



Impact Optimization Of Battery Energy Storage System In Microgrid Operation

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Abstract. In microgrid operation, one of the most vital tasks of the system control is to wisely decide between selling excess power to the local grid or charge the Battery Energy Storage System (BESS). Our study uses Mixed-Integer Linear Programming (MILP) to investigate the impact of storage system on the operational cost of a microgrid. The results suggested that, the presence of BESS would relieve the pressure on the utility grid but not the cost of electricity due to the expensive nature of the storage plant. In view of this, it will be more beneficial to sell excess renewable generated power to the utility grid than to invest in a storage system for larger microgrids

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1. Introduction

In a microgrid operation that involves a storage plant and also connected to the grid, one of the most important tasks of the system control is to decide between feeding the grid with excess power or charge the storage plant. The system control also ensures that, BESS can sustain the demand side during voltage fluctuations [3]. the authors using mixed-integer linear programming discuss the following,

- the behaviour of the power dispatch (load profile).
- the best time to charge and discharge the BESS.

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- the decision made by the system control to either charge or sell excess power to the grid.

With the help of optimization, we can investigate how big of a role storage plant plays in microgrids. A larger energy storage system will require a higher investment cost [1]. Regardless of this, storage plants provides numerous benefits in microgrid operations. Optimization models will be adopted to represent the microgrid operations. These models will represent the objective function and constraints for the optimization. The microgrid will involve photovoltaic modules, storage plants, and the utility grid. The size of the microgrid storage will be proportional to the community it serves [3]. A grid-tie photovoltaic microgrid will consist of many photovoltaic modules, an inverter for converting DC to AC and vice versa, breakers and a bi-directional electric meter. Although previous research works covers a vast variety of such techniques, this paper will focus on using Mixed-Integer Linear Programming (MILP) to investigate the impact of storage system on the operational cost of a microgrid.

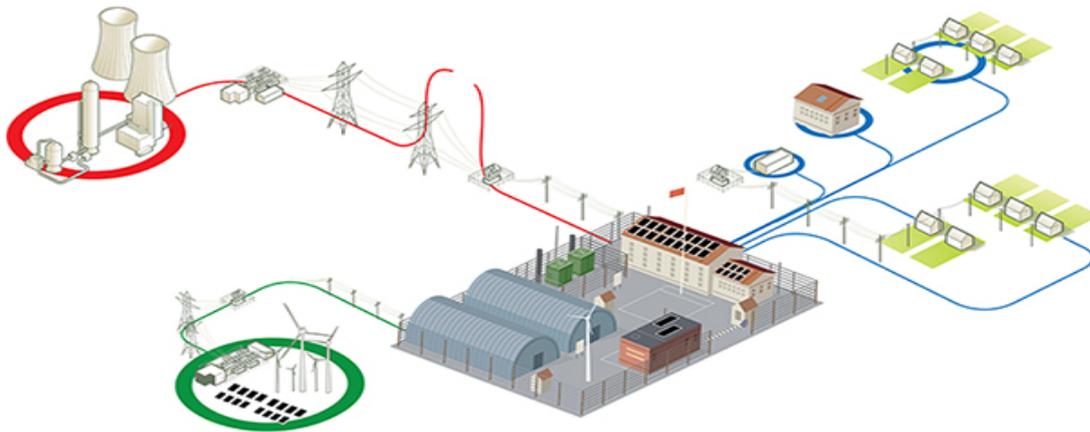


Figure 1: A grid-connected microgrid.

Figure 1 illustrate a diagrammatic representation of a grid-connected microgrid [4].

2. Literature Review

Implementation and the understanding of Battery Energy Storage System (BESS) in microgrid operation have triggered many studies using various techniques. Talking about studies, some of the previous related works on BESS and microgrid are, [5] who studied on the optimal sizing model of a BESS adapting to scheduling plan to investigate the investment cost of wind farm BESS. The focus of this work was aimed at maximizing the benefit of wind farm storage considering BESS investment cost. The result justified that BESS can be applied to a wind farm with less investment cost. For the concern of the depletion of global conventional energy and the fluctuation in distributed energy, [11] researched on how BESS can mitigate the bad effect of distributed energy generation using optimal

scheduling. Using Lagrangian relaxation,[9] recommend an additional method for solving short-term generation scheduling problems. Based on the success of the algorithm, it was concluded that using Lagrangian relaxation offers a fast, robust and efficient computation. For a remote power system, [6] developed a Mixed-Integer Linear Programming (MILP) model in General Algebraic Modeling Systems (GAMS) to optimize the operation of such systems. Due to the nature of the model's simplicity, it was concluded that MILP has an exceptionally low execution time. Lastly, in order to minimize the emissions and cost of microgrids, the branch-and-cut method was used by [10]. The microgrid in this work by [10] involved photovoltaic and for effective coordination, the Markovian process was used to model their uncertainties.

3. Methods

In this study, the models of a grid-connected microgrid involved a storage system, photovoltaics as the renewable energy sources and the utility grid which will serve as the main power supply. The models (objective function and constrained) formed a Mixed-Integer Linear Programming model which was optimized in AMPL using the CPLEX solver. Electricity can travel from the PV modules to the grid but not the reverse as seen from Fig. 2 and electricity from the grid will not be used to charge the BESS. Needless to say, the BESS will be charge with electricity provided by the photovoltaic modules.

4. Optimization Model

Determining the problem parameters and variables remain the most essential part of this work. Some of these parameters were estimated and others were researched from literatures. The problem formulation included identifying the appropriate objective function and its constraints. Electricity consumption data from the Northern Electricity Distribution Company (NEDCo, Ghana's key player in power distribution) was used to determine the parameters of the objective function and constraints, this crucial data includes the prices of electricity and the energy consumed by the community.

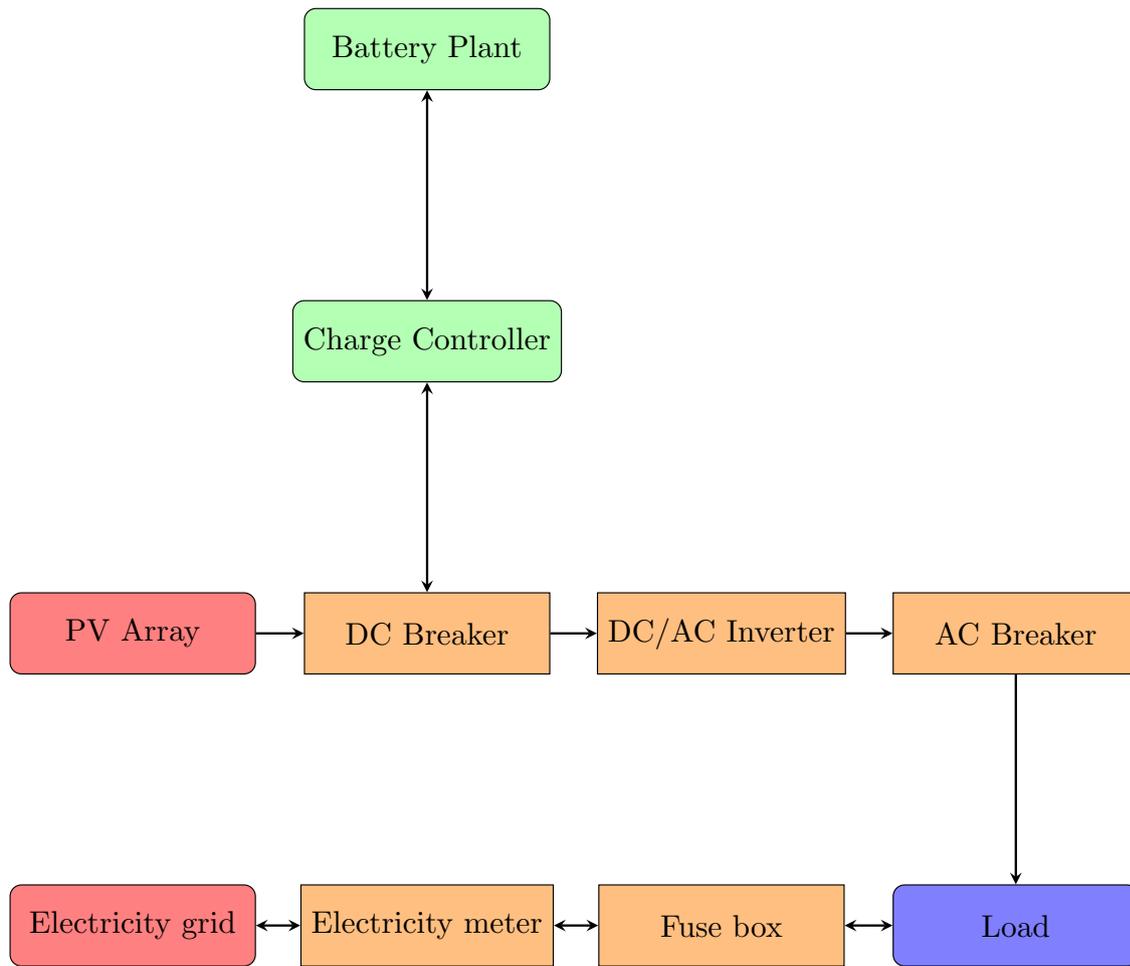


Figure 2: Schematic Diagram of the flow of energy in a microgrid

4.1. Nomenclature of Variables

From Table 1, we find the number of decision variables present in this work. These variables are indexed on a 24-hour time interval.

Table 1: Nomenclature of Variable

Symbols	Description
PV_u^t	used PV power
PV_s^t	sold PV power
$grid_u^t$	used grid power
$batt_c^t$	power used to charge the battery
$batt_d^t$	power discharge from the battery
$batt^t$	power in the storage
$Bstat_c^t$	the battery charging status

$Bstat_d^t$ | the battery discharging status

4.2. Nomenclature of Parameters

Likewise the model variables, we also have the parameters such as the average amount of consumed electricity by the community. This will be part of the model formation and computation.

Table 2: Nomenclature of Parameter

Symbols	Description
PV_m^t	generated PV power
$grid_m^t$	available grid power
$load^t$	the load demand
$price_g$	the price of a unit purchase of electricity
$price_s$	the price of a unit sold of electricity
$payB$	capital, O&M Cost
$Bcap$	the battery maximum capacity.
$Bcap_d$	daily needed battery capacity
$Tload_d$	total daily demand.
SV	battery system voltage.
T	Time=24

4.3. Cost Minimization

The decision to either involve the BESS or not depends on the operational cost. Therefore our objective is to minimize this cost,

$$\text{Minimize } \mathcal{F} = \sum_{t=1}^T price_g * grid_u^t + payB - price_s * PV_s^t \quad (1)$$

4.4. System Power Balance

The power balance constraint ensures that there is greater or equals supply of power to meet the need of the community.

$$grid_u^t + PV_u^t + batt_d^t - PV_s^t - batt_c^t \geq load^t, \quad \forall t \in \{1, 2, \dots, T\} \quad (2)$$

This power balance constraint is very essential because at all times we expect the system to produce enough power to meet the demand of the communities.

4.5. Photovoltaic Maximum Output

This constraint ensures that the amount of available photovoltaic power that can be used is not above the maximum amount of power that can be generated by the photovoltaic

modules at $t \in T$

$$PV_u^t \leq PV_m^t, \quad \forall t \in N_T \quad (3)$$

4.6. Power Available from the Grid

It will be assumed that one can purchase any amount of power from the utility grid.

$$grid_u^t \leq grid_m^t, \quad \forall t \in N_T \quad (4)$$

4.7. Storage Capacity

Storage plant have a maximum capacity of power it can hold. Therefore,

$$batt^t \leq Bcap, \quad \forall t \in N_T \quad (5)$$

4.8. Battery Charging and Discharging Status

The storage plant will not be allowed to charge and discharge at the same time. This reason is to prolong the lifespan of the batteries as most batteries are affected by continuous usage whiles charging [8].

$$Bstat_c^t + Bstat_d^t \leq 1, \quad \forall t \in \{1, 2, \dots, T\} \quad (6)$$

$$Bstat_c^t, Bstat_d^t \in \{0, 1\}$$

Eq(6) enforce a binary constraint on the batteries to prevent them from discharging and charging at the same time.

That is if

$$Bstat_c = 0, \quad Bstat_d = 0 \quad \text{then} \quad 0 + 0 < 1$$

again, if

$$Bstat_c = 0, \quad Bstat_d = 1 \quad \text{then} \quad 0 + 1 = 1$$

again, if

$$Bstat_c = 1, \quad Bstat_d = 0 \quad \text{then} \quad 1 + 0 = 1$$

lastly, if

$$Bstat_c = 1, \quad Bstat_d = 1 \quad \text{then} \quad 1 + 1 \not\leq 1$$

4.9. Discharge Variable Coupled with Discharging Status

It has already been stated in constraint e above that the batteries can not charge and discharge at the same time.

$$batt_d^t \leq Bcap * Bstat_d^t, \quad \forall t \in \{1, 2, \dots, T\} \quad (7)$$

Therefore the maximum amount that can be discharge will depend on the discharging status and the capacity of the batteries. So if the discharge status $Bstat_d = 0$ then, the amount of power that can be discharged from the batteries is zero 0 otherwise less than the maximum capacity of the batteries.

4.10. Charge Variable Coupled with Charging Status:

$$batt_c^t \leq Bcap * Bstat_c^t, \quad \forall t \in \{1, 2, \dots, T\} \quad (8)$$

Therefore the maximum amount that can charge the batteries will also depend on the charging status and the capacity of the batteries. So if the charge status $Bstat_c = 1$ then, the amount of power that can be charged the batteries is less than the maximum capacity of the batteries otherwise zero 0.

4.11. Storage Charging Limit

This constraint checks the amount of power that can charge the batteries.

$$batt_c^t + batt^{t-1} \leq Bcap, \quad \forall t \in \{1, 2, \dots, T\} \quad (9)$$

eqn (9) explains that always the sum of the available power in the batteries at the previous hour ($t - 1$) plus the amount charged at current t should be less or equal to the capacity of the batteries.

4.12. Storage Discharging Limits

Since the storage plant can not discharge an amount of power it does not have, eqn 10 ensures that the amount of power that can be discharged from the microgrid is less or equal to the battery state at period $t - 1$.

$$\lambda_d^t \leq \lambda^{t-1}, \quad \forall t \in \{1, 2, \dots, T\} \quad (10)$$

4.13. State Balance of Battery

Like the power balance, this constraint also ensures that the battery is also balanced. At the long run and at each time period the amount of power stored in the batteries depends on the batteries discharge, the batteries charge and the previous state of charge of the batteries.

$$batt^t = batt^{t-1} - batt_d^t + batt_c^t \quad \forall t \in \{1, 2, \dots, T\} \quad (11)$$

Therefore the current power in the batteries should be equal to the sum of previous power in the batteries and the amount of power that charged the plant minus the amount discharged from the plant.

4.14. Minimum Power to Remain in the Battery

Deep drain of battery has a negative effect on the battery, for this reason it is important that the storage work within a safe operation range of about 20% minimum and maximum of 100% [8].

$$batt^t \geq 0.2 * Bcap, \quad \forall t \in \{1, 2, \dots, T\} \quad (12)$$

4.15. Initial State of the Battery

Here it is assumed that the storage plant is half charged at the beginning of the computation of the models.

$$batt^0 = 0.5 * Bcap \tag{13}$$

4.16. State of the Battery for the Next Day

This constraint replenish the initial power for the next day. If the system is not design to store the initial power at the end of the day then, additional unaccounted power have been fed into the system.

$$batt^{24} \geq 0.5 * Bcap \tag{14}$$

4.17. Avoid Charging from the Grid

This constraint prevents the charge of batteries with energy from the grid.

$$grid_u^t \leq load^t, \quad \forall t \in \{1, 2, \dots, T\} \tag{15}$$

4.18. Non Negativity Constraint

The variables in the optimization problem will not be allowed to assume negative values.

$$\begin{aligned} PV_u^t, PV_s^t, grid_u^t, batt_c^t, batt_d^t, batt^t, Bstat_c^t, \\ Bstat_d^t \geq 0 \quad \forall t \in \{1, 2, \dots, T\} \end{aligned} \tag{16}$$

5. Results

5.1. Solar Panels Connected to the Grid and Batteries

These microgrid components consist of a storage plant, photovoltaic modules, and the grid. Over a 24-hour horizon, the optimal power scheduling will be investigated to decide whether to sell the excess power to the grid or store the energy.

Table 3: Optimization results in MW

T	PV_u	$batt_d$	PV_s	$batt_c$	$grid_u$	$load$	$batt$
0	0	0	0	0	0	0	$T_o = 61.08$
1	0	4.14	0	0	0	4.14	56.94
2	0	4.02	0	0	0	4.02	52.92
3	0	3.93	0	0	0	3.93	48.99
4	0	3.87	0	0	0	3.87	45.12
5	0	4.02	0	0	0	4.02	4.10
6	0.27	3.92	0	0	0	4.19	37.18
7	2.02	1.66	0	0	0	3.68	35.52

8	5.01	0	0	1.62	0	3.39	37.14
9	8.13	0	0	4.80	0	3.33	41.94
10	11.02	0	0	7.59	0	3.43	49.53
11	13.42	0	0	10.06	0	3.36	59.59
12	14.2	0	0	10.76	0	3.44	70.35
13	13.35	0	0	9.85	0	3.50	80.20
14	11.77	0	0	8.25	0	3.52	88.45
15	8.76	0	0	5.02	0	3.74	93.47
16	5.33	0	0	3.77	2.32	3.88	97.24
17	1.84	2.03	0	0	0	3.87	95.21
18	0.22	3.89	0	0	0	4.11	91.32
19	0	5.31	0	0	0	5.31	86.01
20	0	5.36	0	0	0	5.36	80.65
21	0	5.33	0	0	0	5.33	75.32
22	0	5.14	0	0	0	5.14	70.18
23	0	4.71	0	0	0	4.71	65.47
24	0	4.39	0	0	0	4.39	61.08

Optimizing equation (1) subject to constraints (2)-(16) in AMPL determines the values of the unknown variables (Table. 3) for the optimization problem. The value of these variables are then computed by summing their values over the 24-hour horizon. Knowing the decision variables coefficient, $price_g = 801$ (unit MW cost of electricity purchased) and $price_s = 600$ (unit MW cost of electricity sold), we can compute the objective function.

Given the total power purchased from the grid, $\sum_{t=1}^{24} grid_u^t = 2.32$ and the total power sold

to the utility grid, $\sum_{t=1}^{24} PV_s^t = 0$, the cost can be computed as;

$$\begin{aligned}
 \mathcal{F} &= \sum_{t=1}^T (price_g \times grid_u^t - price_s \times PV_s^t) + payB \\
 &= (801 \times 2.32 - 600 * 0) + 264,657.897 \\
 &= 1858.32 - 0 + 264,657.897 \\
 &= 266,516.21
 \end{aligned}
 \tag{17}$$

A plot of the hourly power dispatch.



Figure 3: A graph showing the power scheduling

5.1.1. Sensitivity Analysis

At any hour of the day, a unit increase in the demand for electricity from the consumption side will attract a shadow price of GHS801. Once more, a decrease in the demand will reduce the cost function by the equivalent amount. Increasing and decreasing the photovoltaic maximum output by 1MW affect the cost function by a decrease of GHS801 and an increase of GHS801 respectively at any hour of the day. It is because when demand is not met, a unit increase in the photovoltaic output will spare us GHS801 in purchasing power from the grid. When the battery is sufficiently charged and demand is met, a unit increase in the photovoltaic module output will reduce the cost function by GHS600 since these generated power will be sold to the grid for that amount. Where GHS801 and GHS600 is the price for 1MW of electricity purchased from and sold to utility grid respectively according to the Public Utilities Regulatory Commission [7].

6. Discussion

As stated earlier, the objective of this paper was to optimize a microgrid to investigate the impact of a storage plant. Many factors will contribute to the operational cost of a microgrid. These costs depend on the type of investors or stakeholders involved in the

construction of the microgrid. Since the power from the storage plant doesn't incorporate a cost component in the objective function, what the system does is to discharge the plant in the morning and evening where there is no power supply from the photovoltaic modules as seen from Figure 3. The storage plant then got charged during the day after demand was met. The initial power in the storage plant was 61.08MW and the final power for the next day was 61.08MW. At 4:00 pm the system purchase 2.32MW from the grid to meet the demand of the communities while using the power from the photovoltaic to charge the battery. It cost GHS801 to purchase a unit power from the grid and GHS600 when power is sold to the grid. The system favoured the option of charging the storage plant to selling to the grid because a unit accumulated power can be discharged and save the communities GHS801 than to sell that unit power to the utility grid for GHS600. The presence of the storage plant has relieved the pressure on the utility grid. The microgrid system control will therefore only purchase power from the grid if there is insufficient power from the photovoltaic modules and the storage plant is charging.

7. Conclusion

Due to the expansive nature of energy storage [2] it will be advisable not to involve storage system in larger installed microgrid capacity, but their presence in a microgrid will go a long way to save the amount of power purchased from the grid. If the objective is to minimize the pressure on the utility grid, then the implementation of these storage plants will play a vital role in accomplishing the objective. Keeping up with the operational, maintenance, and replacement of storage plant is expensive and for the purpose of minimizing the operational cost, its involvement will have a negative impact on our initial objective. Then again, in the long run there might be enough cost savings to payback the capital and operational cost of the setup. We will be neglecting the possibility of cost savings because from our initial solution, the amount of PV power sold was zero (0).

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