# Optimal Cost-Based Model for Sizing Grid-Connected PV and Battery Energy System

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*Abstract*— **Photovoltaic-battery energy systems (PV-BESs) have recently emerged as a promising alternative energy solution for electricity consumers. Due to the high level of unpredictability and intermittency associated with solar energy, the optimal sizing and intermittency mitigation of PV-BESs is necessary while integrating them into the grid. This paper presents a technical and economical model for the optimal sizing of a grid-connected PV-BES system for different battery technologies. An iterative analytical approach is utilized to determine the battery capacity, generate multiple combinations of PV-BES over a defined range of PV rated power, and apply a proper energy management strategy to control the energy flow through the system. This is followed by an economic model to calculate the system levelized cost of energy (LCOE) for all possible PV-BES sizes. The optimal PV size and best BES coupled with the PV system is chosen depending on the minimum LCOE. In this context, an improved formula of LCOE is proposed which includes new parameters reflecting the impact of surplus PV output and the energy purchased from the grid. Additionally, the proposed model uses the levelized cost of delivery (LCOD) for BES and compares it with system LCOE. Data over one year of hourly solar irradiation, temperature and load demand are used for system sizing. The results show that the minimum system LCOE is observed when the PV rated power is 710 KW, and the most suitable BES in conjunction with the PV system is redox flow battery with 1 MWh capacity. A cost reduction of 18% obtained compared to the grid electricity price. Moreover, the proposed model allows 75% of self-consumed energy by the PV-BES compared to 48% when using the PV system alone.**

## I. INTRODUCTION

In recent decades, a persistent demand for alternative energy resources has increased to overcome the problems of fossil fuel depletion and environmental degradation. PV systems are considered to be one of the most efficient renewable energy resources (RESs) that are sustainable and release no harmful carbon dioxide or other pollutants. Due to the ease of desig and installation, PV systems are widely applied in many countries. For example, China, Japan, USA, Germany, and the UK were the leading countries applying PV technologies in 2014 with almost 80% of PV global installations for that year [1].

However, the unpredictable output of PV systems leads to instability in the grid and makes the process of integrating PV systems a challenge. Energy storage systems (ESSs) can make the utilization of PV systems in the power grid much more straightforward, by storing excessive PV energy to be used later when needed. Moreover, an ESS maintains a balance between energy production and consumption and improves power grid reliability [2], [3], [4].

Grid-connected PV systems can produce higher energy than actually needed, especially during the summer. This extra energy is either stored in ESSs or fed back to the grid. Theoretically, ESSs are not necessary for grid-connected PV systems as the grid is able to absorb all the surplus PV energy generated. However, research has proven that using ESSs in grid-connected PV systems overcomes the power quality problems of distribution grids and makes PV plants more useful and reliable. Furthermore, ESSs provide auxiliary services to the grid such as load balancing, peak shaving, voltage and frequency regulation, and power flow management [5].

Finding the optimal sizing for both of the PV system and BES is crucial for many reasons. Firstly, it maximizes the utilization of PV-generated energy. Secondly, minimum operating costs can be obtained. Basically, system over-sizing will increase the total cost and reduce profitability while under-sizing may cause system failure. To evaluate the PV-BES system on an economic basis, LCOE is utilized as a metric to find the relative cost of PV systems compared to other RESs [6], and also to compare different ESSs [7].

Many studies have tackled the techno-economic sizing of PV-BES using different models and algorithms for grid-connected and stand-alone systems. A technical and economical model for sizing grid-connected PV-BES has been presented, which determines the PV rated power and the BES capacity based on the minimum LCOE [8]. However, this LCOE model depends on energy demand instead of the total energy generated from the PV-BES system to find the LCOE, and this may give inaccurate indications of total costs. A new methodology for LCOE calculation for combined PV-BES system was then proposed [9], with new parameters included in the LCOE calculation such as a price increase factor and internal transfer cost. These two parameters are currently not well defined in the industry and no literature has discussed them. A deterministic approach for sizing a stand-alone hybrid PV-ESS with an anaerobic digestion (AD) biogas power plant has been proposed [10], in which PV size was determined using particle swarm optimization with the interior point method, and then AD and EES sizes were chosen based on the maximum demand. Following the sizing of components, the LCOE and LCOD are calculated in the presence of ESS to show that the optimal sizing gives the minimum cost. An optimal techno-economic unit sizing of stand-alone hybrid PV/Wind/BEShas also been discussed [11], and a methodology proposed to iteratively find the optimal size of a PV/wind/battery hybrid system based on the availability of the power supply and the lowest LCOE, which is divided into utilized LCOE for the energy used by the system, and not utilized LCOE for the surplus energy. The key principle of the above studies is to find the optimal size of RESs and BESs, which is also the main aim of our work. However, sizing PV-BES, particularly for grid-connected systems using a LCOE model requires a full analysis and clear justification to make this indicator more trust worthy.

In this paper, an analytical and economical model is developed to determine the optimal size, minimum cost and best PV-BES combination in a grid-connected system. The energy demand is mainly covered by the PV-BES system, or by purchasing energy from the grid whenever the energy generated by PV-BES is insufficient to supply load. The surplus PV energy generated will be used to charge the BES, and extra energy will be sold back to the grid. In our work we leverage this opportunity to make the following key contributions:

1) A new analytical model to find optimal PV size and the best PV-BES combination based on economic analysis.
2) A new method for the calculation of LCOE by adding new parameters that make it more accurate, by including the impact of surplus energy sold to the grid and energy purchased from the grid.
3) We demonstrate LCOE values when utilizing three types of existing battery technologies (lead-acid, lithium-ion and redox flow).

To best of our knowledge, this is the first demonstration of a sophisticated LCOE model for grid-connected PV-BES system sizing using real solar irradiation and load profiles for different widely used batteries. The rest of the paper is organized as follows. Section II introduces the methodology applied in the paper, and Section III describes the proposed analytical and economical model. The experimental results and discussion are presented in Section IV, and Section V gives the conclusion.

## II. Methodology

The diagram in Fig. 1 shows the grid-connected PV-BES system including the PV system, battery bank, inverter, charge controller and connections to the load and grid. The DC/AC inverter is necessary to bring the DC output of the PV system to the AC load or grid, while the charge controller preserves the battery from overcharging or under-discharging. Although the inverter efficiency is not constant in reality, in our model it is assumed to be constant. The hourly values of solar radiation and ambient temperature for the Isle of Wight are taken into consideration, as a scheme there is currently working on decarbonising the electricity system of the island to make it self-sufficient in energy using RESs and BESs.

For each hour in the year, an energy balance calculation is conducted, such that the hourly energy demand is mainly covered by the PV-BES, while the grid is treated as a back-up. A simulation program in Matlab is developed in order to calculate the energy balance. The program simulates different scenarios for three battery technologies, which are lead-acid, lithium ion and redox flow (LAB, LIB, and RFB respectively).

An optimization approach is used to determine the size of the PV system by iteratively changing the PV contribution from 200 KW to 1400 KW with a step of 30 KW each time for the three batteries. This range is determined based on the maximum hourly demand which is equal to 417.7 KW, where

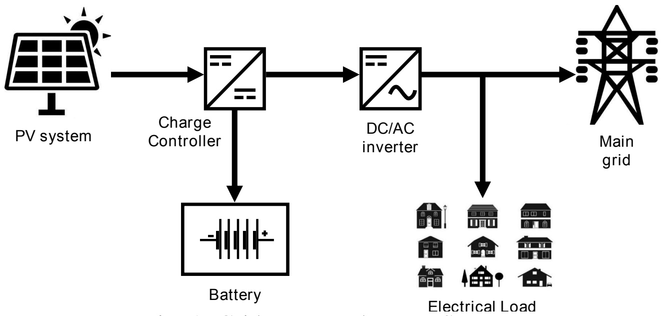


Fig. 1: Grid-connected PV-BES system.

the selected range will cover all possible PV system sizes. The combination that provides the lowest LCOE while covering the load demand will be selected as the optimal solution. Fig. 2 illustrates the energy flow through the system, where $P_{pv-min}$ and $P_{pv-max}$ are the minimum and maximum values in the range of PV rated power, $E_{pv}$ is the energy produced by the PV system, $SOC$ is the state of charge of the battery, and $k$ indicates the number of batteries involved in this study. The priority in the energy management strategy is to supply the load from the energy generated from the PV-BES. When this

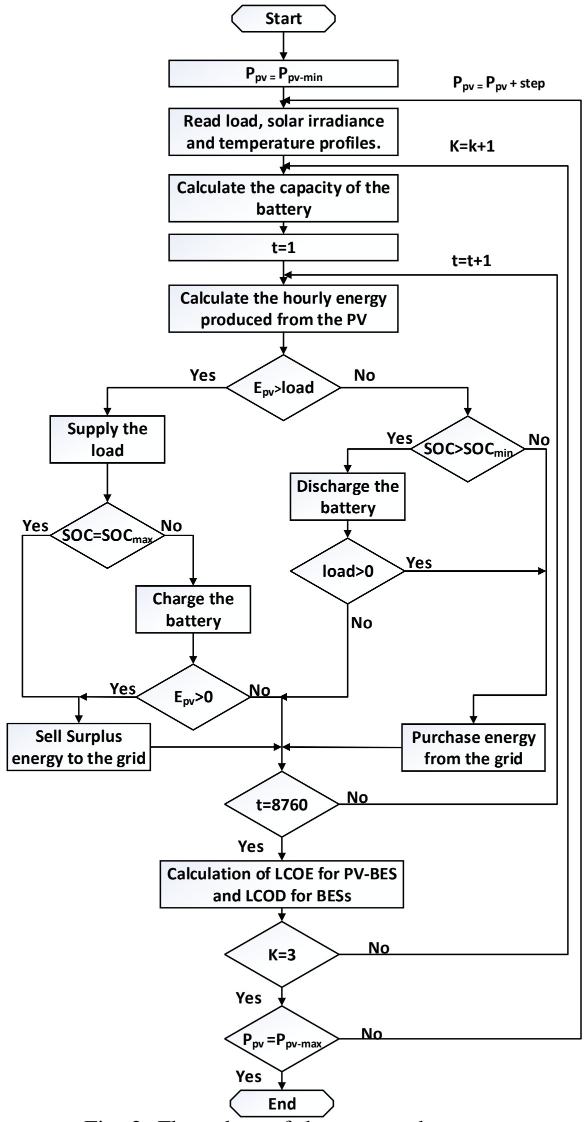


Fig. 2: Flow chart of the proposed system.

energy is insufficient to supply load, the decision to purchase energy from the grid takes place. Alternatively, surplus energy generated from the PV system will be sold to the grid.

## III. PV-BES Analytical and Economic Model

This section presents both the analytical model for the PV-BES system and the economic model used to compute the LCOE in assessing the system's economic profitability.

### A. PV System Analytical Model

The hourly energy produced by the PV arrays $E_{pv}$ can be found using eq. (1), where the solar irradiation $I_{pv}$ used in the calculations is illustrated in Fig. 3, and PV system efficiency $\eta_{pv}$ can be determined using eq. (2). From the equation, $\eta_{pv}$ is affected by several constant parameters such as module efficiency $\eta_{module}$, inverter efficiency $\eta_{inv}$, PV system degradation $DEG_{pv}$, and project lifetime N. Only one parameter is variable with time, which is temperature efficiency $\eta_{temp}$.

$$E_{pv,i} = I_{pv,i} \cdot A \cdot \eta_{pv,i} \ . \quad (1)$$

$$\eta_{pv,i} = \eta_{module} \cdot \eta_{temp,i} \cdot \eta_{inv} \cdot (1 - (N-1)DEG_{pv}) \ . \quad (2)$$

$$\eta_{temp,i} = [1 - \beta(T_{cell,i} - T_{ref})] \ . \quad (3)$$

$$T_{cell,i} = T_{amb,i} + [(NOCT - 20)/800] \cdot I_{pv,i} \ , \quad (4)$$

where A represents the required PV system area in $m^2$ expressed by $A = P_{pv}/(\eta_{module} H)$, and H is the yearly module reference in-plane irradiation, usually assumed to be 1 kW/$m^2$ [12]. The term $\beta$ in eq. (3) is the temperature coefficient of solar cell efficiency (1/° C), $T_{ref}$ is the PV cell reference temperature (° C), and NOCT in eq. (4) is the normal operating cell temperature (° C), while $T_{cell}$ and $T_{amb}$ are the PV cell temperature and ambient temperature respectively. The values of all parameters are shown in Table I.

### B. BES Analytical Model

The size of LAB, LIB and RFB can be obtained using eq. (5), according to which the capacity of the battery expressed in terms of the hours of autonomy HA which means for how many hours a completely charged battery is able to supply the load continuously. The average hourly demand $P_{L.avg}$, in this case, is equal to the total demand for one year divided by the number of hours in the year and is equal to 124.8 KWh. The capacities of the LAB, LIB and RFB are shown in table II.

$$CB = \frac{HA \cdot E_{load}}{\eta_{inv} \cdot \eta_{dch} \cdot DOD} \ , \quad (5)$$

where $\eta_{inv}$ and $\eta_{dch}$ are the inverter efficiency and battery discharge efficiency, and DOD is the depth of discharge which is chosen to be 80% for the three batteries. An important parameter to represent the state of the battery is the state of charge (SOC), which is used to decide whether to charge or discharge and to buy or sell energy. An energy balance is required every hour to find the SOC of the battery. If the PV-generated energy is greater than demand, $E_{pv} > E_{load}$, then the load will be supplied firstly and the extra PV energy will be used to charge the battery. The SOC equation in the charging case can be expressed as follows:

$$SOC_i = SOC_{i-1} + \frac{(E_{pv,i} - E_{load,i}) \cdot \eta_{ch}}{\eta_{inv} * CB} \ , \quad (6)$$

where SOC(t) and SOC(t-1) are the states of charge of the BES at time t and t-1 respectively.

On the other hand, if $E_{pv} < E_{load}$, the energy produced will be used to satisfy the load and any insufficiency will be covered by the BES. Eq. (7) shows the battery SOC discharging equation:

$$SOC_i = SOC_{i-1} - \frac{(E_{load,i} - E_{pv,i})}{\eta_{inv} \cdot \eta_{dch} \cdot CB} \ . \quad (7)$$

At any time, the battery SOC is subject to the following constraints:

$$SOC_{min} < SOC_i < SOC_{max} \ , \quad (8)$$

where $SOC_{min}$ and $SOC_{max}$ represent the minimum and maximum allowable SOC respectively and it is assumed that the initial SOC for the three batteries is equal to $SOC_{min}$.

### C. Economic Model

LCOE methods are widely used to evaluate the economic feasibility of PV systems and BESs. The costs distributed over the project lifetime are considered and this provides a more accurate economic picture of the project under analysis [6], [15], [16]. According to [16], the LCOE of a stand-alone PV-BES system can be obtained by dividing the total

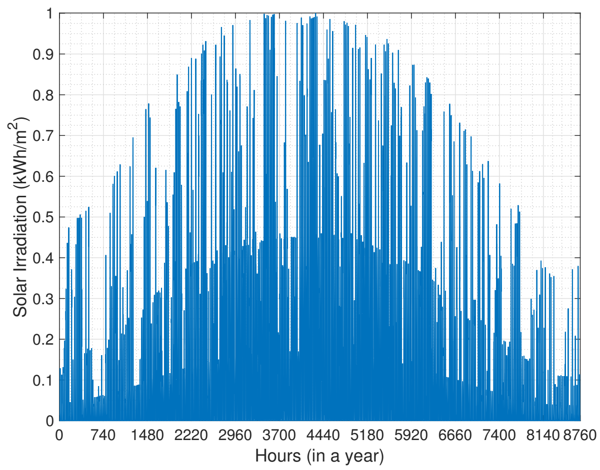


Fig. 3: Solar irradiation distribution over the reference year [13].

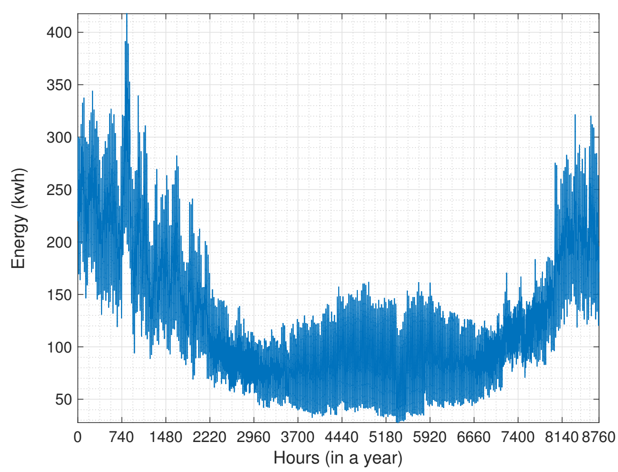


Fig. 4: Load distribution over the reference year [14].

cost of the system on the total energy generated. The energy generated from the PV utilized to supply the load and to charge the battery. Accordingly, the cost of the PV is computed in terms of these two components. The proposed model modifies the above-mentioned LCOE method to be used in a grid-connected PV-BES system. Eq. (14) derives the proposed system LCOE to find the optimal PV-BES size and best combination. According to this equation, the cost of the system is expressed by the cost of the PV system divided into three parts ($C_{PV.charge}$, $C_{PV.LD}$, and $C_{PV.Esold}$), the cost of the BES ($C_{St}$), and the difference between the cost of energy purchased and energy sold ($C_{E.purch} - C_{E.sold}$). Meanwhile the total energy in the system is the summation of energy stored in the BES, energy supplied to the load, energy sold and energy purchased. Equations (9) and (10) give the LCOE for the PV system which has two components: $C_{PV.Extra}$, which is the cost of extra PV energy used to charge the BES and sold to the grid; and $C_{PV.LD}$, the cost of energy used supplied to the load. Meanwhile $E_{PV.Extra}$ and $E_{PV.LD}$ are the extra PV energy and energy supplied to the load by the PV respectively.

$$LCOE_{PV} = \frac{\sum_{j=0}^{j=N} \frac{(C_{PV.Extra}+C_{PV.LD})_j}{(1+r)^j}}{\sum_{j=0}^{j=n} \frac{(E_{PV.Extra}+E_{PV.LD})_j}{(1+r)^j}} . \quad (9)$$

$$LCOE_{PV} = \frac{\sum_{j=0}^{j=N} \frac{C_{PV.charge j}}{(1+r)^j}}{\sum_{j=0}^{j=n} \frac{(E_{PV.Extra}+E_{PV.LD})_j}{(1+r)^j}} + \frac{\sum_{j=0}^{j=N} \frac{C_{PV.LD j}}{(1+r)^j}}{\sum_{j=0}^{j=N} \frac{(E_{PV.Extra}+E_{PV.LD})_j}{(1+r)^j}} . \quad (10)$$

The formula for LCOD in eq. (11) has also been introduced in [16], which modifies the storage LCOE by adding the cost of the PV arrays that are responsible for generating energy to charge the BES, taking into account the round trip efficiency ($\eta_{rt}$) of each battery and the levelized cost of storage (LCOS).

$$LCOD = LCOE_{E_{out}} = \frac{1}{\eta_{rt}} LCOE(E_{PV.charge}) + LCOS . \quad (11)$$

$$C_{E.purch} = E_{purch} \cdot P_{e.purch} . \quad (12)$$

$$C_{E.sold} = E_{sold} \cdot P_{e.sold} . \quad (13)$$

$$LCOE_{sys} = \frac{\sum_{j=0}^{j=N} \frac{C_{sys_j}}{(1+r)^j}}{\sum_{j=0}^{j=N} \frac{E_{sys_j}}{(1+r)^j}}$$

$$= \frac{C_{PV.charge} + C_{St} + C_{PV.LD} + C_{PV.Esold} + C_{E.purch} - C_{E.sold}}{E_{St,j} + E_{PV.LD,j} + E_{sold,j} + E_{purch,j}} . \quad (14)$$

Equations (15-18) represent the total cost of the PV-BES system (N=30 years, where r is the discount rate equal to 5%). Table I demonstrates the installation costs of the BES ($C_{St}$) and PV system considering three components of the PV cost. $C_{B.o\&m}$ and $C_{pv.o\&m}$ are the operating and maintenance costs for the BES and PV, while $N_{PVextra_T}$, $N_{PVload_T}$, $N_{PVEsold_T}$ are the fractions of PV arrays used to find the cost of PV and calculated using equations (22-24).

$$C_{St} = C_{B.inst} + \sum_{j=0}^{j=N} \frac{C_{B.o\&m}}{(1+r)^j} . \quad (15)$$

$$C_{PV.charge} = (C_{pv.inst} + \sum_{j=0}^{j=n} \frac{C_{pv.o\&m}}{(1+r)^j}) \cdot N_{PVextra_T} . \quad (16)$$

$$C_{PV.LD} = (C_{pv.inst} + \sum_{j=0}^{j=N} \frac{C_{pv.o\&m}}{(1+r)^j}) \cdot N_{PVload_T} . \quad (17)$$

$$C_{PV.Esold} = (C_{pv.inst} + \sum_{j=0}^{j=N} \frac{C_{pv.o\&m}}{(1+r)^j}) \cdot N_{PVEsold_T} . \quad (18)$$

$$E_{St,j} = \eta_{rt} \sum_{j=0}^{j=N} \frac{E_{PV.Extra} \cdot (1 - DEG_{BAT})^j}{(1+r)^j} . \quad (19)$$

$$E_{PV.LD,j} = \sum_{j=0}^{j=N} \frac{E_{PV.LD} \cdot (1 - DEG_{pv})^j}{(1+r)^j} . \quad (20)$$

$$E_{sold,j} = \sum_{j=0}^{j=N} \frac{E_{sold} \cdot (1 - DEG_{pv})^j}{(1+r)^j} . \quad (21)$$

The total energy generated by the grid-connected PV-BES, distributed over the lifetime of the project and including the energy purchased from the grid, are computed using equations (18-21), where $DEG_{BAT}$ is the degradation rate BES.

$$N_{PVcharge_T} = \frac{\sum_{i=0}^{i=Y} P_{PV.charge,i}}{\eta_{pv} \sum_{i=0}^{i=Y} I_{PV,i}} . \quad (22)$$

$$N_{PVload_T} = \frac{\sum_{i=0}^{i=Y} P_{PV.LD,i}}{\eta_{pv} \sum_{i=0}^{i=Y} I_{PV,i}} . \quad (23)$$

$$N_{PVEsold_T} = \frac{\sum_{i=0}^{i=Y} P_{PV.Esold,i}}{\eta_{pv} \sum_{i=0}^{i=Y} I_{PV,i}} , \quad (24)$$

Tables I and II demonstrate the values of all parameters in the proposed model.

TABLE I: Cost and technical specifications of PV system parameters.

| Parameter | Value/range | Ref. |
|---|---|---|
| $P_{pv}$ | 200-1400 KW, step 30 KW | |
| $\eta_{pv}$ | 14% | [8] |
| $\eta_{inv}$ | 92% | [8] |
| $DEG_{pv}$ | 0.5% | [8] |
| $\beta$ | 0.005/° C | [8] |
| $C_{PV}$ | $P_{pv} \cdot 2828.7 \cdot P_{pv}^{-0.128}$ | [12] |
| $C_{inv}$ | $1.1 \cdot P_{pv} \cdot Pr_{inv}$ | [17] |
| $Pr_{inv}$ | 0.56 £/W | [17] |
| $C_{pv.inst}$ | $C_{PV}$+$C_{inv}$ | |
| $C_{pv.o\&m}$ | 1% of $C_{pv.inst}$ | [18] |
| $C_{inv.rep}$ | $C_{inv}$, for j=10 &20 | [12] |
| $Pr_{cc}$ | 4.62 £/A | [17] |
| $C_{cc}$ | $(P_{pv}/V_b) \cdot Pr_{cc}$ | [17] |
| NOCT | 45° C | [8] |
| $T_{ref}$ | 25° C | |
| N | 30 years | |
| $P_{L.avg}$ | 124.8 KW | |
| HA | 5 Hours | |
| H | 1 KWh/$m^2$ | [12] |
| r | 5% | |
| $Pr_{e.purch}$ | 0.13822 £/KWh | [19] |
| $Pr_{e.sold}$ | 0.0485 £/KWh | [19] |

TABLE II: Cost and technical specifications of the batteries.

| Parameter | Lead-Acid | Lithium-Ion | Redox Flow | Ref. |
|---|---|---|---|---|
| $\eta_{rt}$ | 80% | 90% | 85% | [20] |
| $DEG_{BAT}$ | 3.7% | 2% | 0.1% | [9] |
| $\eta_{dch}, \eta_{ch}$ | 85% | 85% | 80% | [21] |
| life time | 5-15 | 5-20 | 10-15 | [22] |
| $C_{B.inst}$ | 250£/KWh | 850£/KWh | 700£/KWh | [21] |
| $C_{B.o\&m}$of $C_{B.inst}$ | 5% | 1% | 2% | [9] |
| CB | 1 Mwh | | | |
| $C_{B.rep}$ | $C_{B.inst}$ for j=10&20 | | | [8] |
| $SOC_{max}$ | 100% | | | |
| $SOC_{min}$ | 20% | | | |
| DOD | 80% | | | |

TABLE III: PV-BES system, PV system only and Grid only scenarios.

| Parameter | PV-RFB | Grid only | PV only |
|---|---|---|---|
| Energy Produced | 632.69 MWh | 0 MWh | 632.69 MWh |
| Energy Demand | 1093.4 MWh | 1093.4 MWh | 1093.4 MWh |
| Energy Purchased | 616.23 MWh | 1093.4 MWh | 789.14 MWh |
| Energy Sold | 156.3 MWh | 0 MWh | 328.38 MWh |
| Energy Self-Consumed | 75.3% | 0 % | 48.1% |

## IV. RESULTS AND DISCUSSION

The aim of the proposed model is to find the optimal configuration of the PV-BES for a grid-connected system using a technical and economic model. To implement the proposed model, a number of simulations are performed in Matlab for three combinations: PV-LAB, PV-LIB, and PV-RFB. The LAB and LIB are conventional rechargeable batteries that offer a simple and efficient way to store electricity, while The RFB is a recent battery technology with advantages of high efficiency and large scale. The solar irradiation and temperature profiles used in these simulations are for the Isle of Wight and downloaded from NREL (National Laboratory of the US Department of Energy) [13]. Since it was difficult to get the actual load profiles for the Isle of Wight, the profiles used in these simulations were downloaded from OpenEI (US Department of Energy) [14]. In this study the lifetime of the system is 30 years, where the batteries, inverter and charge controller are replaced twice during the system lifetime at 10 and 20 years. Using eq. (5) the capacities of the batteries are calculated for 5 HA. As illustrated in Table II, the variations in capacities were around 1MWh, and so all of the batteries are assumed to have values of 1MWh. After running the simulations, the relationship between the different sizes of

TABLE IV: System LCOE and batteries LCOD at 710 KW.

| PV-BES | $LCOE_{sys}$ (£/KWh) | Battery | $LCOD$ (£/KWh) |
|---|---|---|---|
| PV-LAB | 0.1211 | LAB | 0.167 |
| PV-LIB | 0.1348 | LIB | 0.1711 |
| PV-RFB | 0.1135 | RFB | 0.1394 |

TABLE V: PV-RFB components sizes.

| Component | Size |
|---|---|
| PV | 710 KW |
| RFB | 1 MWh |
| Inverter | 781 KW |
| Charge controller | 14791.7 A |

PV with the three batteries are illustrated in Fig. 5, where each line represents the LCOE of the three combinations. In order to find the optimal PV size and battery type, the LCOE values should be lower than 0.13822 £/KWh (the price of energy purchased from the grid) for all tested scenarios. Table IV shows the minimum values of LCOE for the three combinations and LCOD values for LAB, LIB, and RFB. It can be seen that the best scenario presenting a minimum LCOE equal to 0.1135 £/KWh is when the PV rated power is 710 KW for the combination PV-RFB. Furthermore, by looking at LCOD values for the RFB, we found that their values are higher than LCOE values for the whole system, and this is due to the high cost of BES and the energy stored in it being small compared to the energy produced by the system. The ratio of the BES cost to its energy will be higher than the ratio of the total system cost to its produced energy, and this is the reason why the LCOD values shown in Fig. 6 is higher than the system LCOE values. Fig. 7 demonstrates the energy purchased and sold during one year. It is noticed that, during the winter the energy purchased from the grid is much higher than in the summer, which is obviously due to the lower generation of PV energy in the winter. The extra PV energy sold to the grid is concentrated in the summer months and is almost zero during the rest of the year. Fig. 8 displays the RFB state of charge during the same year, the SOC during summer days is higher due to the availability of solar irradiation. The sizes of all components of the grid-connected PV-RFB are displayed in Table V. The inverter size is found by $P_{inv} = 1.1 \cdot P_{pv}$, while the charge controller size is determined by $P_{cc} = P_{pv}/battery\ voltage$ (battery

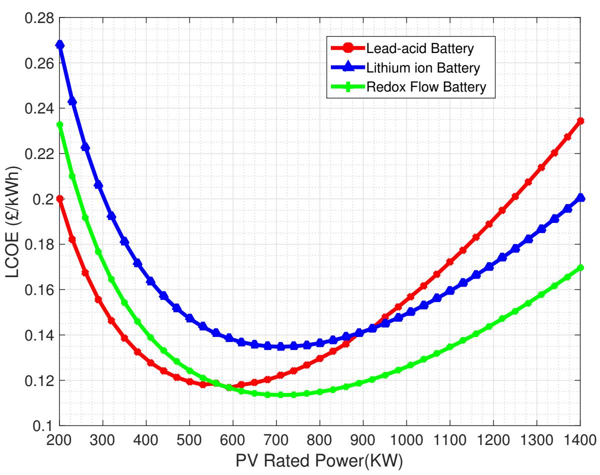


Fig. 5: LCOE of the grid-connected PV-BES.

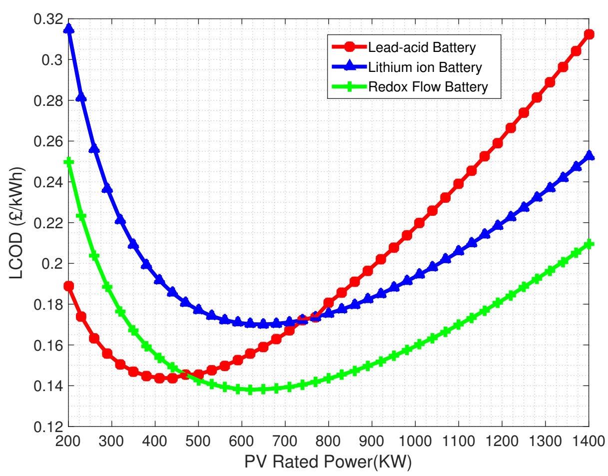


Fig. 6: LCOD of LAB, LIB and RFB.

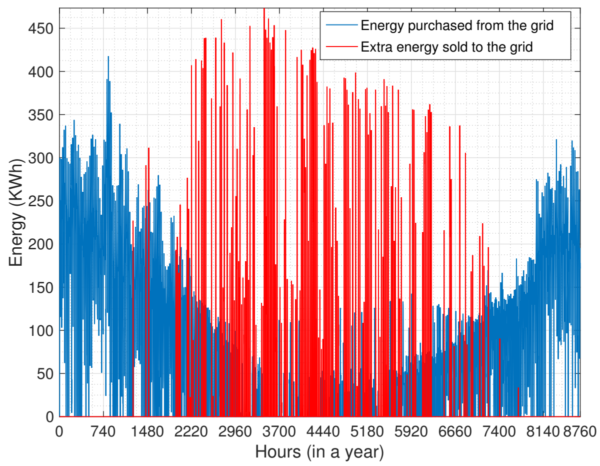


Fig. 7: Energy purchased and extra PV energy sold to the grid.

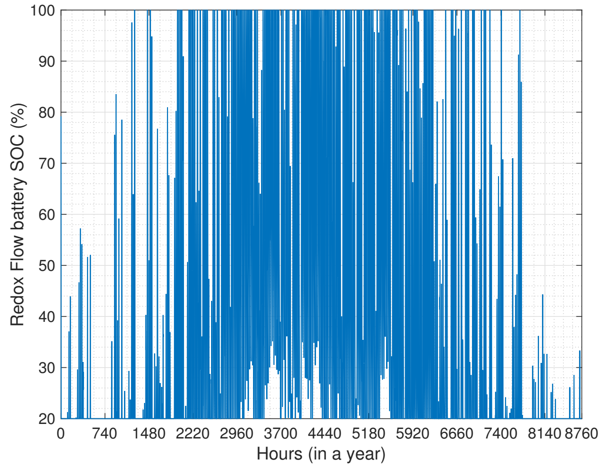


Fig. 8: State of charge for redox flow battery.

voltage=48 V). Table III illustrates the amount of yearly energy production, yearly energy demand and the energy purchased and sold to the grid for the three scenarios. For the PV-BES the percentage of self-consumed energy is higher than considering the PV system alone (75% and 48% respectively). Moreover, the energy purchased from the grid for the proposed PV-BES is 616.23MWh, which is obviously less than the energy purchased in the other two scenarios. Therefore, the proposed technical and economical model has been proven to produce promising results that will help in solving energy problems in the Isle of Wight.

## V. Conclusion

In this paper, a technical and economical model for the optimal sizing of a grid-connected PV-BES system for different battery technologies is proposed. An improved formula for LCOE is utilized to find the best PV-BES combination at the optimal PV rated power. The LCOE calculation includes new parameters to reflect the impact of surplus PV output and the energy purchased from the grid, as well as looking at the PV system cost in a different way by dividing it into three parts: i) the cost of the part generating energy to supply the load; ii) the cost of the part generating energy to charge the battery; and iii) the cost of the part generating extra energy. The results obtained show that the best battery type to be combined with the PV system to give the minimum system LCOE (0.1135£/KW) is the redox flow battery with a size of 1 MWh, and the PV size at 710 KW. A reduction of 18% in electricity cost with respect to the grid electricity price is obtained (0.13822£/KWh). Moreover, the proposed model allows for 75% of self-consumed energy of the PV-BES system compared to 48% when using the PV alone.

## References


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