency of the battery (RTE)	90%
Efficiency degradation of BESS (Deg)	5%
The efficiency of the inverter (η_{inv})	97.5 %
Depth of discharge for 3000 cycles (DoD)	80%
The discharge rate of the battery per cycle (D_{rate})	0.5 (C)
Present value rate for the total life of the project (PV_{rate})	8.53
Total number of working days in a year (N_{days})	250
Proposed unit of power and energy costs of the battery (k)	484.495

As explained before, the BCR can be evaluated by Equation (20) which consists of BCR_1 and BCR_2. By calculating discussed parameters, it is possible to find the ratios of BCR for commercial customers in Malaysia:

$$BCR_1 = \frac{[(\beta \times 0.03 \times 0.9 \times 250)] \times 8.53}{\frac{484.495 \times \beta}{0.8}} + \frac{[(10.72 \times 0.95 \times 97.5 \times 12) - 12.11] \times 8.53}{\frac{484.495 \times \beta}{0.8}} = 0.095 + \frac{167.65}{\beta}$$

and

$$BCR_2 = \frac{[(\beta \times 0.03 \times 0.9 \times 250)] \times 8.53}{\frac{484.495}{0.5}} + \frac{[(10.72 \times 0.95 \times 97.5 \times 12) - 12.11] \times 8.53}{\frac{484.495}{0.5}} = (0.059 \times \beta) + 104.79$$

As the β is the only variable in the two ratios, simply changing its value in BCR_1 and BCR_2, the final graph is achieved, and the maximum point of β that evaluated at 1.6. Figure 6 shows the final BCR against β for Commercial buildings in Malaysia. The result shows that the maximum benefit-cost ratio of the project is based on the optimum energy to power ratio achieved at 1.08.

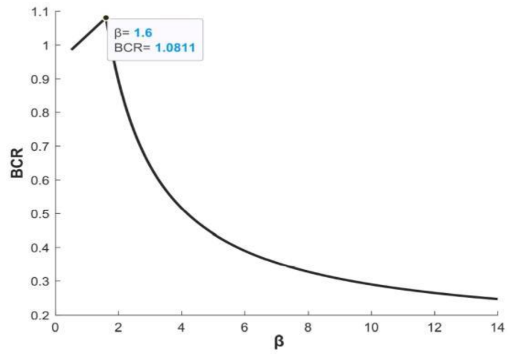

Figure 6. BCR against β in Commercial buildings

4. 2. Battery Sizing Utilizing Optimum β in Commercial Buildings In this section, the results of the economic calculation's optimum β are compared to the commercial building's suggested battery sizing, which employs the iterative method of peak shaving. Peak shaving takes into account a commercial building's 1-day load profile. Peak hours in Malaysia last 14 hours, from 8 a.m. to 10 p.m. The minimum peak shaving indicates that the threshold line is close to peak power. The power and energy of the battery will increase as the threshold line is moved to the mean of the load. The load profile is derived from the one-day load profile of the commercial building, which has a maximum power of 740.66 kW and a mean power of 382.17 kW. By running MATLAB with the proposed peak shaving algorithm, the size of the battery for different threshold considerations is shown in Figure 7:

The number of threshold considerations is determined by the algorithm's required accuracy. By increasing the number of thresholds, the total number of battery sizing considerations increase as shown in Figure 8. For commercial load profiles, the graph of β versus ΔE can show the different sizes of batteries over each fixed

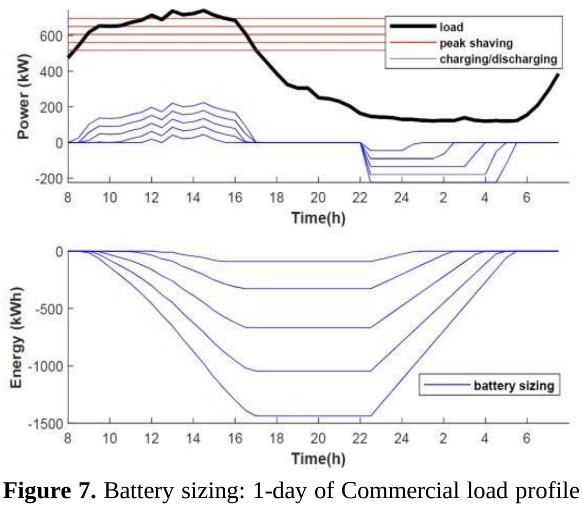

Figure 7. Battery sizing: 1-day of Commercial load profile based on an iterative method

threshold consideration. As is obvious, increasing the size of the battery increases the amount of energy saved in a load profile. Nonetheless, as previously discussed, it is critical to assess the project's economic feasibility to determine the optimal battery size.

In economic terms, the maximum β in total BCR in commercial buildings shown in Figure 6 is fixed at 1.6. By determining the optimum β from the economic calculation in Figure 8, the feasible size of the battery in β=1.6 is specified at 66.84 kWh, representing the best feasible battery size consideration for that specific commercial load profile. The BCR against the β graph can be plotted by taking the minimum of the previously explained Equations (18) and (19). This represents the BCR of a BI-BESS project under a specific tariff structure, and BESS technology is solely a function of DoD and Drate, which is dependent on the BESS technology selected.

According to several manuals from battery manufacturers, the DoD in batteries is considered to be 80% and the Drate to be 0.5 C. By plugging them into Equation (26), the fixed β can be calculated as follows:

$$\beta_{opt} = \frac{DOD}{D_{rate}} = \frac{0.8}{0.5} = 1.6$$

that is independent of the building load profile and will apply to all buildings that are using the same tariff and BESS technology. The result from the Final BCR against β in Figure 6 shows that based on optimum β, the BCR is fixed at 1.08, which means it is economically feasible to use BESS in commercial buildings in Malaysia and the investments will be compensated during the life of the project.

There are some related studies conducted by Rosati et al. [20], Yan et al. [21] and Mayyas et al. [22] they have developed technoeconomic models to find the best size of the battery utilizing different economical tools. Comparing the results of this study with mentioned research proves the simplicity and applicability of our research on all other commercial buildings without huge initial data from the load of buildings.

In addition, it is required to check the feasibility of the project based on market interest to ensure the return of investments in this project is still beneficial in comparison with market interest investments. In this case, the market interest factor as a crucial element for planning and installing the project will be discussed in the next session.

4. 3. Finding the Feasibility of BI-BESS in the Marketplace Utilizing the Payback Period The feasibility of the project depends on the BCR calculation. Whenever the BCR is evaluated more than 1, it means that there are some economic benefits to using BESS in the project and the total economic benefit of the project will be more than the total initial investments. Figure 9 shows the feasibility area of the BCR−β graph. The result shows that it is economically possible to employ BESS in commercial buildings in Malaysia, and the investments will be repaid during the 10 years of the project's life consideration. However, by considering the impact of the payback period in the marketplace, the desired payback period in Malaysia considers less than 5 years which impacts the total BCR calculation. That means the project with more than mentioned period is not interesting enough to be planned.

The payback period is a simple useful tool that calculates the total required payback period consideration of the project based on the ratio of total cost per total revenue:

$$PP = \frac{C_{tot}}{R_{tot}} [year] \tag{26}$$

By defining the payback period as PP, the total revenue can consider as follows:

$$R_{tot} = \frac{C_{tot}}{PP} [year] \tag{27}$$

Regarding the benefit-cost ratio in Equation (17), the total BCR for 10 years of consideration can be represented as follows:

$$BCR = \frac{R_{tot} \times PV_{10}}{C_{tot}} \tag{28}$$

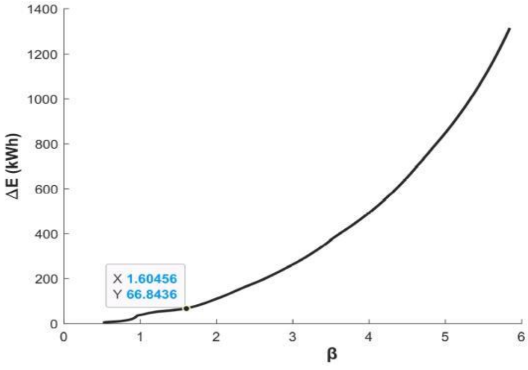

Figure 8. The optimum size of the battery based on β in the commercial load profile

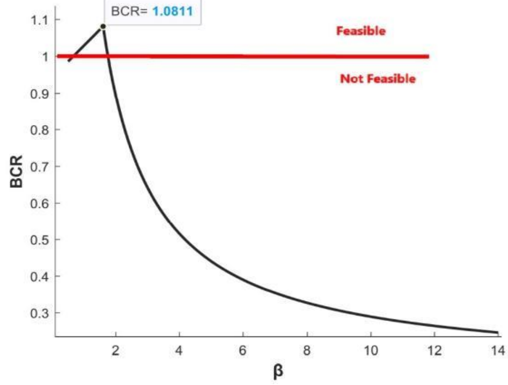

Figure 9. Feasibility area of BCR

where PV_{10} is the present value rate for 10 years life span consideration of the BI-BESS project. After replacing total revenue in Equation (28), the benefit-cost ratio can be defined as Equation (29) where the benefit-cost ratio is defined as the ratio of the present value of the project for 10 years of consideration, and PP is the desired payback period.

$$BCR = \frac{PV_{10} \times \left(\frac{C_{tot}}{PP}\right)}{C_{tot}} = \frac{PV_{10}}{PP} \quad (29)$$

Considering the 3% rate of return from the market and 10 years for the lifespan of BESS the present value rate based on Equation (16) is evaluated as 8.53. The benefit-cost ratio based on Equation (29) can be evaluated:

$$BCR = \frac{PV_{10}}{PP} = \frac{8.53}{5} = 1.7$$

Comparing the new calculated BCR based on market interest with the achieved one at 1.08, the result shows that however, the evaluated BCR for the commercial building is more than 1, and using BI-BESS demonstrates economic benefit for the project, but the result is less than the market expectation.

4. 4. The Impact of Cost Reduction on the Feasibility of the Project While the costs of lithium-ion technologies have dropped dramatically since their commercialization, their adoption will be influenced by both their costs and trends in alternative battery technologies. We explore the principles of the cost drop witnessed for lithium-ion technologies to better understand prior improvements and inform plans to further develop electrochemical storage technologies. Once it comes to determining the feasibility of a project, the price of the battery and inverter can have a significant influence on the project's viability. In upcoming years, as it is estimated by Mongird et al. [19], the cost of BESS will decrease by around half of the present value. Considering the cost reduction for different scenarios, the new benefit-cost ratio for commercial buildings is shown in Figure 10:

Since the maximum BCR is less than 1.7, it is clear that even with a 25 percent cost reduction, installing BESS in commercial buildings will remain unattractive to Malaysian investors, despite the cost reduction.

As a consequence of the predicted 40 percent cost reduction in the approaching years, the BCR would be larger than 1.7, indicating that using BI-BESS for commercial buildings will be profitable for investors when considering market interests. Since the value of β is the same before and after the cost reduction, the size of the battery remains unchanged. In this example, the BCR improves dramatically as a result of cost reduction, highlighting the relevance of cost reduction in enhancing a project's viability.

Aside from the study's findings, Figure 11 demonstrates the significance of BESS cost reduction in the project's overall profit. In this situation, many scenarios were explored to determine the best BESS cost reduction for the overall profit of the project. As is obvious, the project will be considered beneficial after around 40% cost reduction. Many experts assessed a cost decrease of 50 to 60% by Cole et al. [23]. Based on the present market position and various cost-cutting estimates, this should happen soon.

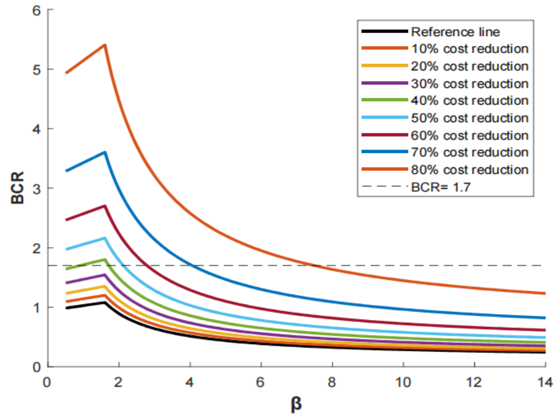

Figure 10. BCR against β in commercial buildings before and after cost reductions

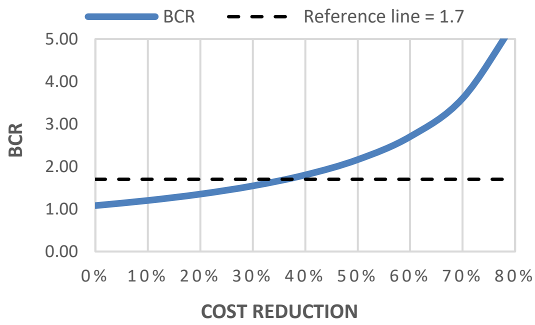

Figure 11. The impact of cost reduction on BCR

5. CONCLUSION

The current study developed a techno-economic model to assess the viability of commercial building-integrated BESS. Because the energy and power attributes of a BESS are interrelated, an energy-to-power factor ($\beta = \Delta E/\Delta P$)) was merged into a single metric allowing both metrics to be addressed, resulting in high accuracy. A Benefit-Cost Ratio (BCR) versus β relationship was created to describe the tariff structure and BESS parameters independently of the building load profile. By modeling a real-world building load profile in MATLAB, the suggested technique was detailed and validated. The summary of the critical results is represented as follows:

- The assessed β from economic calculation was established at 1.6 by charting the BCR- β ratio.
- The final $\Delta E - \beta$ ratio was obtained via the peak shaving approach by calculating different battery sizing from the 1-day load profile of a commercial building in Malaysia.
- After comparing two graphs from the proposed model's economic and technical parts, the optimum size of the battery was determined to be 66.84 kWh.
- Based on the BCR-β graph, the maximum BCR was achieved at 1.08 which means it is economically feasible to install BESS for peak shaving in commercial buildings.
- Considering market interests for the initial investments and economic calculations, the desired payback period in Malaysia considered 5 years that impacted the BCR calculation, and the critical BCR was evaluated at 1.7
- Different BESS cost reduction scenarios were evaluated to check the improvement of the profitability of the project.
- Finally, the findings demonstrated that once the tariff structure and BESS technology are determined, the proposed techno-economic analysis will apply to all buildings.

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Persian Abstract

چکیده

یافتن سایز مناسب باتری در موفقیت مالی پروژه اهمیت بسزایی دارد. بسیاری از تحقیقات از شبیه سازی های بسیار پیچیده برای تعیین بهترین سایز باتری استفاده می کنند. همچنین، استفاده مجدد از خروجی این بهینه سازی در پروژه های دیگر نیز بسیار دشوار است. در این مقاله با معرفی فاکتور β به عنوان رابط انرژی در ضریب توان، مدل تکنو اکونومیک ساده ای ارائه شده که ارزیابی سریع سیستم ذخیره انرژی باتری به صورت یکپارچه را ممکن می سازد و همزمان میتوان آن را برای تمامی ساختمان های تجاری با تعرفه ی یکسان ،بدون در نظر گرفتن پروفایل مصرفی ساختمان ها بکار برد. از آنجا که انرژی و توان باتری در کنار هم قرار گرفته اند، با تعیین β هر دو معیار مورد مطالعه قرار گرفته و در نتیجه دقت محاسبات نیز افزایش می یابد. برای اعتبار سنجی نتایج، نمایه مصرف انرژی یک ساختمان تجاری براساس ساختار تعرفه مالزی در نظر گرفته شده و اندازه ی بهینه ی باتری با استفاده از مدل تکنو اکونومیک پیشنهادی، و با در نظر گرفتن نسبت سود به هزینه (BCR) و با به کار گیری یک مدل تکرار شونده ی بسیار ساده برای مدیریت اوج بار محاسبه شده است. نتایج نشان می دهند با یافتن بهینه BCR=1.08، مناسبترین سایز باتری kWh ٦٦.٨٤ است. اگرچه با در نظر گرفتن نرخ بهره بازار در دوره ی بازپرداخت، ارزش اقتصادی نصب و راه اندازی پروژه برابر با BCR=1.7 ارزیابی می شود که بسیار بالاتر از نتایج می باشد. به این ترتیب تاثیر ناشی از کاهش هزینه باتریب در آینده نیز ارزیابی شده است.