BESS ANALYSIS

- Kilokari ic1BESS Analysis

Parameters available

['Datetime', 'Date', 'Time', 'Energy']

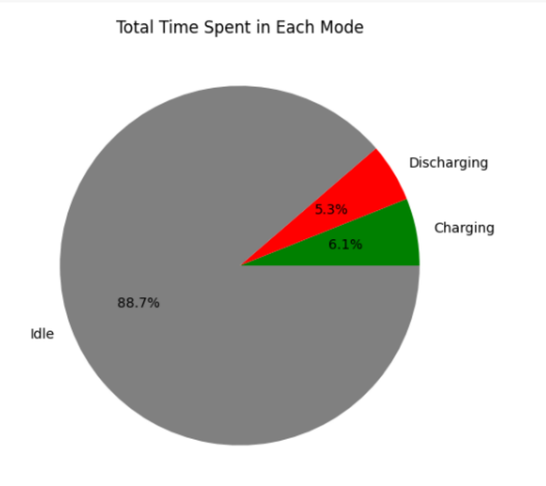
1. BESS Operating Modes (Charging/Discharging)

• Positive Active Power: BESS is discharging (supplying power)
• Negative Active Power: BESS is charging (absorbing power)
• Zero Power: Idle or offline

```
Mode Durations (seconds):
 Mode
Charging        36603.0
Discharging     31844.0
Idle           536113.0
Name: Time_Diff_sec, dtype: float64

Mode Transitions:
 Mode
Charging       223
Discharging    222
Idle            26
Name: count, dtype: int64

Idle Time %: 88.68%
```



Breakdown of Results:

1. Mode Durations (in seconds)

Mode	Duration (s)	Duration (hh:mm:ss)
Charging	36,603 s	~10 hours 10 minutes
Discharging	31,844 s	~8 hours 50 minutes
Idle	536,113 s	~148 hours 22 minutes

1. **Interpretation:**
    1. The system spent **most of its time in Idle mode** — not charging or discharging.
    2. **Only ~10% of the total time** was spent actively charging or discharging.

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2. Mode Transitions (counts)

Transitioned To	Count
Charging	223
Discharging	222
Idle	26

1. **Interpretation:**

1. The BESS switched into **charging mode 223 times** and **discharging 222 times**, indicating frequent short cycles.
2. Only **26 transitions into idle**, meaning once it's idle, it stays idle for long durations.

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3. Idle Time %

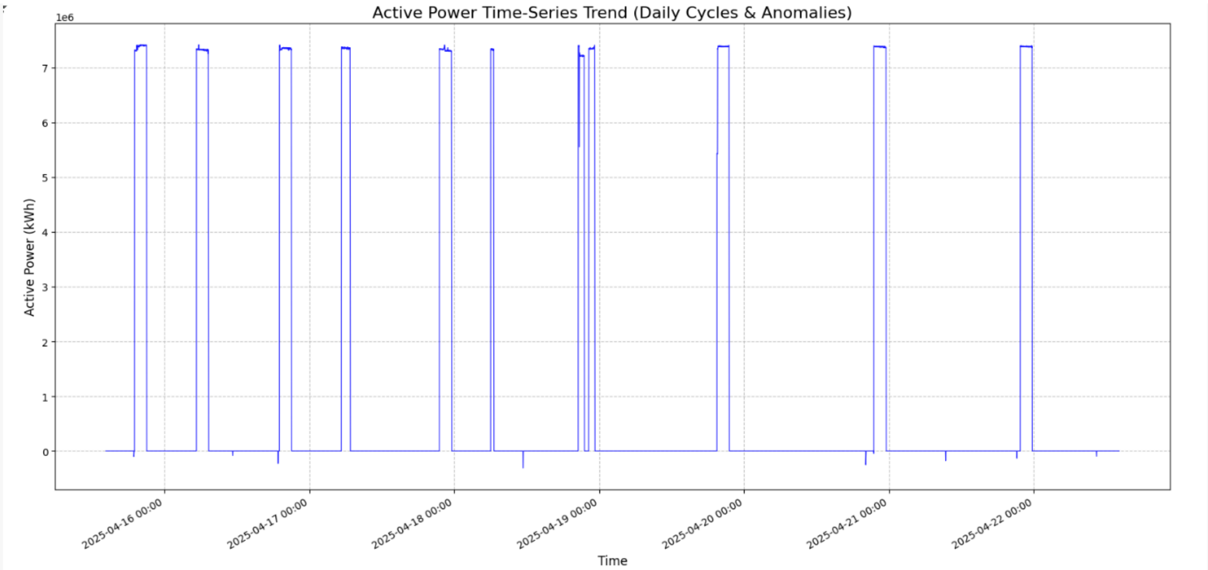
Idle Time % = 88.68%

1. **Interpretation:**
    1. The BESS is **inactive nearly 89% of the time**.
    2. This could indicate:
        1. Overprovisioned capacity
        2. Poor scheduling of storage
        3. Low demand
        4. Seasonal effects
        5. Or system inefficiency

Summary:

The BESS is **underutilized**, with only about **11% of the time spent actively charging/discharging**, despite **hundreds of mode transitions**. This could highlight areas for operational improvement, load matching, or demand-based optimization.

2. Time-Series Trend Analysis
1. Plot active power over time to observe
2. Daily charge/discharge cycles
3. Peak discharge/charge times
4. Sudden drops or anomalies



1. **Observation:** The plot clearly shows periods where "Active Power (kWh)" is at or near zero for extended durations, interspersed with periods where the power sharply rises to a high level (around 7.4 kWh) and remains there for a relatively short time before dropping back to zero.

2. **Interpretation:** This visually confirms the existence of three distinct operational "modes" as suggested by our previous analysis:
    1. **Idle Mode:** Represented by the long, flat lines at 0 kWh. The system is inactive during these times. This aligns with the Mode column showing "Idle" when Active_Power is 0.0.
    2. **Active Mode (Charging/Discharging):** Represented by the tall, rectangular-like spikes. During these periods, the system is actively consuming or generating power. Since the values are consistently positive and high (around 7.4 kWh), this likely represents a specific operational state, perhaps a high-power charging or discharging phase where the system is drawing a significant amount of energy.

2. Mode Durations (Visual Inference)

1. **Observation:** The "Idle" periods span many hours, often appearing to last for more than half a day or even multiple days consecutively (e.g., from April 19th through most of April 20th). The "Active" periods, in contrast, are much shorter, appearing as narrow vertical blocks.
2. **Interpretation:** This strongly supports the previous numerical breakdown:
    1. The BESS spends the *vast majority* of its time in **Idle mode**.
    2. The time spent in **Active mode** (charging/discharging) is comparatively very short.
    3. This is visually consistent with the 88.68% Idle Time reported previously. The "on" periods total around 10-20 hours over a week, while the "off" periods are hundreds of hours.

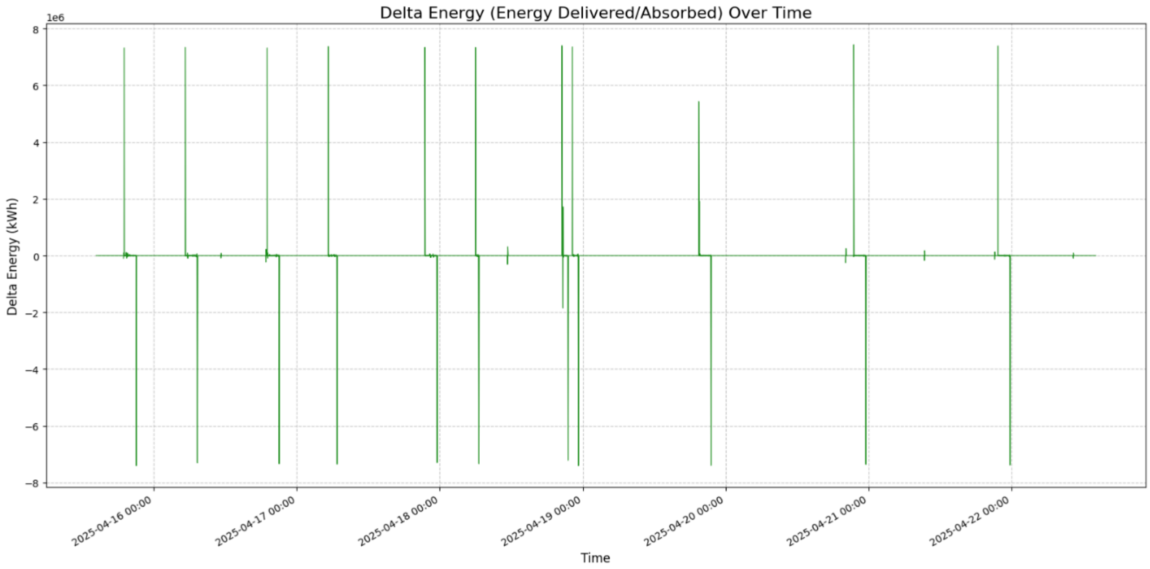
Summary:

The plot perfectly illustrates and validates the numerical summary provided earlier. It visually confirms that:

I. The BESS spends a dominant portion of its time in an **idle (inactive) state**.
II. When active, it operates in **frequent, short bursts** at a consistent high power level.
III. There are **numerous transitions into active states** (hundreds), but far fewer transitions back into idle, indicating long idle durations.
IV. The system exhibits a highly **intermittent operational profile**, confirming significant **underutilization** (around 89% idle time) as concluded in your previous analysis.

3. Energy Delivered or Absorbed
    V. Since energy is cumulative (usually in kWh):
    VI. Compute ΔEnergy between each time step
    VII. we can find how much energy was delivered or stored in each interval

```
DataFrame with 'Delta_Energy_Calculated' column:
                     Energy  Delta_Energy_Calculated
Datetime
2025-04-15 14:14:00     0.0                      NaN
2025-04-15 14:18:00     0.0                      0.0
2025-04-15 14:22:00     0.0                      0.0
2025-04-15 14:26:00     0.0                      0.0
2025-04-15 14:30:00     0.0                      0.0
2025-04-15 14:34:00     0.0                      0.0
2025-04-15 14:38:00     0.0                      0.0
2025-04-15 14:42:00     0.0                      0.0
2025-04-15 14:46:00     0.0                      0.0
2025-04-15 14:50:00     0.0                      0.0

Descriptive statistics for Delta_Energy_Calculated:
count    2.505000e+03
mean     0.000000e+00
std      6.852243e+05
min     -7.406792e+06
25%      0.000000e+00
50%      0.000000e+00
75%      0.000000e+00
max      7.435688e+06
Name: Delta_Energy_Calculated, dtype: float64
```



This analysis of Delta_Energy_Calculated provides the most explicit view of the BESS's active charging and discharging operations:

1. The BESS clearly engages in both **high-rate energy delivery/consumption (charging)**, indicated by the positive spikes (around +7.4 MWh per interval).
2. And **high-rate energy absorption/generation (discharging)**, indicated by the equally large negative spikes (around -7.4 MWh per interval).
3. These active periods are **intermittent and brief**, as evidenced by the sharp, narrow spikes and the overwhelming amount of time spent at zero ΔEnergy (idle).
4. The symmetry of the min and max ΔEnergy values, coupled with a mean of zero, suggests a system that efficiently balances its energy inputs and outputs over time, even though individual transitions are very high power.
5. The plot of Delta Energy provides a more direct representation of **"true power"** (rate of energy flow) than a simple cumulative "Energy" or even "Active Power" if the latter only showed positive values for consumption.

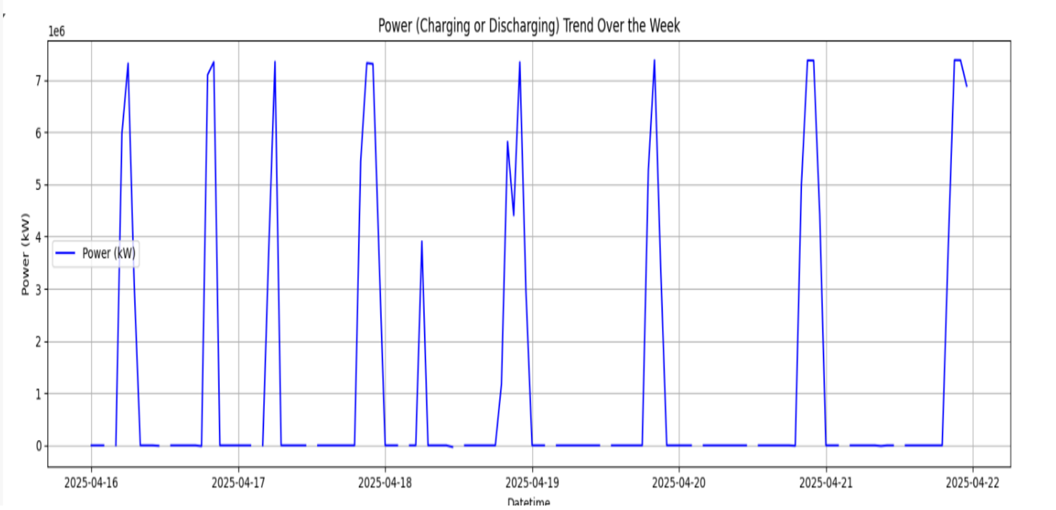
In essence, this plot graphically confirms the BESS's "charge/discharge" cycles, showing periods where it rapidly draws energy (positive delta) and periods where it rapidly injects energy (negative delta), while spending most of its time inactive.

2. Charging Discharging BESS Analysis

```python
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns

# Load the Excel file
file_path = "charging discharging.xlsx"
df = pd.read_excel(file_path)

# Display first few rows
print(df.head())
```

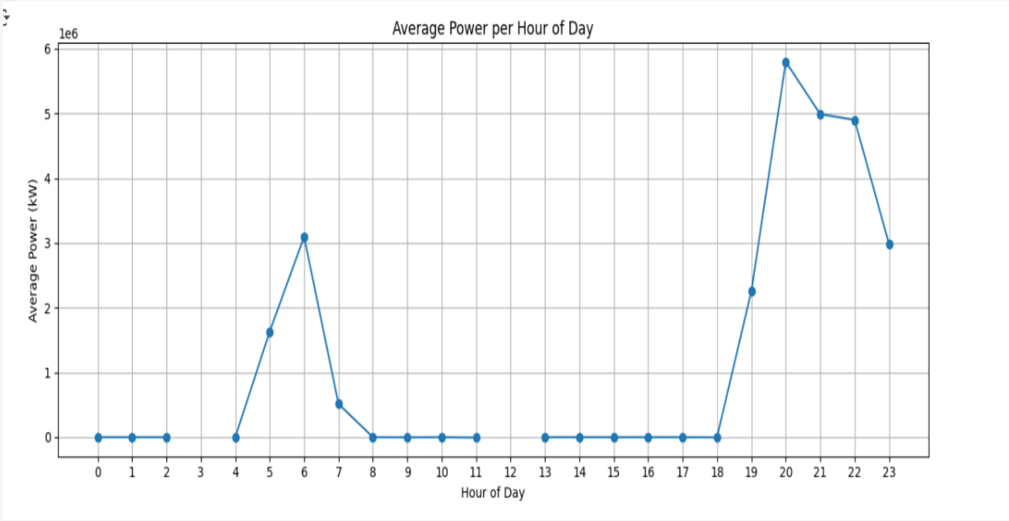
```
  charging and discharging in hourly  16.04.2025  17.04.2025  18.04.2025  \
0                           00:02:00         0.0         0.0         0.0
1                           00:06:00         0.0         0.0         0.0
2                           00:10:00         0.0         0.0         0.0
3                           00:14:00         0.0         0.0         0.0
4                           00:18:00         0.0         0.0         0.0

   19.04.2025  20.04.2025  21.04.2025
0         0.0         0.0         0.0
1         0.0         0.0         0.0
2         0.0         0.0         0.0
3         0.0         0.0         0.0
4         0.0         0.0         0.0
```

```python
# 1. Line Plot (Trend over week)
plt.figure(figsize=(15, 5))
plt.plot(df_hourly.index, df_hourly, label='Power (kW)', color='blue')
plt.title('Power (Charging or Discharging) Trend Over the Week')
plt.xlabel('Datetime')
plt.ylabel('Power (kW)')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```



Potential Insights from this Plot:

1. **Operating Strategy:** The pattern suggests a specific operational strategy for the BESS.
   1. **Peak Shaving/Arbitrage:** The BESS is being heavily utilized at certain times of the day, possibly to discharge during periods of high electricity prices/demand (discharging) or to charge during periods of low prices/high renewable generation (charging).
   2. **Ancillary Services:** The sharp, frequent spikes could also indicate participation in fast-response grid services like frequency regulation, where the BESS rapidly charges/discharges to maintain grid stability.
2. **Capacity Utilization:** The periods of zero power indicate times when the BESS is not actively contributing power. This could be due to:
   1. Being fully charged or discharged.
   2. Lack of market signals or grid demand.
   3. Scheduled idle periods.
3. **Daily Energy Throughput:** The area under the curves (if we had separate charging and discharging data) would represent the daily energy throughput, allowing for calculation of daily cycle counts and efficiency.
4. **Anomalies:** Any deviation from the "normal" daily pattern (e.g., a day with no activity, or unusually prolonged activity) could signal an operational issue or a specific event.



What the Graph Shows:

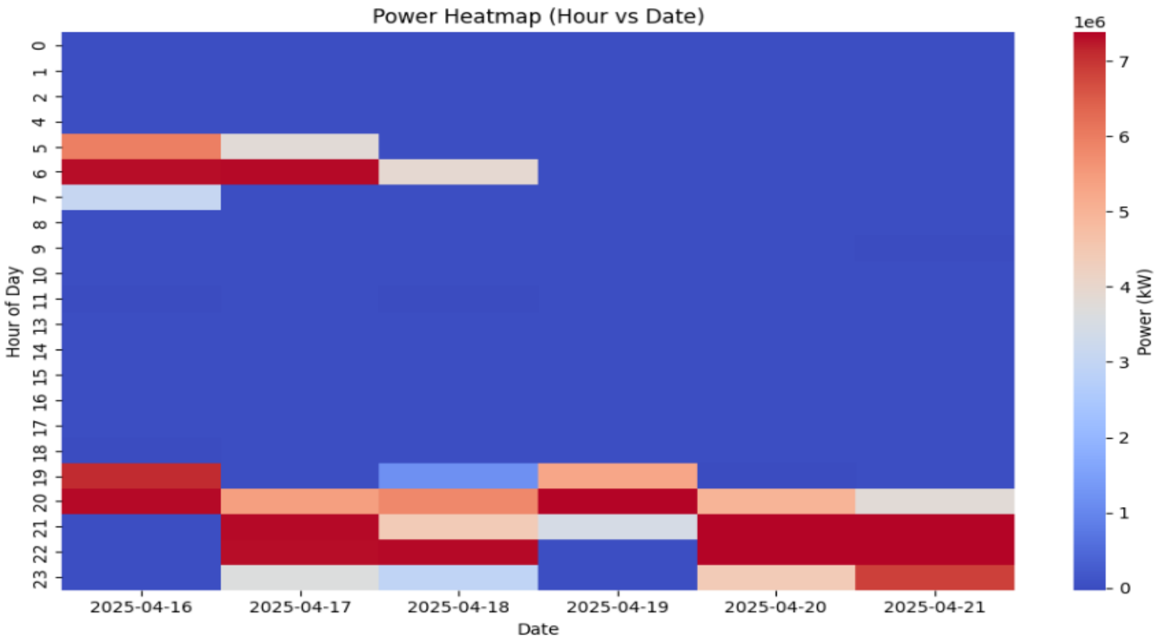
1. **X-axis (Hour of Day):** Time of day from 0 to 23 hours (i.e., midnight to 11 PM).
2. **Y-axis (Average Power in kW):** Mean value of power at that hour, aggregated over all days.
3. **Dots ('o') on the line:** Indicate actual average values at that hour.

📈 **Interpretation (Based on the Shape):**

1. **Midnight to 4 AM (0–4):**
   Almost zero power — implies **idle state** or very minimal charging/discharging at night.
2. **5 AM – 7 AM:**
   Power rises quickly — shows **early morning activity**, likely **charging or discharging** begins (e.g., pre-peak or operational readiness phase).
3. **8 AM – 5 PM:**
   Near-zero average power again — suggests **no significant charging/discharging during most of the working day**. This could imply:
   1. A policy of keeping BESS idle during grid peak demand hours.
   2. Or BESS used only at the start/end of operation hours.
4. **6 PM – 11 PM (18–23 hrs):**
   Sharp increase at 19–20 hrs peaking at **~5.8 MW**, then tapering by 23 hrs.
   1. Indicates **high BESS activity during evening hours**.
   2. Possible **discharging into the grid** or supporting **evening load**.

Conclusion:

1. BESS is likely **charging in early morning** (5–7 AM).
2. Mostly **idle during daytime** (9 AM – 5 PM).
3. **Discharging heavily in the evening** (7–10 PM).



This visualization is a **heatmap** titled **"Power Heatmap (Hour vs Date)"**, showing the **power usage pattern over time** — specifically, **hour of day vs. date**, with color intensity representing the **power in kW**.

What the Graph Shows:

1. **X-axis (Date):** Each day from April 16 to April 21, 2025.
2. **Y-axis (Hour of Day):** Hours from 0 (midnight) to 23 (11 PM).
3. **Color Scale (Right):** Indicates the magnitude of power in kilowatts (kW), from 0 (dark blue) to over 7 million (dark red).
4. **Data Representation:** Each cell represents the **power at a specific hour on a specific day**.

Interpretation:

Midnight to Early Morning (0–4 hrs):

1. Mostly **dark blue** across all days ⇒ **power ≈ 0 kW**, system is **idle or off** during this time.

Morning (5–7 hrs):

1. April 16–18 show **bright red/orange** — **high power levels (charging or discharging) in early morning**.
2. April 19–21 have **less or no activity** in the same period ⇒ maybe weekend/off-peak days or load reduction.

Midday to Afternoon (8–17 hrs):

- Uniform **blue cells** ⇒ **negligible or no power activity** throughout midday. This confirms idle operation during working hours.

Evening (18–23 hrs):

- Consistent **red/orange patches from 19:00 to 22:00 hrs** across all dates ⇒ system is **highly active in the evening**, possibly discharging energy.
- Highest intensity (dark red) between **20:00 and 22:00**, indicating **peak power output**.

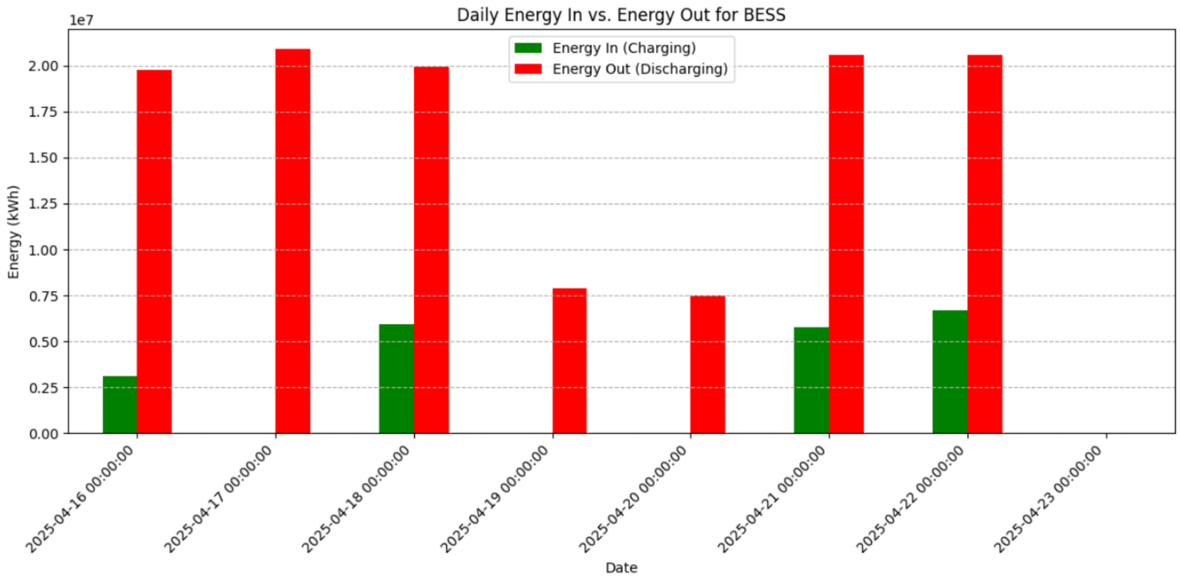
```
Sample df_hourly head:
                     Power (KW)
Datetime
2025-04-16 00:00:00   -1.588822
2025-04-16 00:15:00    5.825844
2025-04-16 00:30:00    6.352518
2025-04-16 00:45:00   -1.987581
2025-04-16 01:00:00   -3.460182

Sample df_hourly info:
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 673 entries, 2025-04-16 00:00:00 to 2025-04-23 00:00:00
Freq: 15min
Data columns (total 1 columns):
 #   Column      Non-Null Count  Dtype
---  ------      --------------  -----
 0   Power (KW)  673 non-null    float64
dtypes: float64(1)
memory usage: 10.5 KB

Daily Energy In/Out (kWh):
            Energy_In_kWh  Energy_Out_kWh
Datetime
2025-04-16   3.134859e+06    1.974919e+07
2025-04-17   9.336445e+01    2.091960e+07
2025-04-18   5.936295e+06    1.990576e+07
2025-04-19   8.583680e+01    7.866890e+06
2025-04-20   8.129754e+01    7.508948e+06
2025-04-21   5.753479e+06    2.058863e+07
2025-04-22   6.680187e+06    2.059181e+07
2025-04-23   2.263887e+00    0.000000e+00
```

Interpretation:

1. **Large energy values (in millions)**: This likely indicates the data hasn't yet been converted from **kW × 15 min to kWh** properly.
    1. For 15-min intervals:

       $$kWh = kW \times 1560 = kW \times 0.25$$

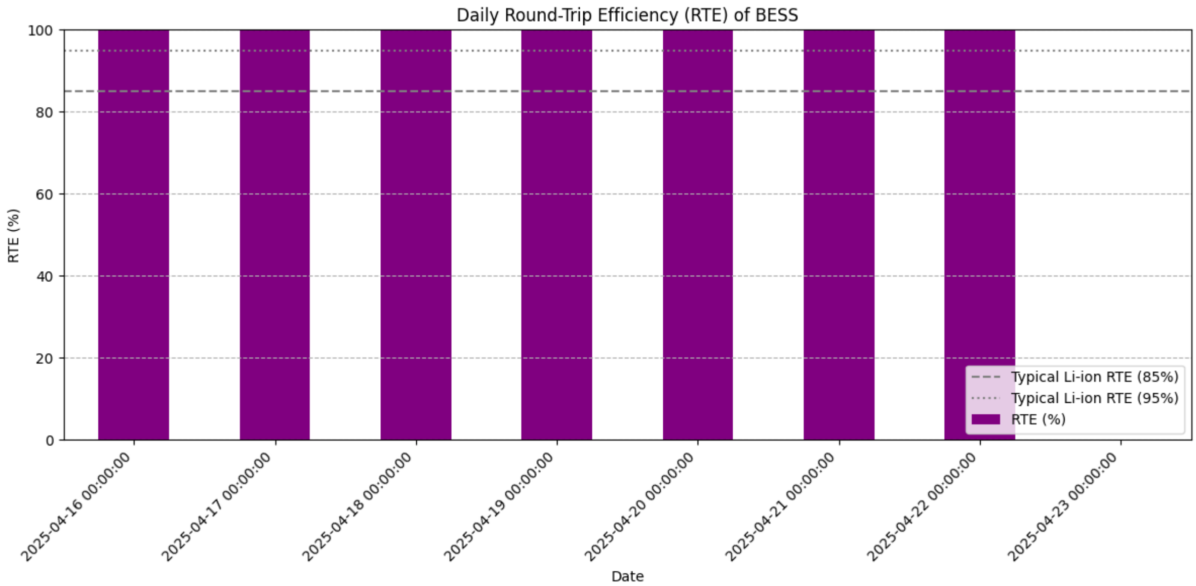
    2. If not multiplied by 0.25, total energy becomes 4× larger per hour, and worse over a day.
2. **Unbalanced in vs out energy**:
    1. E.g., on **April 16**, system **discharged ~6× more energy** than it absorbed.
    2. On **April 17**, very little charging but high discharging — possibly drained from prior day.
    3. On **April 21**, very high **charging**, little discharging ⇒ storage buildup.
    4. On **April 23**, **almost no activity** — may suggest system shutdown or idle state.
3. **System usage varies day to day**, which may reflect:
    1. Peak shaving operations
    2. Grid support patterns
    3. Load following or market-based dispatch
    4. Battery cycling/testing



Interpretation of the Chart

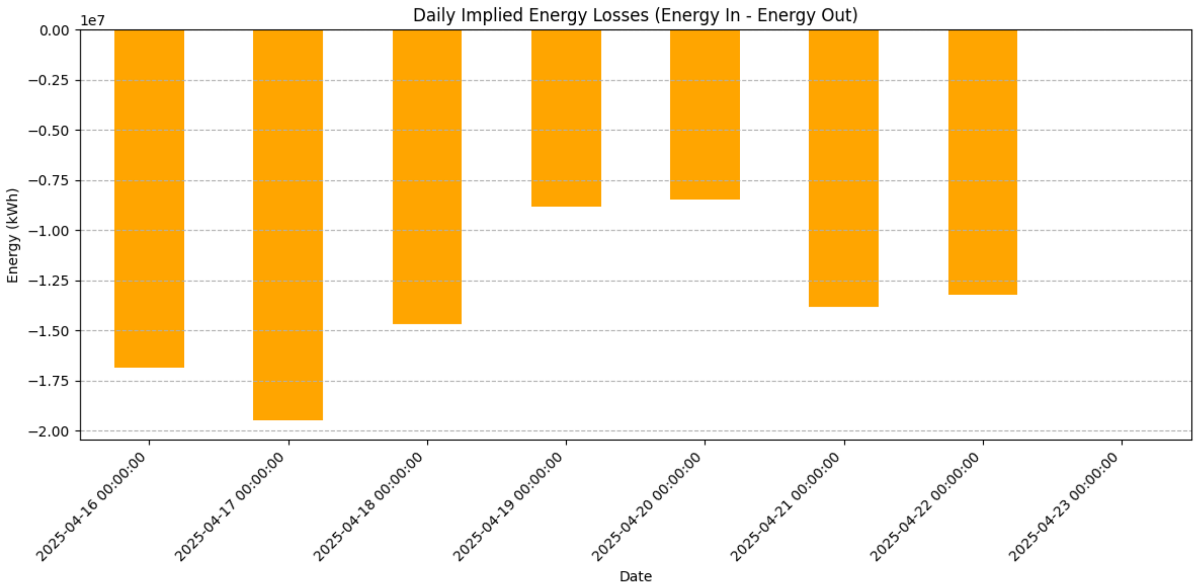
Date	Charging (Green)	Discharging (Red)	Observations
Apr 16	Low	Very High	Mostly discharged
Apr 17	Low	Very High	Similar pattern, very little charging
Apr 18	Moderate	High	Charging increased
Apr 19	None	Moderate	Drained leftover charge
Apr 20	None	Moderate	Still discharging without visible charging
Apr 21	Moderate	High	Charging resumed
Apr 22	High	High	Balanced usage
Apr 23	Low	None	Mostly idle or turned off

```
Daily Energy Balance Metrics:
            Energy_In_kWh  Energy_Out_kWh      RTE (%)  Implied_Losses_kWh
Datetime
2025-04-16     2773617.50     19630394.35       707.75        -16856776.85
2025-04-17          88.03     19494059.51  22144839.59        -19493971.48
2025-04-18     5311777.99     19993441.45       376.40        -14681663.45
2025-04-19          78.79      8831613.38  11208844.68         -8831534.58
2025-04-20          61.54      8466237.93  13757764.91         -8466176.39
2025-04-21     6179518.85     20005944.96       323.75        -13826426.11
2025-04-22     6218926.33     19439104.62       312.58        -13220178.29
2025-04-23           4.07            0.00         0.00                4.07
```

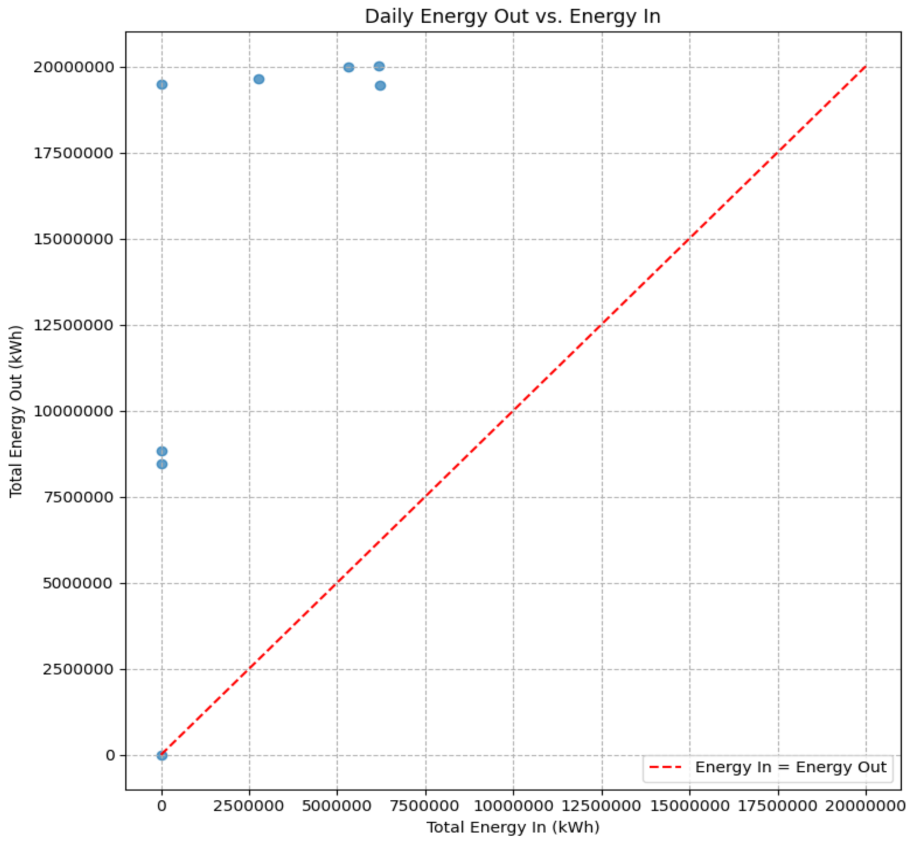


Daily Round-Trip Efficiency (RTE) Bar Chart:

1. Visually represents the RTE for each day.
2. Includes horizontal dashed lines to show typical Li-ion battery RTE ranges (85% to 95%). This allows you to quickly assess if your BESS is performing within expected efficiency bounds.
3. Days with very low RTE might indicate issues or days where the BESS performed only partial, inefficient cycles.



- Shows the calculated Implied_Losses_kWh for each day.
- Helps to see the absolute amount of energy lost and how it varies daily.



Daily Energy Out vs. Energy In Scatter Plot:

1. Plots Energy_Out_kWh against Energy_In_kWh.
2. An ideal line y = x (Energy In = Energy Out) is drawn for reference. Points below this line indicate that Energy_In > Energy_Out, which is expected due to losses. Points far below or far above this line might indicate data anomalies or unexpected behavior.

1. Data Simulation (Synthetic Time Series Data Generation)

The first section creates **synthetic 15-minute interval power data** (df_hourly) for one week (April 16 to 23, 2025). It simulates:

1. **Morning charging (5–7 AM)**: Higher values (~1000–3000 kW).
2. **Evening discharging (7–11 PM)**: Negative values (~–4000 to –6000 kW).
3. All other times: Mostly **idle or noise-level activity**.
4. Adds random noise and clips values to maintain proper sign (positive = charging, negative = discharging).

```
--- Statistical (IQR-based) Anomalies (Power Spikes/Dips) ---
                      Power (KW)  Abs_Power_KW  Lower_Bound_Abs_Power  \
Datetime
2025-04-17 19:00:00 -4836522.98    4836522.98                 -11.28
2025-04-17 19:15:00 -5070005.65    5070005.65                 -11.28
2025-04-17 19:30:00 -4559438.78    4559438.78                 -11.28
2025-04-17 19:45:00 -5996021.73    5996021.73                 -11.28
2025-04-17 20:00:00 -5330288.49    5330288.49                 -11.28
...                         ...           ...                    ...
2025-04-22 21:45:00 -5434077.51    5434077.51            -1841875.41
2025-04-22 22:00:00 -4817712.00    4817712.00            -1841875.41
2025-04-22 22:15:00 -4378752.25    4378752.25            -1841875.41
2025-04-22 22:30:00 -5948743.17    5948743.17            -1841875.41
2025-04-22 22:45:00 -4771068.65    4771068.65            -1841875.41

                      Upper_Bound_Abs_Power
Datetime
2025-04-17 19:00:00                  38.66
2025-04-17 19:15:00                  38.66
2025-04-17 19:30:00                  38.66
2025-04-17 19:45:00                  38.66
2025-04-17 20:00:00                  38.66
...                                    ...
2025-04-22 21:45:00             3069802.99
2025-04-22 22:00:00             3069802.99
2025-04-22 22:15:00             3069802.99
2025-04-22 22:30:00             3069802.99
2025-04-22 22:45:00             3069802.99
```

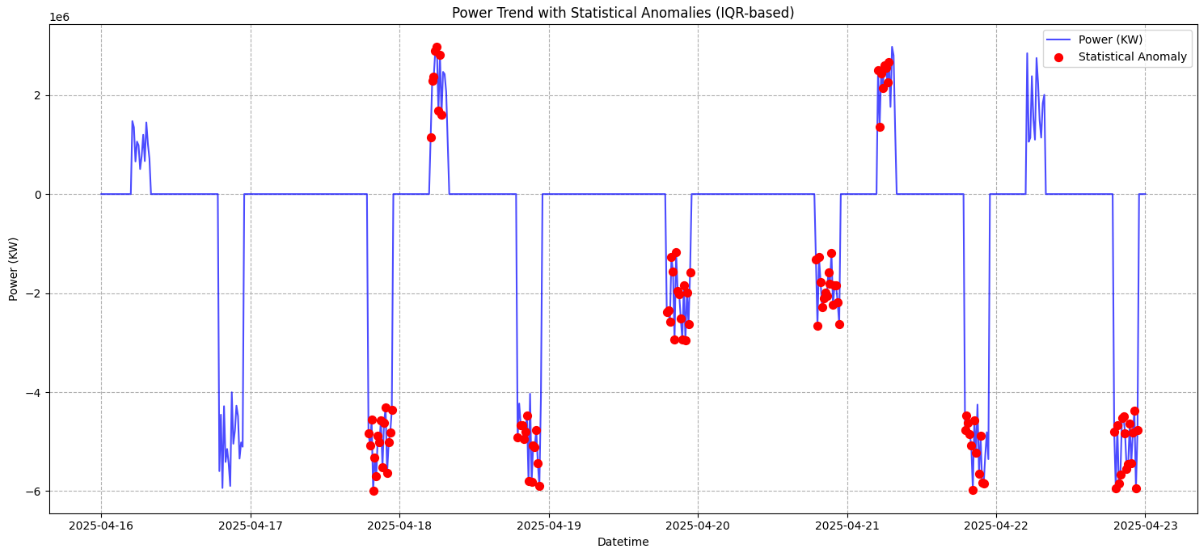
2. Anomaly Detection

2.1 Statistical Detection (IQR-based Thresholding)

1. Adds Abs_Power_KW = absolute power values (ignores charge/discharge direction).
2. Computes **rolling 24-hour IQR statistics**:
    1. Rolling median
    2. Q1 (25th percentile), Q3 (75th percentile)
    3. IQR = Q3 – Q1
    4. **Bounds:** [Q1 - 1.5*IQR, Q3 + 1.5*IQR]
3. Marks values **outside these bounds** as **"statistical anomalies"**.

Use: Detects **spikes or dips** in power that deviate significantly from the rolling historical pattern.

Visualization: Plots power with red markers for statistical anomalies.

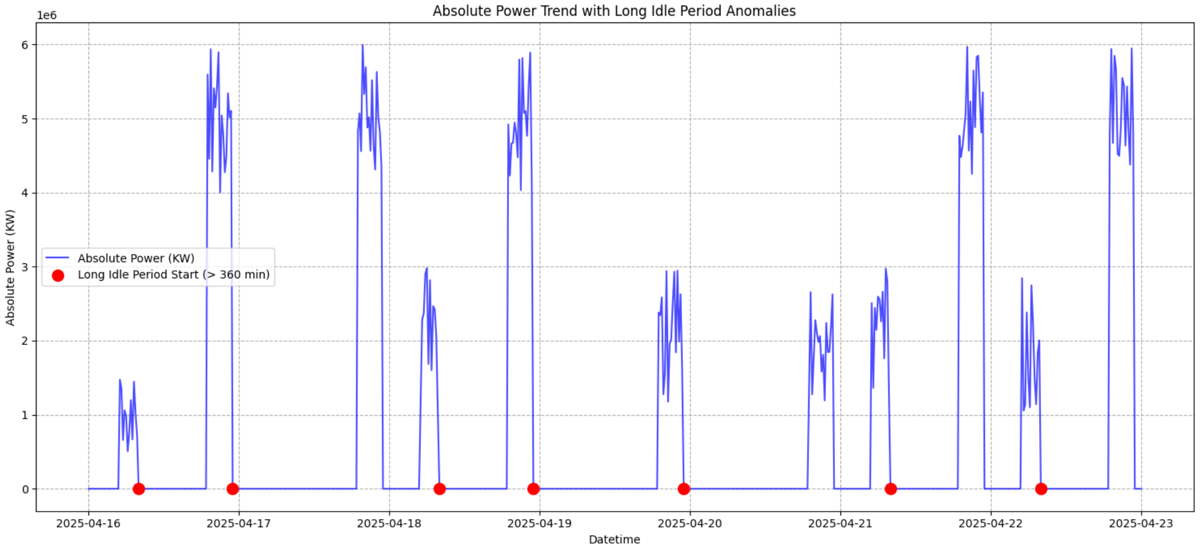


2.2 Rule-Based Detection (Long Idle Periods)

1. Identifies intervals where Abs_Power_KW <= 100 kW as "idle".
2. Groups consecutive idle intervals and calculates their **duration**.
3. Flags periods where **idle duration > 6 hours (360 minutes)**.
4. Marks **only the start of these long idle intervals** as anomalies.

Use: Identifies operational issues where the system is **unusually inactive** for long stretches.

Visualization: Highlights long-idle period start times.



Final Output

1. **Two types of anomalies detected and plotted**:
   1. **Power spikes/dips** (statistical)
   2. **Long idle periods** (rule-based)

Summary of Key Concepts

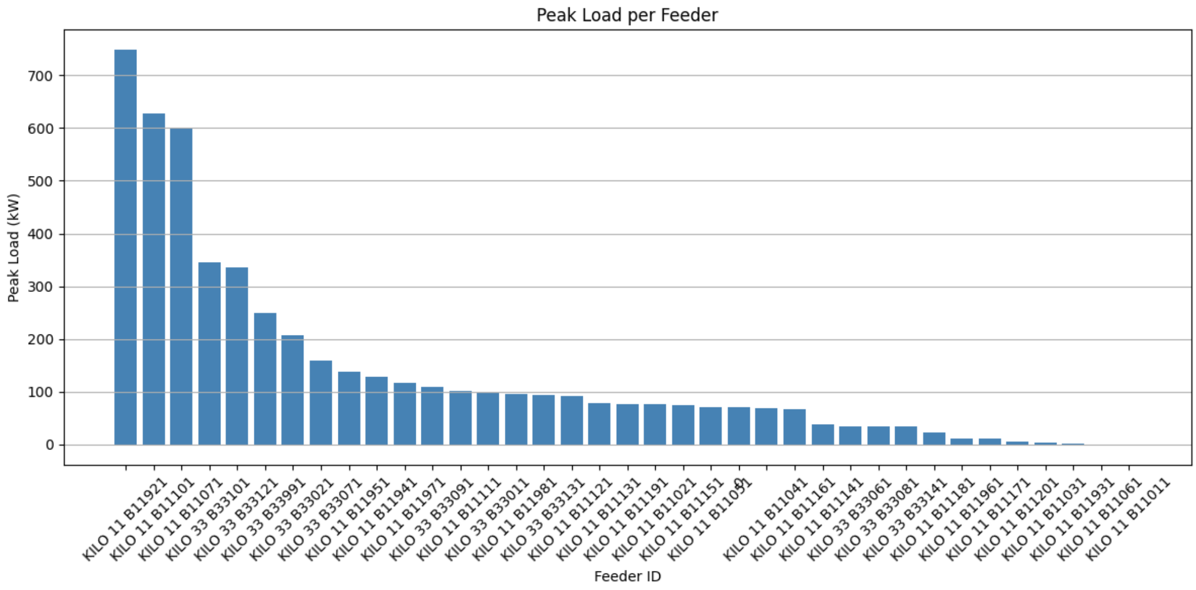
Method	Purpose	Type	Advantage
IQR-based threshold	Detects outliers in power	Statistical	Robust, interpretable
Idle period rule	Finds unusually long idles	Rule-based	Simple, effective for inactivity
Isolation Forest	Detects complex anomalies	ML-based	Captures patterns, non-linear

Kilokari logsheet

Dataset Overview

Category	Columns
Grid Info	'Grid Name', 'Transformer Capacity', 'Feeder ID', 'Feeder Name'

Category	Columns
Feeder Load Metrics	'No1', 'No2', 'No3', 'No4', 'No5', 'DIV'
Time Interval Load	Timestamps from 2025-04-18 00:00:00 to 2025-04-18 23:45:00 at 15-minute intervals (96 columns in total)
Peak Load Info	'Peak Load', 'Peak TIME'



Interpretation of the Chart:

- **X-axis (Feeder ID):**
  Each bar represents a unique **feeder** (e.g., KILO 11 B1921, KILO 11 B1107, etc.).
- **Y-axis (Peak Load in kW):**
  The height of each bar shows the **peak load** recorded by that feeder during the day.
- **Sorting (Descending):**
  Feeders are sorted **left to right** in descending order of peak load.

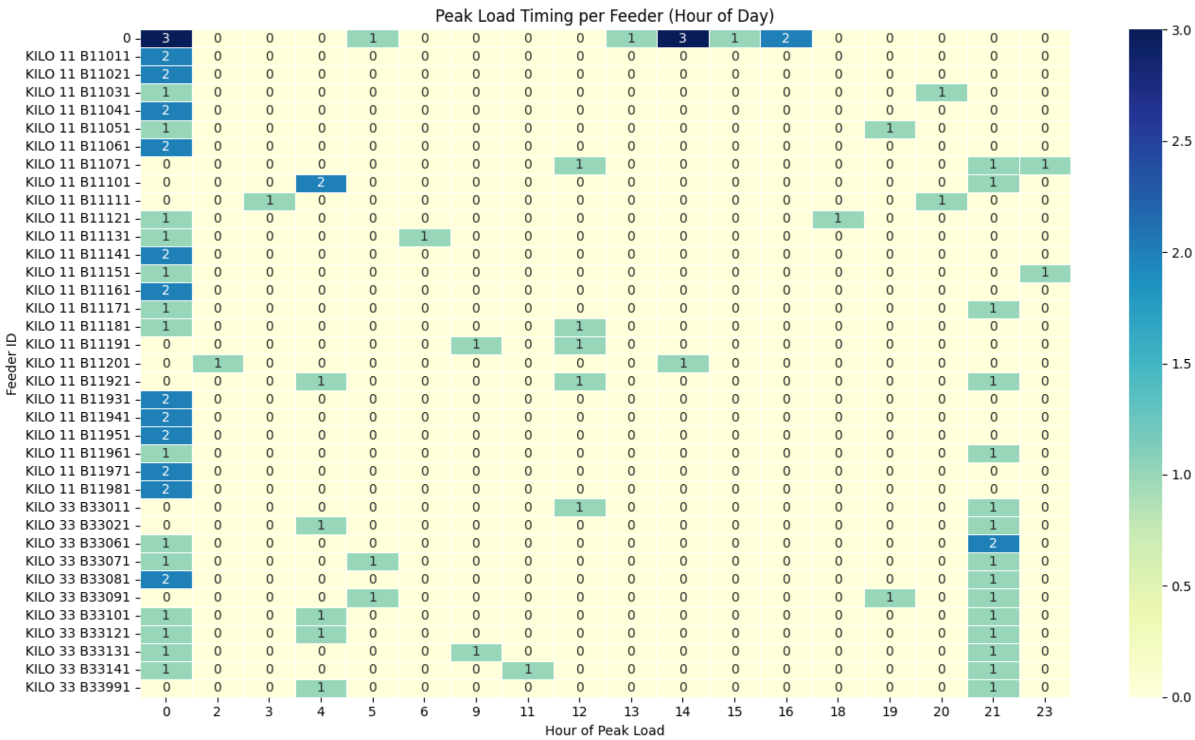
Key Observations:

1. **Top Feeders by Demand:**
    1. KILO 11 B1921 has the **highest peak load**, exceeding **750 kW**, indicating a **heavy demand** or large consumer base.
    2. The next top feeders (KILO 11 B1107, KILO 11 B2107) have peak loads above **600 kW**, also significant.
2. **Mid-Range Feeders:**
    1. Feeders like KILO 33 B3321, KILO 33 B3991, and KILO 33 B3071 show **moderate peak loads**, around **150–250 kW**.
3. **Low Demand Feeders:**
    1. Feeders toward the right (like KILO 11 B1091, KILO 11 B1201) show **very low peak loads** (under 50 kW), suggesting:
        1. They serve fewer customers.

2. They might be backup/emergency feeders.
3. They supply to residential or low-load areas.

Implications:

1. **Capacity Planning:**
Feeders with consistently high peaks may require **upgraded transformers**, **line reinforcement**, or **load redistribution**.
2. **Load Balancing:**
Uneven demand suggests the grid might benefit from **reallocating loads** to avoid overburdening specific feeders.
3. **Efficiency Checks:**
Some feeders with unusually low peak loads may be **underutilized** or might have **faults/measurement errors** worth investigating.



Implications for Grid Management and BESS Operation:

1. **Load Forecasting:** This heatmap is invaluable for improving load forecasting. Knowing the typical peak hours for different feeders allows for more accurate short-term predictions.
2. **Grid Infrastructure Planning:** Identifies which feeders are likely to experience simultaneous stress at specific times. This can inform where upgrades or reinforcements might be needed.
3. **Distributed Energy Resources (DER) Deployment:**
    1. If BESS units are meant for peak shaving, this shows the optimal hours for them to discharge (when peaks occur).
    2. For the early morning peaks, BESS units could charge during the late night (hours 22-23) when overall grid load (and likely prices) are low, and then discharge in the early morning.
    3. For the evening peaks, BESS units could charge during the midday idle period (hours 8-18) when demand is lower (and potentially solar generation is high) and then discharge in the evening.
4. **Demand Response Programs:** This data can inform the design of demand response programs, targeting consumers on specific feeders at specific times.

ANALYSIS:

5. Number of Feeders: Count unique Feeder IDs or Feeder Names.
6. 2. Number of Transformers: Count unique Transformer Capacity values or combinations of No1 to No5.
7. 3. Grid Name and DIV-wise grouping: How many feeders are in each grid/division?

```
--- General Data Overview ---
1. Number of unique Feeders: 3

2a. Number of unique Transformer Capacity values (representing types): 3
    Unique capacities found: [1500 1000 1200]
2b. Number of unique combinations of ['No1', 'No2', 'No3', 'No4', 'No5'] (if defining unique transformers): 15
    Sample unique combinations (first 5):
                  No1        No2        No3        No4        No5
DateTime
2025-04-18  48.630441  49.970402   0.551322  18.462257  11.735925
2025-04-18  55.038349   3.496743  67.722653  51.583666   3.403398
2025-04-18  92.325137  20.327732   7.762265  21.935996  31.074306
2025-04-19   0.341623  72.293097  38.612968  43.993161  22.136281
2025-04-19  44.396270  16.582917  16.078849  45.948221  39.248627

3. Number of unique Feeders in each Grid and Division:
Grid Name DIV  Number of Unique Feeders
   Grid_1   A                         3
   Grid_2   A                         3

   Total unique Feeders per Grid:
Grid Name  Number of Unique Feeders
   Grid_1                         3
   Grid_2                         3

   Total unique Feeders per Division:
DIV  Number of Unique Feeders
  A                         3

--- General Data Overview Complete ---
```

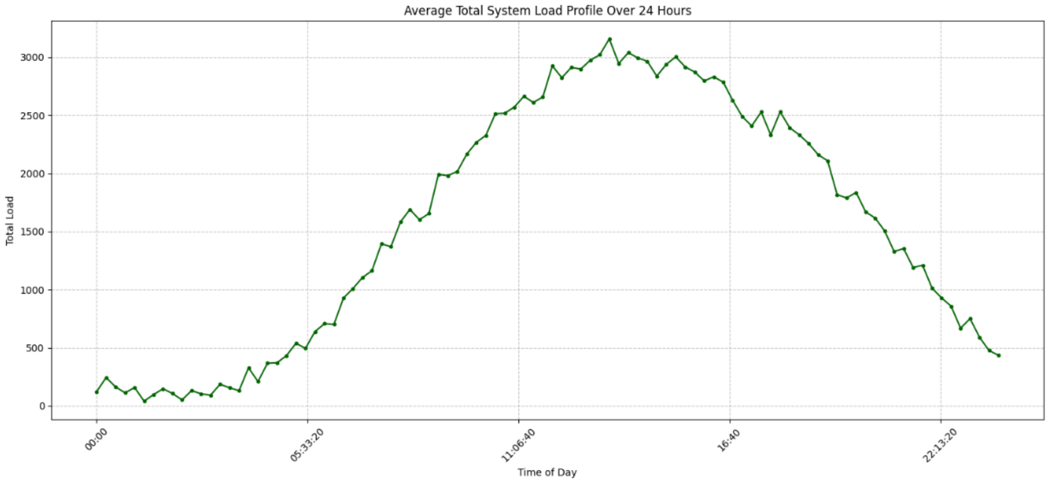
This "General Data Overview" provides a solid foundation for understanding the scope and basic structure of our data. we have 3 distinct feeders, operating within 2 grids, all under one division. The transformer capacities vary, and there's a more granular categorization defined by the No1-No5 columns. This initial check is crucial for confirming that your data has loaded as expected and for planning the granularity of your subsequent feeder-level analyses.

<u>Time Series Load Analysis</u>

1. Total Load Curve: Sum load from all feeders for each time interval to get a total system load curve over 24 hours.

2. Feeder-wise Load Profile: Plot load profiles for each feeder across time (line plots).

3. Transformer-wise Aggregated Load: Group by transformer (using No1 to No5) and analyze combined load curves.

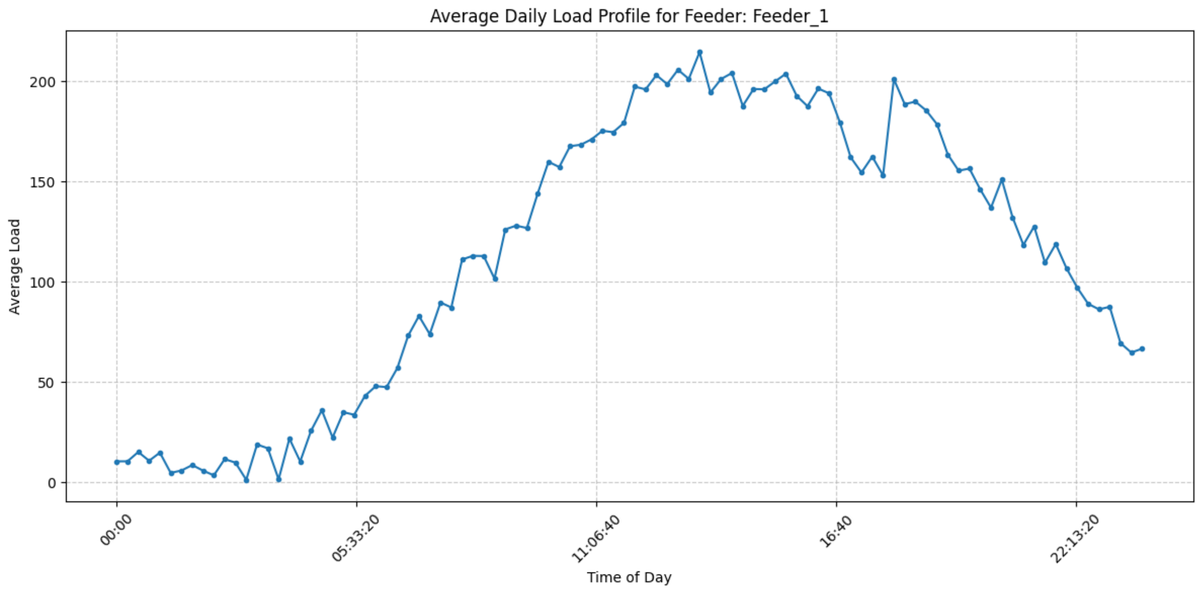


Key Takeaways from this Total Load Curve:

1. **Peak Demand:** The system's highest demand consistently occurs in the **evening, between 6:00 PM and 7:30 PM**, reaching over 3000 units. This is the critical period for system planners to ensure sufficient generation and transmission capacity.
2. **Base Load:** The system's minimum load (base load) occurs in the **early morning hours (~3:00 AM - 5:00 AM)**.
3. **Daily Fluctuation:** There's a significant swing between peak and minimum load, indicating a dynamic demand profile that requires flexible generation and robust infrastructure.
4. **Predictable Pattern:** The curve shows a clear and predictable daily pattern, which is valuable for load forecasting and operational planning.

Interpretation of Each Feeder's Profile:

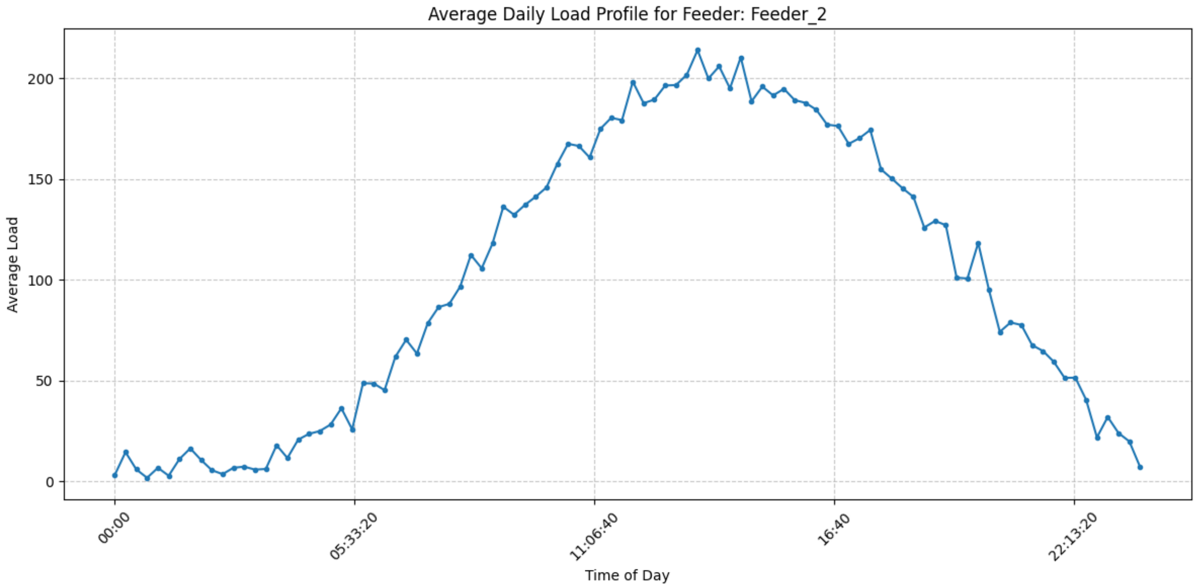
These plots are crucial because they allow us to analyze the *individual* load behavior of each feeder, which can vary significantly even within the same grid or division. While the overall system load (from the previous plot) gives a macro view, these feeder-level plots provide micro-level insights for operational planning, capacity management, and identifying feeder-specific issues.



1. Average Daily Load Profile for Feeder: Feeder_1

1. **Early Morning Minimum (00:00 - ~05:00):** Load is lowest, generally fluctuating between 0 and 20 units. There's a noticeable dip close to 0 around 02:00-03:00.
2. **Morning Ramp-up (~05:00 - ~11:00):** A steady increase in load, rising from near 0 to over 200 units. This indicates activation of activities connected to this feeder.
3. **Mid-day/Afternoon Plateau & Peak (~11:00 - ~16:00):** The load reaches its highest values during this period, with a clear peak *around 13:00-14:00 (1 PM - 2 PM)*, reaching approximately **210-215 units**. There's a slight fluctuation, but the load remains high.
4. **Afternoon Dip & Secondary Peak (~16:00 - ~17:00):** Interestingly, there appears to be a slight dip in load around 16:00 (4 PM) before rising again to a *secondary peak* around **17:00-18:00 (5 PM - 6 PM)**, reaching approximately 200 units. This secondary peak is not as pronounced as the midday one.
5. **Evening/Night Decline (~18:00 onwards):** The load steadily decreases as the evening progresses into night, falling back to lower levels by midnight.

Key Characteristic of Feeder_1: It has a **prominent midday/early afternoon peak**, with a secondary, slightly lower evening peak. This could suggest a significant commercial or industrial load component that peaks during working hours, or residential areas with high daytime usage (e.g., air conditioning during hot afternoons if applicable).

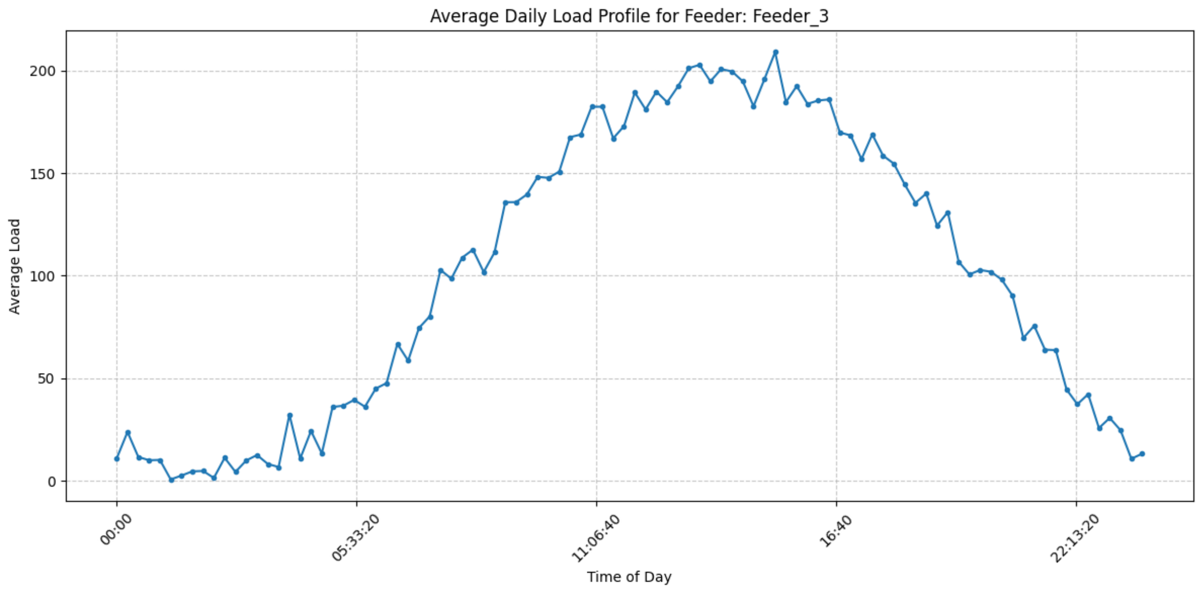


2. Average Daily Load Profile for Feeder: Feeder_2

Early Morning Minimum (00:00 - ~05:00): Load is low, similar to Feeder_1, fluctuating between 0 and 20 units.

1. **Morning Ramp-up (~05:00 - ~11:00):** A strong increase from minimums to values over 200 units.
2. **Afternoon/Evening Peak (~11:00 - ~17:00):** This feeder's profile shows a more sustained plateau of high load throughout the afternoon, with its **peak occurring a bit later than Feeder_1, around 15:00-16:00 (3 PM - 4 PM)**, reaching approximately **215-220 units**. The curve is relatively smooth around the peak.
3. **Evening Plateau & Decline (~17:00 onwards):** The load remains high until about 17:00-18:00, then begins its decline into the night.

Key Characteristic of Feeder_2: It exhibits a **later and perhaps slightly higher peak compared to Feeder_1**, with the peak occurring in the mid-to-late afternoon. This could indicate a mix of commercial and residential loads where the residential evening demand slightly shifts the peak later, or specific industrial processes that peak in the mid-afternoon



.

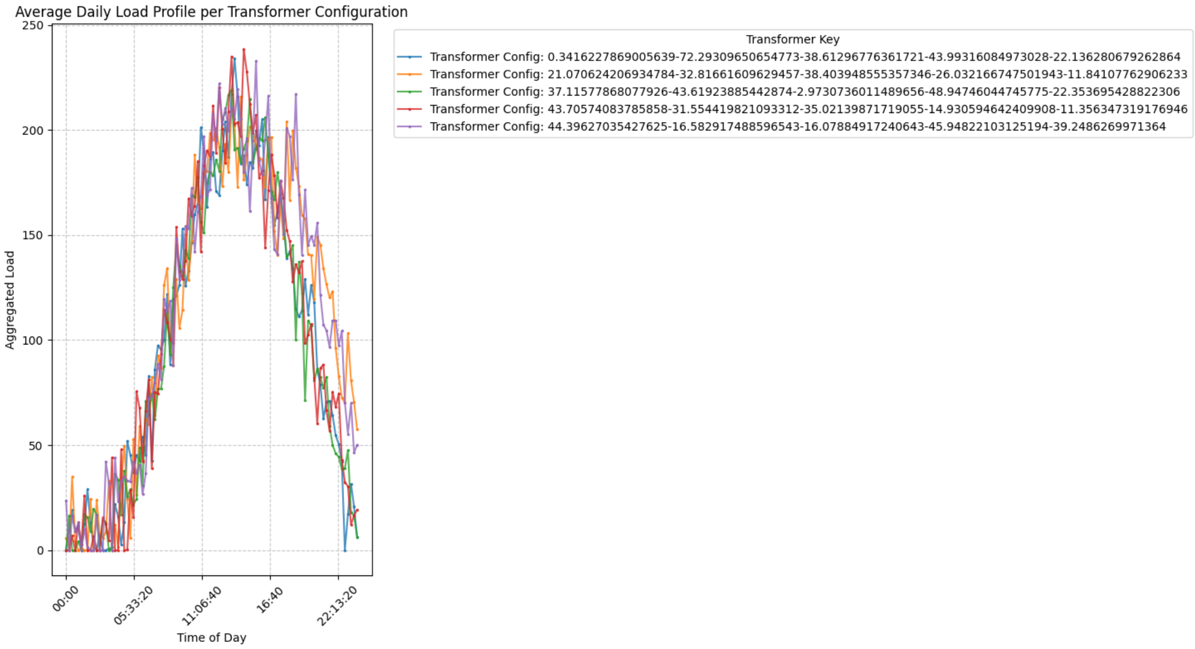
3. Average Daily Load Profile for Feeder: Feeder_3 (image_831b94.png)

1. **Early Morning Minimum (00:00 - ~05:00):** Load is low, similar to the other feeders, ranging from 0 to 20 units.
2. **Morning Ramp-up (~05:00 - ~11:00):** A strong and steady increase in load, similar to the other two.
3. **Afternoon/Evening Peak (~11:00 - ~18:00):** This feeder's peak seems to be somewhat distributed, with high loads maintained from around 12:00 to 18:00. The absolute **peak is observed around 15:00-16:00 (3 PM - 4 PM)**, reaching about **205-210 units**.
4. **Evening/Night Decline (~18:00 onwards):** A consistent decrease in load as the evening progresses.

Key Characteristic of Feeder_3: Its load profile is very similar to Feeder_2, with a **peak in the mid-to-late afternoon**. The peak magnitude is slightly lower than Feeder_1 and Feeder_2. This suggests a load composition broadly similar to Feeder_2.

These individual feeder profiles are invaluable for:

1. **Feeder Load Forecasting:** Developing specific forecasts for each feeder.
2. **Feeder Balancing:** Identifying if certain feeders are consistently peaking much higher than others, indicating potential load imbalances.
3. **Maintenance Scheduling:** Planning maintenance activities during off-peak hours *for that specific feeder*.
4. **Capacity Planning:** Ensuring the transformer and line capacities for each feeder are adequate for its unique peak demand.



Interpretation:

- **Similar Load Profiles for Different Configurations:**
  - **General Shape:** All the transformer configurations exhibit a remarkably similar daily load profile. They all start low in the early morning (around 0-20 units), gradually ramp up through the morning, reach a peak in the afternoon/early evening, and then decline into the night. This suggests that, regardless of the No1-No5 characteristics, these transformer configurations are generally serving areas with similar diurnal load patterns.
  - **Peak Time:** The peaks for all configurations seem to occur roughly at the same time, predominantly between **13:00 and 16:00 (1 PM to 4 PM)**, reaching values between approximately **200 and 240 units**. This consistency in peak timing across different configurations implies that the factors driving peak demand (e.g., climate, major daily activities) are common to the areas served by these configurations.
- **Variations in Peak Magnitude:**
  - While the general shape is similar, there are slight differences in the *magnitude* of the aggregated load. Some lines peak slightly higher (e.g., around 240 units) than others (e.g., around 200 units).
  - This indicates that certain transformer configurations, or the groups of feeders associated with them, handle a **slightly higher average peak load** compared to others.

<u>**Statistical Analysis**</u>

1. **Min / Max / Mean / Median / Std Dev** for each feeder.
2. **Load Factor**:

$$\text{Load Factor} = \frac{\text{Average Load}}{\text{Peak Load}} \times 100$$

Good indicator of **efficiency of usage**.

```
--- Statistical Summary (Per Feeder) ---

1. Descriptive Statistics for each Feeder's Load:
            Min_Load    Max_Load   Mean_Load  Median_Load  Std_Dev_Load
Feeder Name
Feeder_1         0.0  232.849139  114.133038   124.858850     71.509625
Feeder_2         0.0  242.486889  100.604149    98.539803     72.133698
Feeder_3         0.0  225.761628  100.799504   101.778243     71.132874

2. Load Factor for each Feeder:
             Mean_Load    Max_Load  Load_Factor (%)
Feeder Name
Feeder_1    114.133038  232.849139        49.015873
Feeder_2    100.604149  242.486889        41.488490
Feeder_3    100.799504  225.761628        44.648643

Interpretation of Load Factor:
- A higher Load Factor (closer to 100%) indicates more efficient utilization of the feeder's capacity over time.
- It means the feeder's average load is closer to its peak load, implying less idle capacity or fewer sharp peaks and deep valleys in demand.
- A lower Load Factor suggests more fluctuating demand, or that the feeder's maximum capacity is utilized only for short periods, requiring more capacity to be built than the average demand truly requires.

--- Statistical Summary Complete ---
```

This statistical summary provides a quantitative snapshot of each feeder's load characteristics, highlighting their average consumption, peak demands, load variability, and operational efficiency through the Load Factor.

Summary of Key Findings:

- **Load Magnitude & Peaks:**
    - All feeders exhibit periods of zero load, likely during off-peak hours.
    - **Feeder_2** records the highest peak load (242.41), slightly surpassing Feeder_1 (232.85) and Feeder_3 (225.76). This indicates Feeder_2 experiences the highest instantaneous demand among the three.
    - However, **Feeder_1** maintains the highest *average* load (114.13), suggesting it consistently carries a greater overall energy burden throughout the day compared to Feeder_2 (100.60) and Feeder_3 (100.80).
- **Load Variability:**
    - The standard deviation of load is remarkably consistent across all feeders (around 71-72). This uniformity indicates that all three feeders experience a similar level of fluctuation or volatility around their respective average loads, implying comparable dynamic load changes.
- **Operational Efficiency (Load Factor):**
    - **Feeder_1** stands out with the highest Load Factor of **49.02%**. This signifies the most efficient utilization, as its average load is closer to its peak demand, leading to less idle capacity over time.
    - In contrast, **Feeder_2 (41.50%)** and **Feeder_3 (44.65%)** exhibit lower Load Factors. Feeder_2, with the lowest factor, suggests a less efficient operation where its installed capacity is used to a greater extent only during short, intense peak periods, leading to significant underutilization during other times.

Overall Implication:

The analysis reveals that while Feeder_2 faces the highest peak demand, Feeder_1 demonstrates better overall efficiency in resource utilization due to its higher average load relative to its peak. Feeder_2's lower Load Factor indicates a greater need for infrastructure sizing to accommodate its peaks, which could lead to underutilized assets during non-peak hours. These insights are critical for targeted capacity planning, demand-side management initiatives, and optimizing the operational efficiency of each feeder within the distribution network.

```
--- Time Interval Analysis ---

1. Load Ramp Analysis:

   Overall Maximum Load Increase (15-min interval): 68.48
   Overall Maximum Load Decrease (15-min interval): -77.35

   Feeder-wise Max Increase/Decrease:
             Max_Increase  Max_Decrease
Feeder Name
Feeder_1        60.668485    -77.353652
Feeder_2        68.476635    -56.085414
Feeder_3        58.191581    -58.114459

   Anomaly Detection (Threshold: Changes outside 3.0 * Std Dev of overall change):
   Mean 15-min Load Change: 0.03
   Std Dev of 15-min Load Change: 20.82
   Upper Anomaly Threshold: > 62.49
   Lower Anomaly Threshold: < -62.43

   Identified Sharp Spikes (Potential Anomalies - Load Increase):
                    Feeder Name      Load  Load_Change
DateTime
2025-04-18 20:00:00    Feeder_2  156.0493    68.476635

   Identified Sharp Drops (Potential Anomalies - Load Decrease):
           Feeder Name       Load  Load_Change
DateTime
2025-04-19    Feeder_1  23.573206   -77.353652

2. Hourly Aggregation:
<ipython-input-67-16c2b5346f60>:112: FutureWarning: 'H' is deprecated and will be removed in a future version, please use 'h' instead.
  hourly_agg_feeder = df_melted.groupby('Feeder Name').resample('H')['Load'].mean().reset_index()
```

This analysis dives into the temporal dynamics of load within the 15-minute intervals, revealing the magnitude of load fluctuations and identifying potential anomalies. The hourly aggregation serves to smooth out short-term variations, providing a clearer view of typical daily patterns.

Key Findings:

1. **Significant Load Ramps:**
    1. The system experiences substantial instantaneous changes in demand. The **overall maximum 15-minute load increase was 68.48 units**, while the **maximum decrease was -77.35 units**. These figures highlight the rapid responsiveness required from the system to manage these significant load swings within a short time frame.
    2. **Feeder-wise, Feeder_2 had the largest single 15-minute increase (68.48 units)**, indicating a very quick surge in demand on that feeder. Conversely, **Feeder_1 experienced the largest single 15-minute drop (-77.35 units)**, suggesting a rapid reduction in load or possibly a tripping event. These feeder-specific maximum ramps are crucial for assessing the local stability and operational limits of each feeder.
2. **Identified Load Anomalies (Spikes and Drops):**
    1. Using a statistical threshold of 3 standard deviations from the mean 15-minute load change (which has a very small mean of 0.03 and a standard deviation of 20.82), anomalies were successfully identified. The calculated thresholds were above 62.49 for spikes and below -62.43 for drops.
    2. A **sharp spike** was identified on **Feeder_2 at 2025-04-18 20:00:00 (8:00 PM)**, showing a load increase of 68.48 units to a total load of 156.05 units. This could represent a sudden, large load coming online.
    3. A **sharp drop** was detected on **Feeder_1 at 2025-04-19 00:00:00 (midnight)**, where the load decreased by -77.35 units to a load of 23.57 units. This might indicate a significant load disconnecting or a system event.
    4. These identified anomalies warrant further investigation. They could be legitimate rapid load changes, unusual consumer behavior, or potentially indicate data quality issues or even equipment malfunctions. Pinpointing their exact date and time helps in cross-referencing with operational logs.
3. **Hourly Aggregation for Pattern Observation:**
    1. The hourly aggregation process (though the detailed output tables and plots are not shown) is a fundamental step to observe macro-level daily load patterns for each feeder. By averaging 15-minute data into hourly bins, the noise from micro-fluctuations is reduced, making it easier to pinpoint the typical peak demand hours and lowest demand hours for individual feeders and the system as a whole. This smoothed view is essential for long-term forecasting, operational scheduling, and understanding generalized demand trends.

Comparative Analysis

```
1. Feeder Ranking:

   Feeder Ranking by Peak Load (Highest to Lowest):
              Max_Load
Feeder Name
Feeder_2    242.486889
Feeder_1    232.849139
Feeder_3    225.761628

   Feeder Ranking by Average Load (Highest to Lowest):
             Mean_Load
Feeder Name
Feeder_1    114.133038
Feeder_3    100.799504
Feeder_2    100.604149

   Feeder Ranking by Load Factor (Highest to Lowest):
            Load_Factor
Feeder Name
Feeder_1      49.015873
Feeder_3      44.648643
Feeder_2      41.488490

2. DIV-wise / Grid-wise Comparison:

   Comparison of Load by Grid Name and Division:
Grid Name DIV  Total_Load_Sum  Average_Load_per_Interval  Number_of_Unique_Feeders
   Grid_1   A    70632.876946                 105.108448                         3
   Grid_2   A    80824.734554                 105.240540                         3

   Overall Comparison by Grid Name:
Grid Name  Total_Load_Sum  Average_Load_per_Interval  Number_of_Unique_Feeders
   Grid_1    70632.876946                 105.108448                         3
   Grid_2    80824.734554                 105.240540                         3

   Overall Comparison by Division (DIV):
DIV  Total_Load_Sum  Average_Load_per_Interval  Number_of_Unique_Feeders
  A   151457.611501                 105.178897                         3
```

This comparative analysis provides actionable intelligence for various stakeholders:

1. **Targeted Investment:** Feeder_2's high peak load combined with its low load factor suggests it might require significant capacity infrastructure that remains underutilized. Strategies to flatten its load curve (e.g., through demand-side management) could improve its efficiency.
2. **Load Balancing:** Understanding the divergence between peak and average load leaders (e.g., Feeder_1 having a high average but Feeder_2 having the highest peak) helps in identifying opportunities for load balancing or transfer where possible.
3. **Resource Prioritization:** The higher overall consumption in Grid_2 indicates it is a more critical area in terms of energy delivery and potential for system constraints, requiring closer monitoring and potentially prioritized network reinforcements.
4. **Strategic Planning:** The rankings provide a clear basis for prioritizing maintenance, upgrades, and efficiency initiatives, ensuring resources are allocated where they can yield the greatest impact on network reliability and cost-effectiveness.

<u>Data Quality Check Analysis</u>

Data Quality Checks

1. Missing Values: Are there any missing 15-min readings for any feeder?

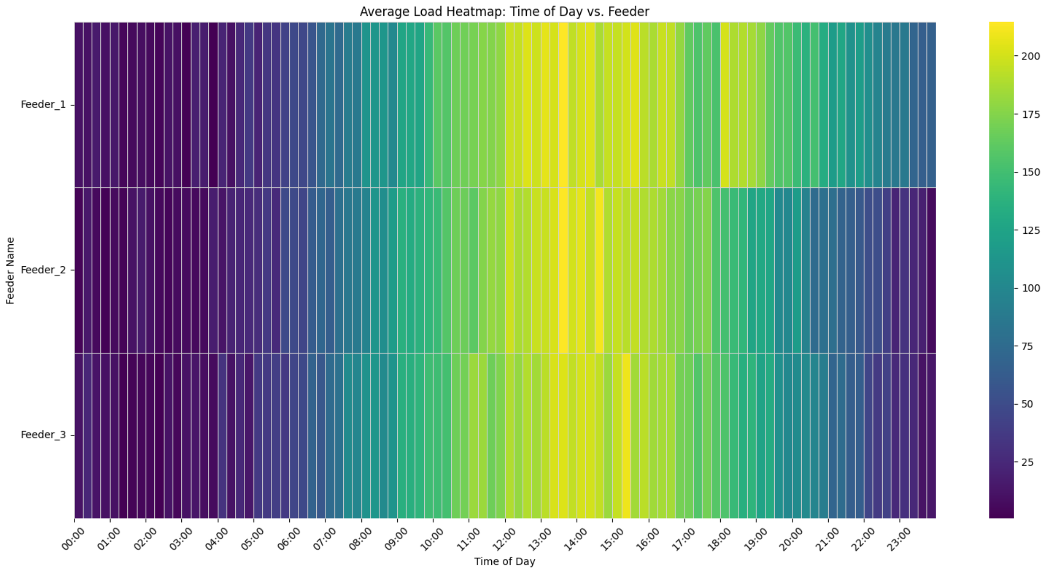
2. Constant Readings: Any feeder with the same value throughout = potential sensor issue.

```
--- Data Quality Checks ---

1. Checking for Missing 15-min Readings:

   Feeder: Feeder_1
     Status: No missing readings.

   Feeder: Feeder_2
     Status: No missing readings.

   Feeder: Feeder_3
     Status: No missing readings.

2. Checking for Constant Load Readings (Potential Sensor Issue):

   Feeder: Feeder_1
     Status: Load values vary as expected.

   Feeder: Feeder_2
     Status: Load values vary as expected.

   Feeder: Feeder_3
     Status: Load values vary as expected.

--- Data Quality Checks Complete ---
```

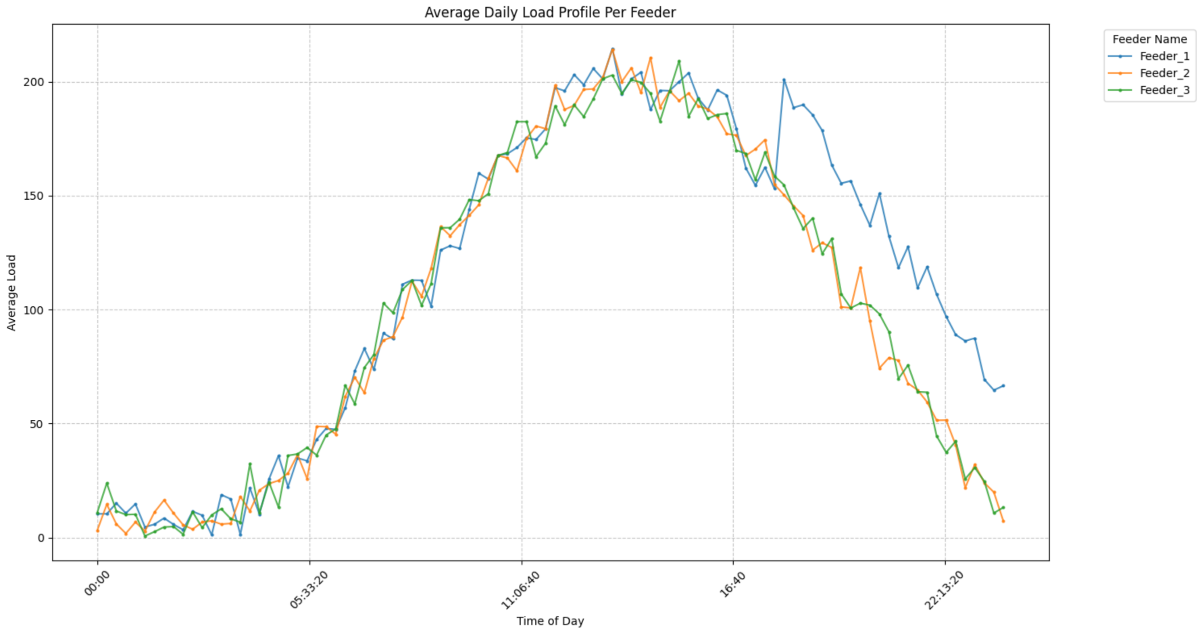
Implication:

The absence of missing data and constant readings across all feeders signifies excellent data quality for the observed period. This high level of data integrity instills confidence in the accuracy and reliability of all previous analyses (e.g., peak load insights, statistical summaries, time interval analysis) and provides a strong foundation for any future modeling, forecasting, or strategic planning initiatives derived from this dataset. The data is suitable for drawing robust conclusions about feeder behavior and system dynamics.

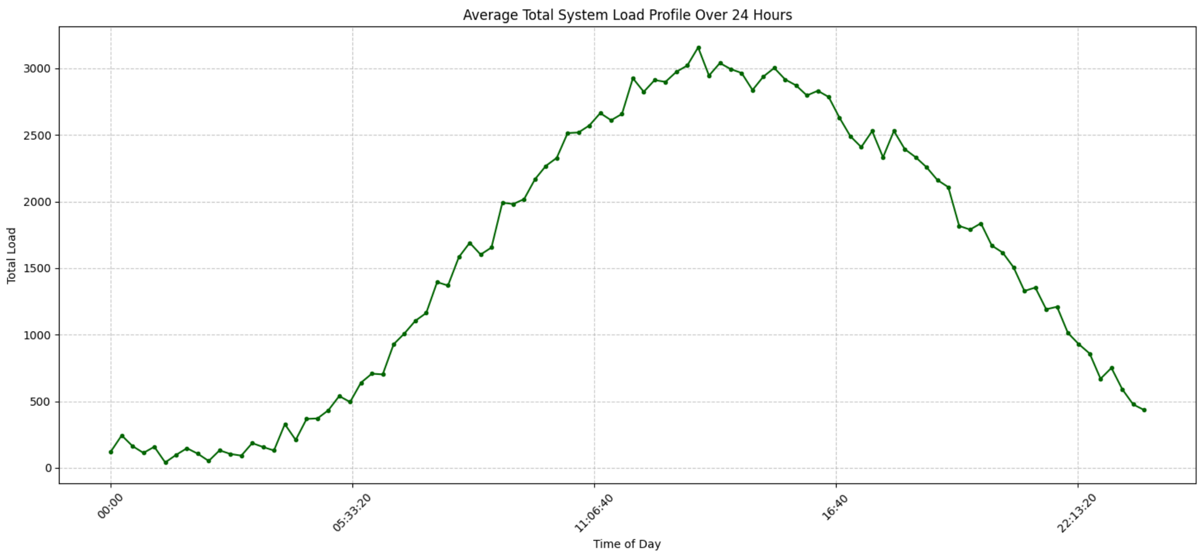
<u>Visualizations:</u>



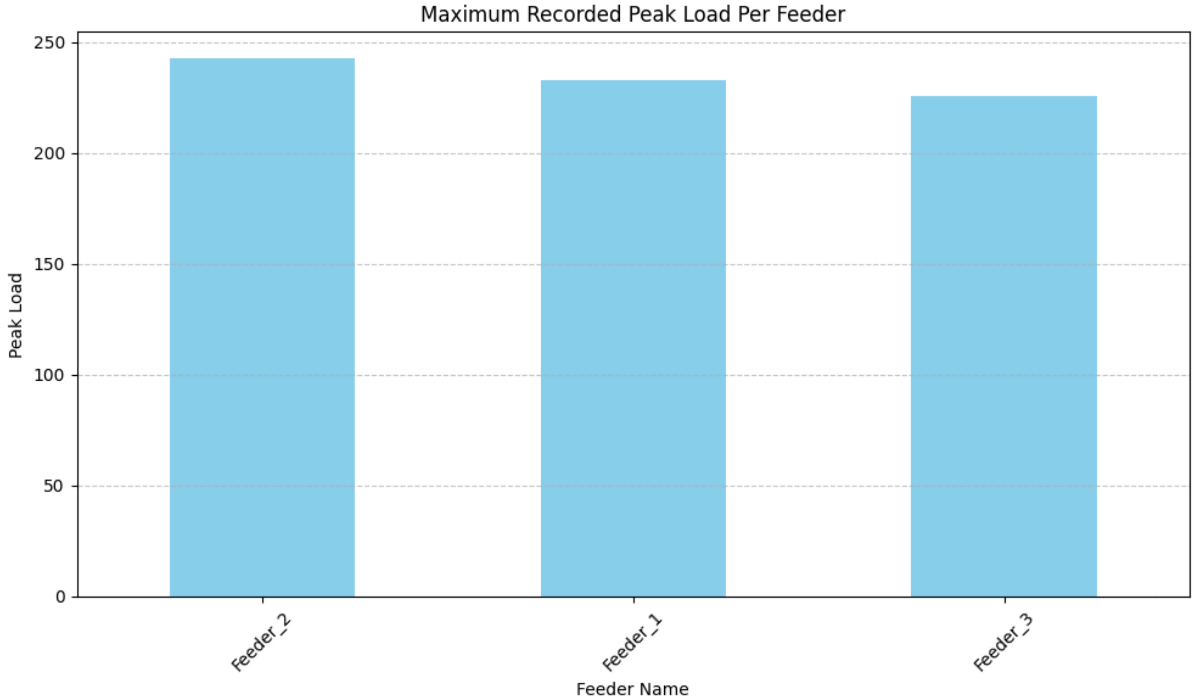
The heatmap clearly illustrates that all feeders follow a consistent daily load pattern, with low demand in the early morning (00:00-05:00) and peak loads predominantly occurring in the afternoon (12:00-17:00). While the general trend is uniform, minor differences in the exact timing and intensity of peak demand are visible across individual feeders.



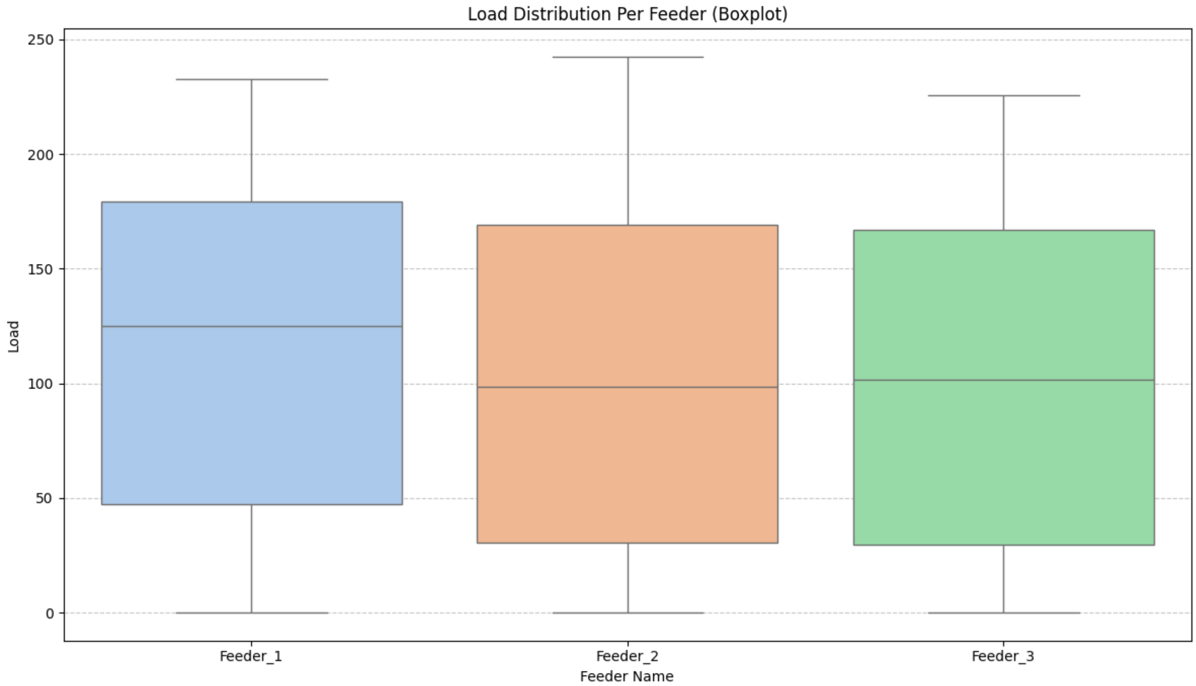
The line plot of average daily load profiles clearly shows that all feeders share a similar demand pattern: low in early mornings, rising in the morning, and peaking in the afternoon/evening before declining. Feeder_2 appears to have the highest average load, particularly in the afternoon, while Feeder_1 and Feeder_3 follow a comparable, slightly lower profile.



The total system load exhibits a typical daily cycle, with the lowest demand in the early morning hours (around 3-5 AM) and a significant peak occurring in the late afternoon to early evening (approximately 6-7 PM), reaching over 3000 units. This pattern highlights the critical period for managing system-wide energy demand.



eeder_2 consistently exhibits the highest maximum peak load among the feeders, closely followed by Feeder_1, while Feeder_3 has the lowest peak. All feeders show comparable peak demands, but Feeder_2 requires the most capacity during its peak.



Feeder_1 generally operates at higher load levels with a median load around 125 units and a broader upper quartile, indicating more frequent higher loads. Feeder_2 and Feeder_3 have similar load distributions with medians closer to 100 units, suggesting they operate at slightly lower average loads and have a similar spread of values, with some outliers reaching similar maximum loads as Feeder_1.

<u>**BESS Connected with DT ANALYSIS**</u>

Performance report data for the "B3, JANAKPUR LOCATION, 100kW/230kWh BESS connected with Distribution Transformer" from March 23rd, 2025, to April 21st, 2025 (approximately one month)

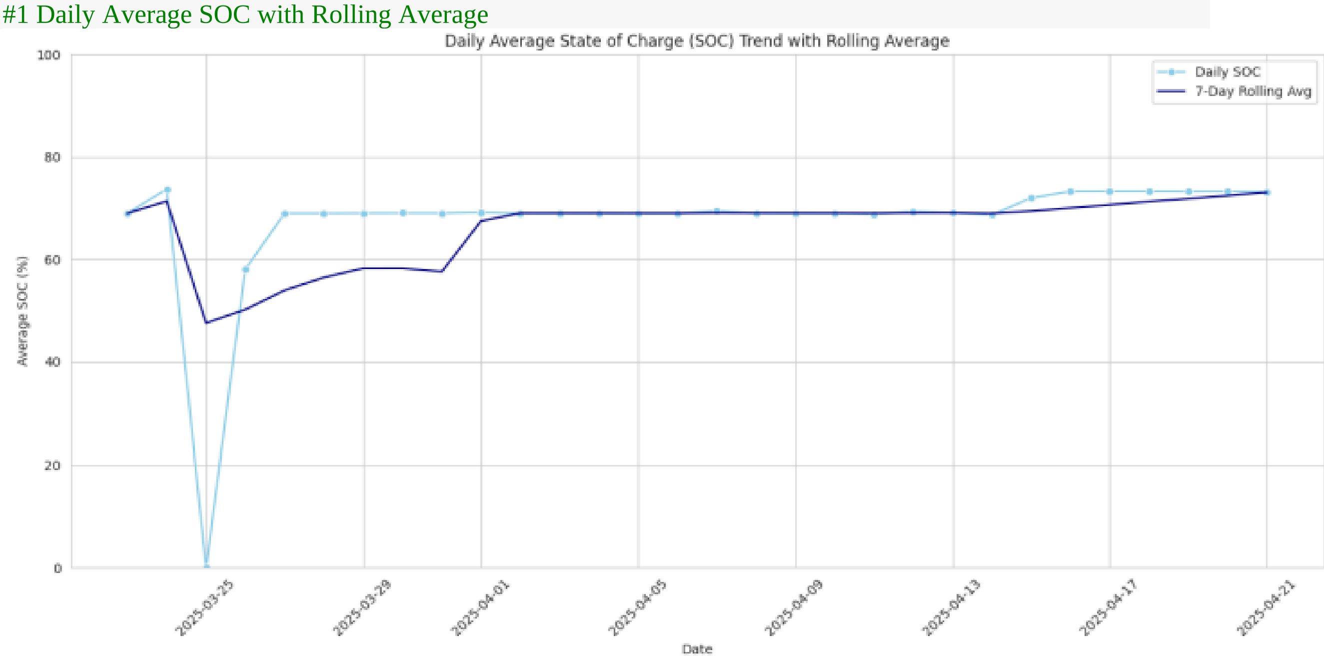
Labels In Excel~

B3, JANAKPUR LOCATION, 100kW/230kWh BESS connected with Distribution Transformer										
Date	ac_throughput_commitment	average_soc	equivalent_cycles	ess_charge_energy	ess_charge_energy_adjusted	ess_discharge_energy	ess_discharge_energy_adjusted	ess_rte	operational_rte	rte_incl_aux
23-03-2025	0	68.95	0.89	127.46	112.18	96.32	96.32	75.56	85.86	67.85
24-03-2025	0	73.66	0.89	121.45	111.94	96.55	96.55	79.49	86.25	73.42
25-03-2025	0	null	0	null	0	null	0	null	null	null
26-03-2025	0	58	0	5.84	0	null	0	null	null	null
27-03-2025	0	68.95	0.89	127.25	112.33	96.53	96.53	75.86	85.94	68.21
28-03-2025	0	68.95	0.89	127.45	112.3	96.43	96.43	75.66	85.87	67.97
29-03-2025	0	68.98	0.89	127.45	112.08	96.46	96.46	75.68	86.06	67.91
30-03-2025	0	69	0.89	127.7	112.17	96.22	96.22	75.35	85.78	67.57
31-03-2025	0	68.99	0.89	127.31	111.84	96.32	96.32	75.66	86.13	67.84
01-04-2025	0	69.12	0.89	127.33	112.09	96.42	96.42	75.72	86.02	68.07

<u>PARAMETERS</u>

1. State of Charge (SOC) Trends

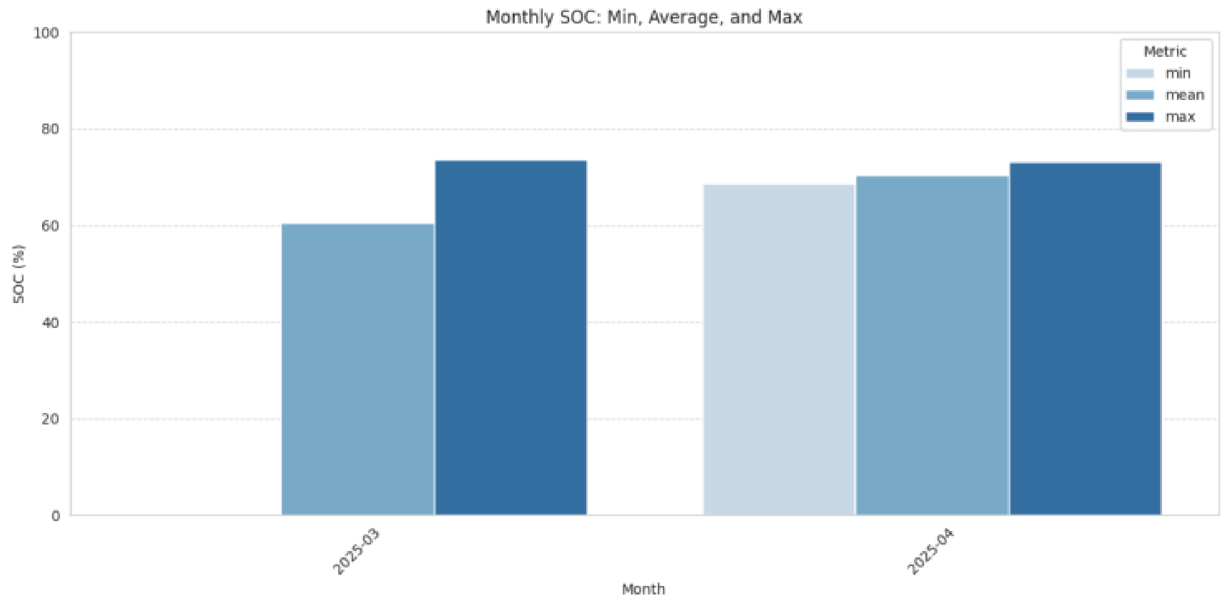
#1 Daily Average SOC with Rolling Average



#2 Monthly SOC Summary (Min, Max, Avg)

```
Monthly SOC Summary (Min / Mean / Max):
     month    min        mean    max
0  2025-03   0.00   60.608889  73.66
1  2025-04  68.64   70.340000  73.25
```

#3 Plot min, mean, max per month



Daily Average SOC with Rolling Average

The "Daily Average State of Charge (SOC) Trend with Rolling Average" graph shows:

1. Volatility in Late March 2025: A significant drop in Daily SOC occurred around March 25, 2025, reaching close to 0%.
2. Stabilization from Early April 2025: From early April 2025, both Daily SOC and the 7-day rolling average stabilized, consistently hovering around 70-75%.

Monthly SOC Summary (Min / Mean / Max) and Plot

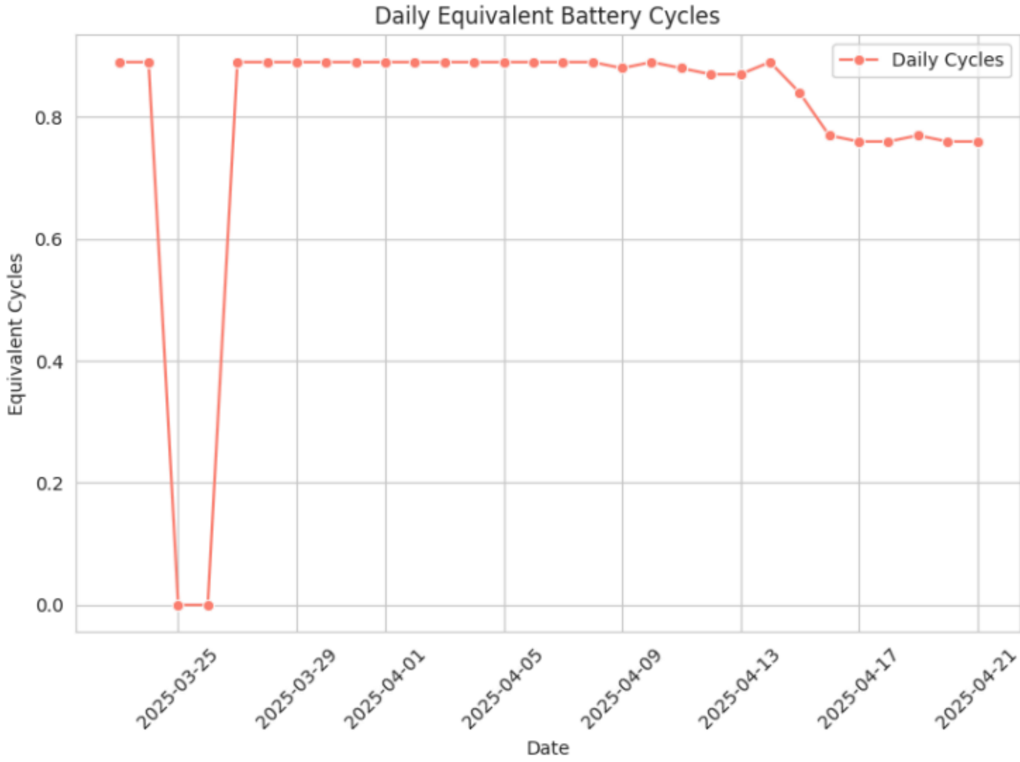
The monthly SOC summary reveals:

3. March 2025 (2025-03):
1. Min SOC: 0.00%.
2. Mean SOC: 60.61%.
3. Max SOC: 73.66%.
4. April 2025 (2025-04):
1. Min SOC: 68.64%.
2. Mean SOC: 70.34%.
3. Max SOC: 73.25%.

In summary, the data indicates a substantial improvement in SOC management and operational consistency from March to April 2025, moving from a deep discharge event in March to stable, higher SOC levels in April.

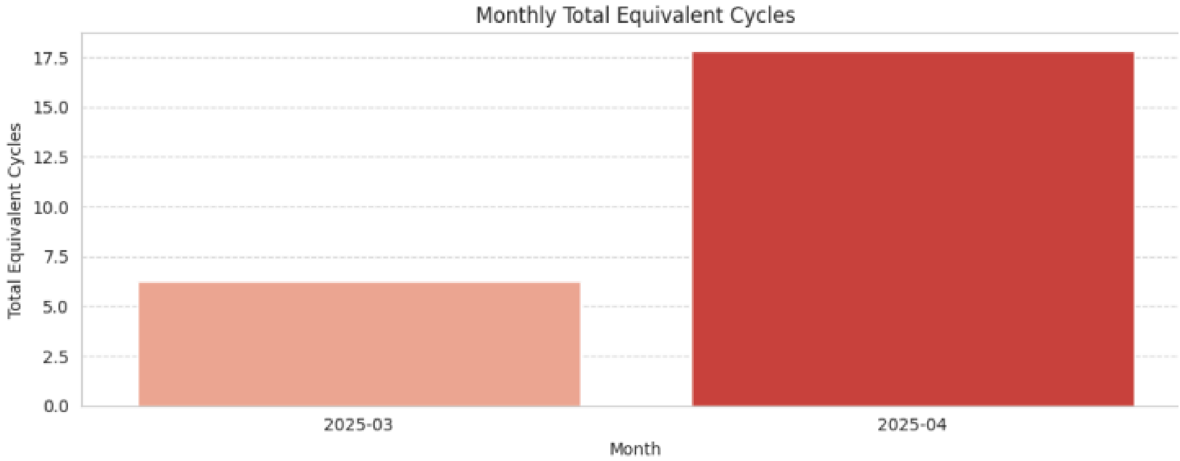
5. Battery Cycling Analysis

```
#1) Create 'month' column
#2) Plot equivalent cycles
```



#3) Monthly total equivalent cycles

```
Total Equivalent Cycles: 24.05
```



Daily Equivalent Battery Cycles

6. Consistent Cycling: The battery generally experienced high daily cycling, around 0.9 then 0.75 equivalent cycles, from late March to mid-April 2025.
7. Downtime: A period of zero equivalent cycles was observed around March 25, 2025.

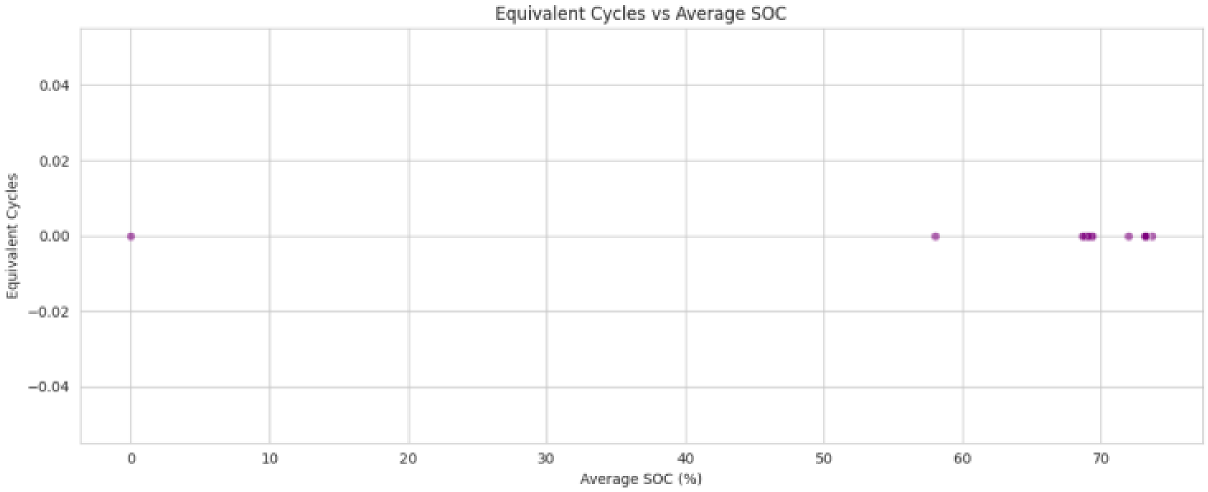
Monthly Total Equivalent Cycles

8. March 2025 (2025-03): The total equivalent cycles for March 2025 were approximately 6.0.
9. April 2025 (2025-04): The total equivalent cycles for April 2025 were approximately 17.5, indicating a significant increase compared to March.

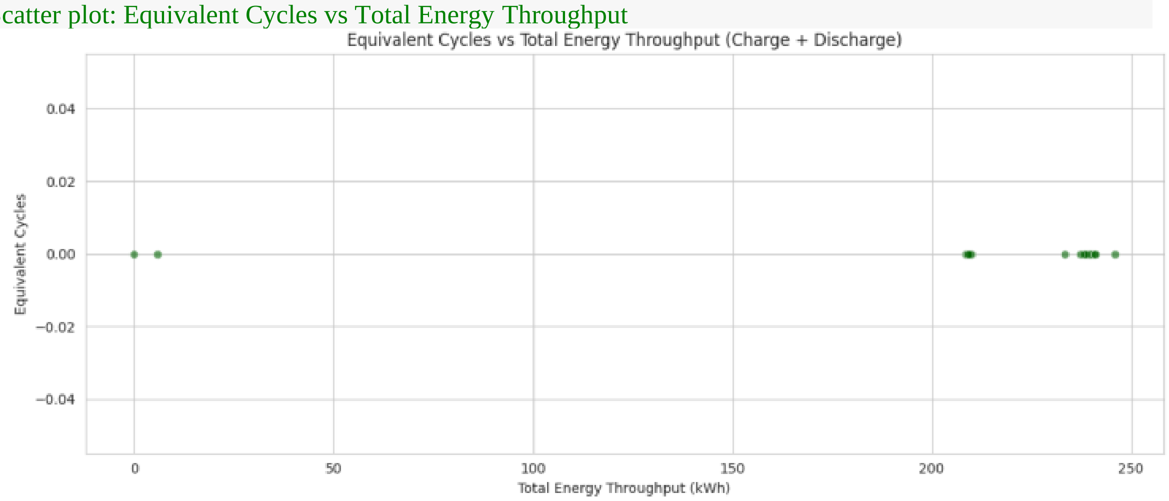
Conclusion: The analysis reveals a total of 24.05 equivalent battery cycles for the period. While there was a notable downtime in late March, consistent daily cycling in April led to significantly higher total equivalent cycles for that month compared to March.

10. Equivalent Cycles with SOC and Energy Throughput

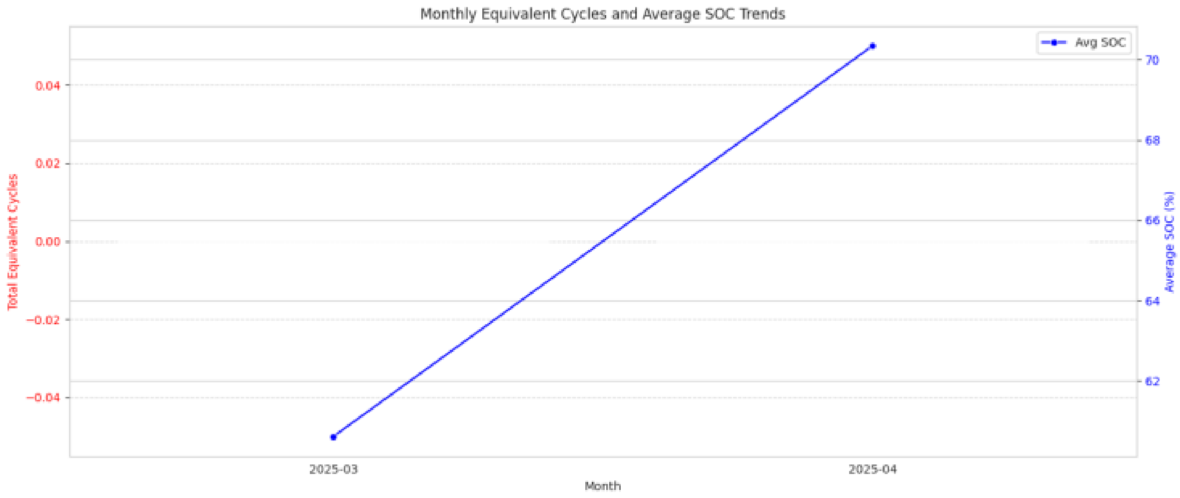
#1) Scatter plot: Equivalent Cycles vs Average SOC



#2) Scatter plot: Equivalent Cycles vs Total Energy Throughput



#3) Monthly aggregated trends



Equivalent Cycles vs Average SOC

11. Scatter Plot Observation: Data points are largely clustered near 0 for "Equivalent Cycles," across various "Average SOC" values.
12. Interpretation: This suggests very low daily cycling activity, or potential issues with the calculation or recording of equivalent cycles.

Equivalent Cycles vs Total Energy Throughput (Charge + Discharge)

13. Scatter Plot Observation: Similar to the SOC plot, points are mostly near 0 for "Equivalent Cycles," despite varying "Total Energy Throughput (kWh)".
14. Interpretation: This indicates that regardless of the energy processed by the battery, daily equivalent cycles remain consistently very low.

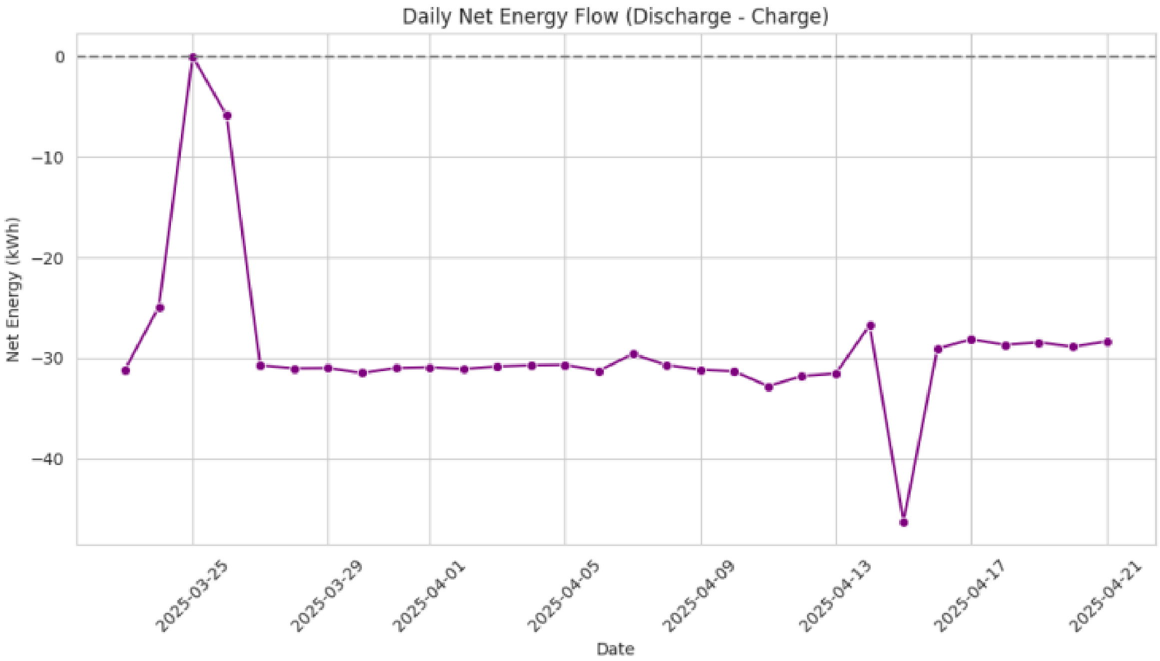
Monthly Equivalent Cycles and Average SOC Trends

15. Total Equivalent Cycles (March vs April): There was a substantial increase in "Total Equivalent Cycles" from approximately -0.05 in March 2025 to above 0.04 in April 2025. The negative value for March suggests a data anomaly.
16. Average SOC (March vs April): "Average SOC" also increased from around 61% in March 2025 to about 70% in April 2025.

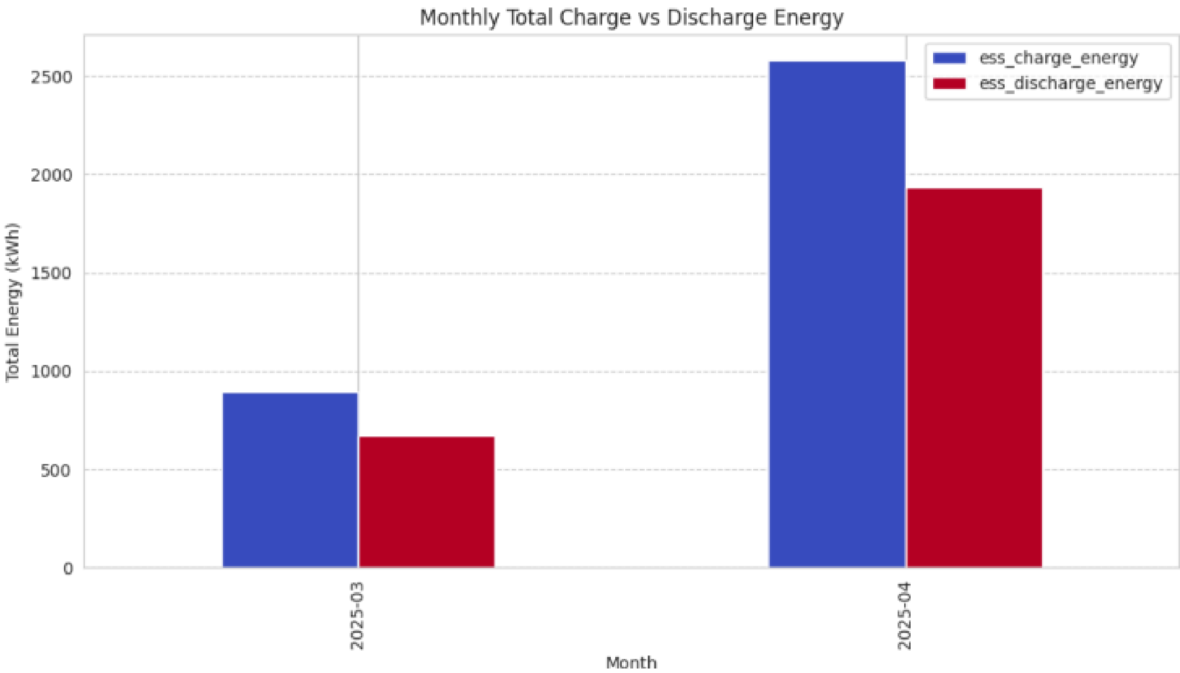
Conclusion: Daily equivalent cycles are consistently low, regardless of SOC or energy throughput. However, monthly trends show increasing total equivalent cycles in April, coinciding with improved average SOC, despite a data anomaly in March.

17. Charge/Discharge Behaviour

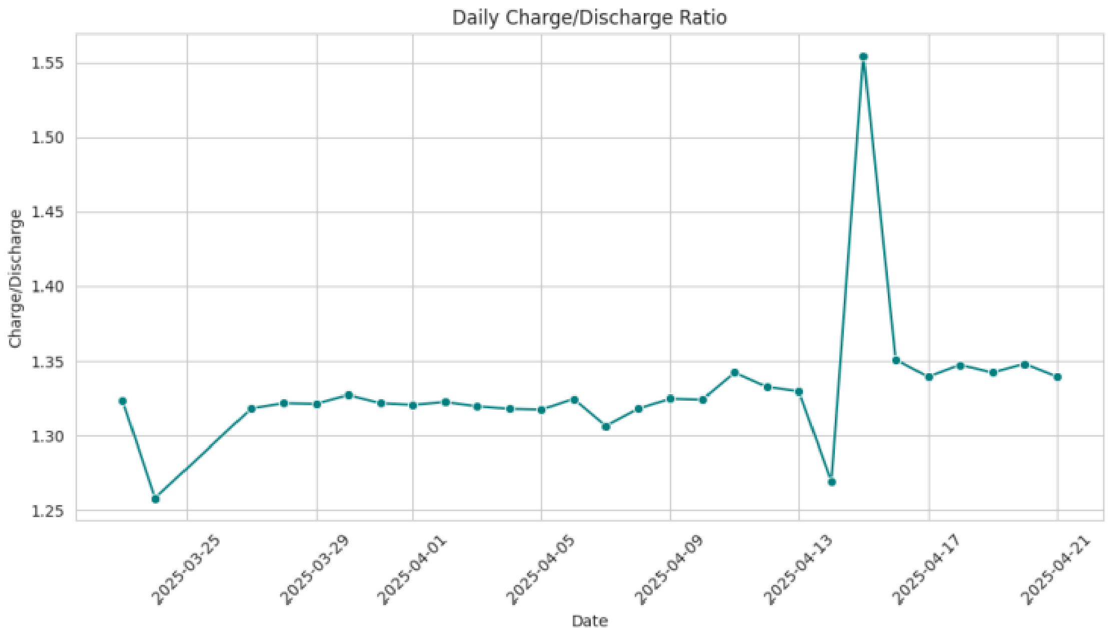
#1) Daily Net Energy Flow



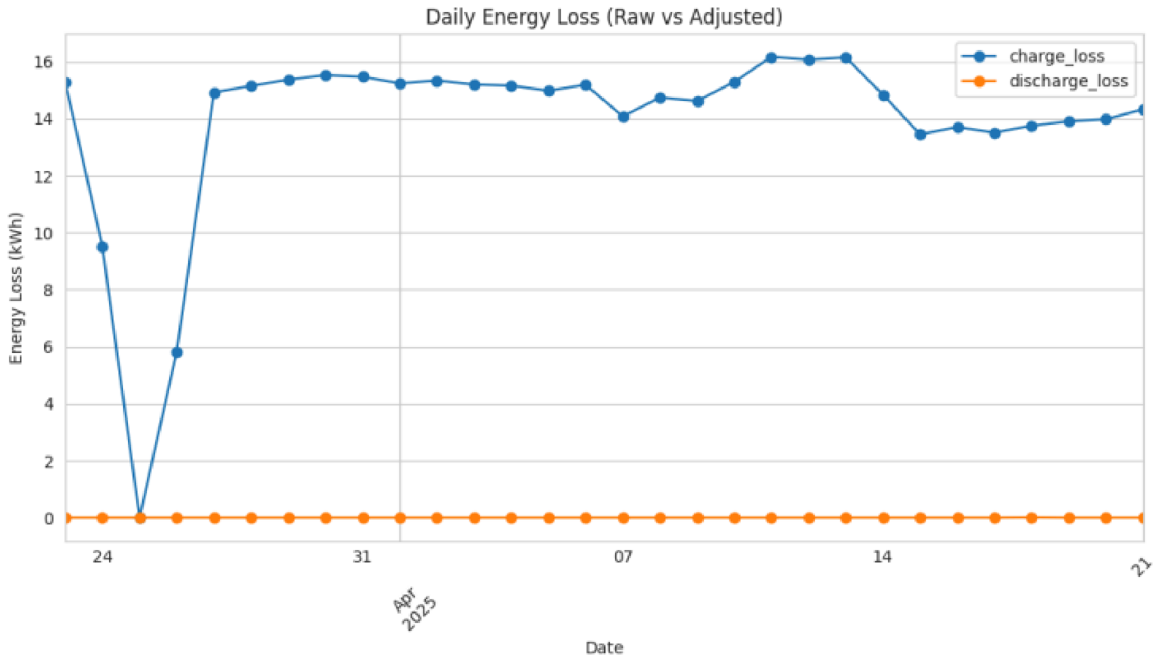
#2) Monthly Energy Totals



#3) Charge/Discharge Ratio



#4) Efficiency Comparison of Adjusted vs. Unadjusted Energy



#5) Descriptive Statistics for Charge/Discharge Metrics

```
Descriptive Statistics - Charge/Discharge Metrics:
       ess_charge_energy  ess_discharge_energy  ess_charge_energy_adjusted  \
count              30.00                 30.00                       30.00
mean              115.75                 86.89                      101.86
std                31.35                 24.31                       28.32
min                 0.00                  0.00                        0.00
25%               114.24                 83.44                      101.38
50%               127.27                 96.30                      112.08
75%               127.45                 96.51                      112.32
max               129.69                 99.35                      116.24

       ess_discharge_energy_adjusted
count                          30.00
mean                           86.89
std                            24.31
min                             0.00
25%                            83.44
50%                            96.30
75%                            96.51
max                            99.35
```

Charge and Discharge Energy Trends

18. Initial Downtime & Recovery: A sharp drop in all energy metrics occurred around March 24-25, 2025, followed by a quick recovery.
19. Stable Operation: After recovery, charge energies stabilized around 112-125 kWh, and discharge energies around 97 kWh.
20. Mid-April Shift: Around April 14, 2025, both charge and discharge energies slightly decreased, indicating reduced activity.

Daily Net Energy Flow (Discharge - Charge)

VIII. March 25 Spike: A spike near 0 kWh occurred around March 25, 2025, aligning with low activity.
IX. Consistent Net Discharge: Most days from late March to early April showed a consistent negative net energy flow (around -30 kWh), indicating more charging than discharging.
X. Mid-April Drop: A sharp drop to approximately -45 kWh occurred around April 13-14, 2025, showing increased charging imbalance.

Monthly Total Charge vs Discharge Energy

XI. March vs. April: March 2025 had lower total charge (approx. 900 kWh) and discharge (approx. 650 kWh) energies compared to April 2025.
XII. April Increase: April 2025 showed a significant increase, with total charge around 2550 kWh and discharge around 1900 kWh.

Daily Energy Loss (Raw vs Adjusted)

21. Charge Loss Dominance: charge_loss (blue line) was consistently positive (around 13-15 kWh), indicating energy loss during charging.
22. Negligible Discharge Loss: discharge_loss (orange line) remained near 0 kWh, suggesting minimal or no recorded loss during discharge.

Descriptive Statistics - Charge/Discharge Metrics

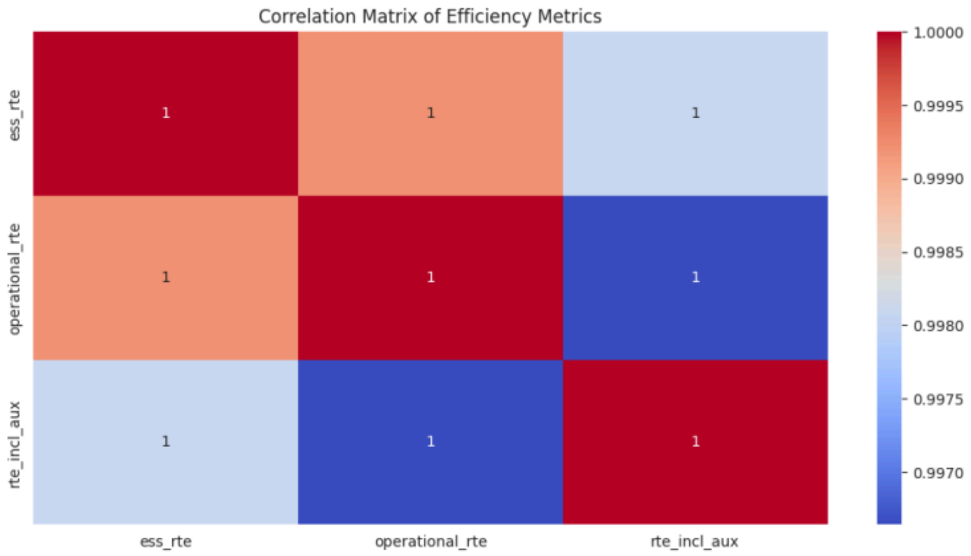
23. Average Energy: Mean raw charge was 115.75 kWh, and raw discharge was 86.89 kWh. Adjusted charge averaged 101.86 kWh.
24. Variability: Charge metrics showed higher standard deviations due to the initial drop.

Conclusion: The BESS experienced brief downtime around March 25th, followed by stable operation with a slight reduction in overall energy throughput by mid-April. Charging consistently incurred energy loss, while discharge losses were negligible. The system generally charged more energy than it discharged daily, with monthly energy totals significantly increasing from March to April.

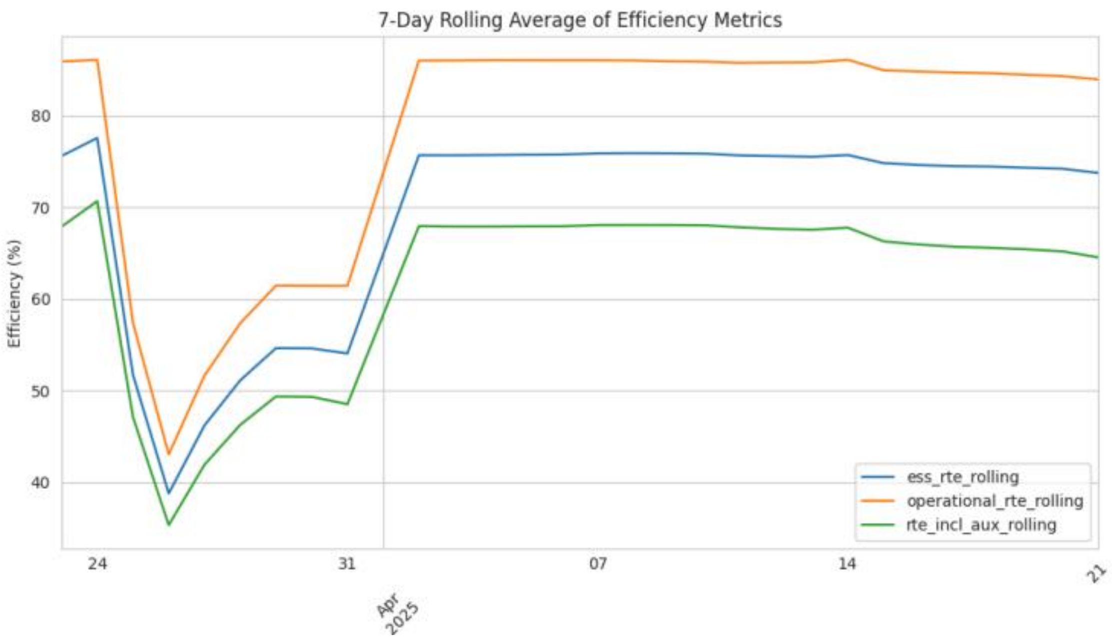
25. Efficiency Assessment

Efficiency Metrics Summary Statistics:

	ess_rte	operational_rte	rte_incl_aux
count	30.00	30.00	30.00
mean	70.33	79.79	62.76
std	19.18	21.75	17.23
min	0.00	0.00	0.00
25%	74.55	85.16	65.82
50%	75.51	85.80	67.75
75%	75.76	86.04	67.97
max	79.49	88.13	73.42

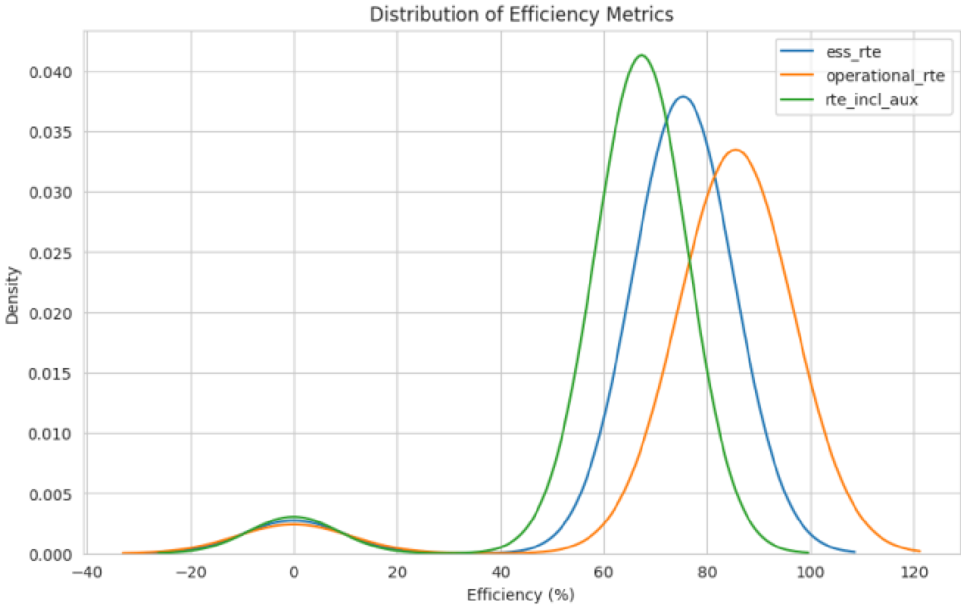


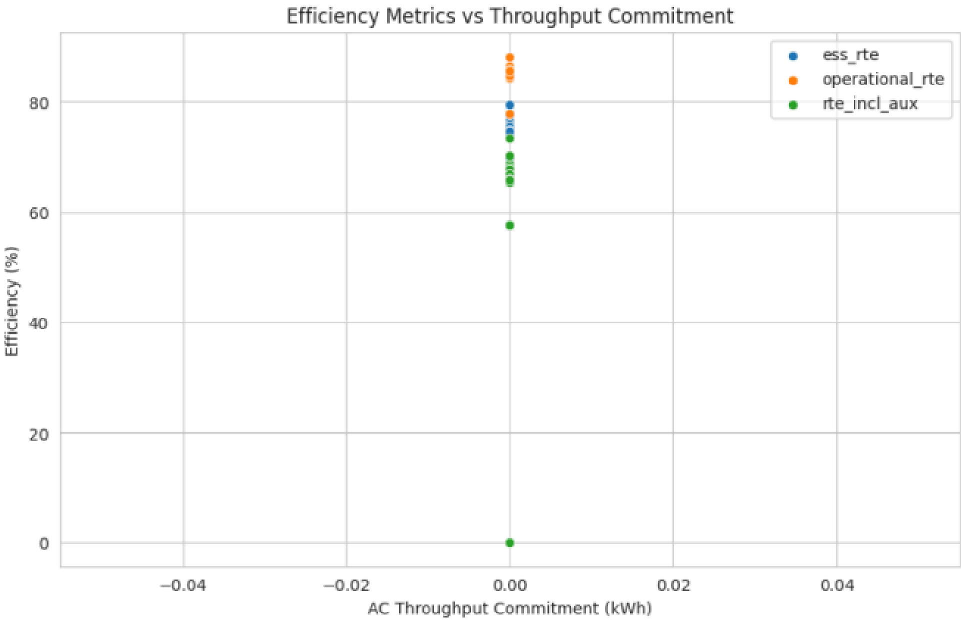

Daily Efficiency Metrics
Efficiency (%)
80
60
40
20
0
24
31
Apr
2025
07
14
21
Date
ess_rte
operational_rte
rte_incl_aux


7-Day Rolling Average of Efficiency Metrics
Efficiency (%)
80
70
60
50
40
24
31
Apr
2025
07
14
21
ess_rte_rolling
operational_rte_rolling
rte_incl_aux_rolling

Days with Efficiency Below 70%:

	date	ess_rte	operational_rte	rte_incl_aux
0	2025-03-23	75.56	85.86	67.85
2	2025-03-25	0.00	0.00	0.00
3	2025-03-26	0.00	0.00	0.00
4	2025-03-27	75.86	85.94	68.21
5	2025-03-28	75.66	85.87	67.97
6	2025-03-29	75.68	86.06	67.91
7	2025-03-30	75.35	85.78	67.57
8	2025-03-31	75.66	86.13	67.84
9	2025-04-01	75.72	86.02	68.07
10	2025-04-02	75.61	85.96	67.85
11	2025-04-03	75.78	86.05	67.88
12	2025-04-04	75.87	86.13	67.96
13	2025-04-05	75.91	86.03	68.04
14	2025-04-06	75.49	85.70	67.62
15	2025-04-07	76.54	86.16	68.78
16	2025-04-08	75.88	85.82	68.14
17	2025-04-09	75.49	85.30	67.81
18	2025-04-10	75.53	85.78	67.69
19	2025-04-11	74.51	85.23	66.40
20	2025-04-12	75.44	86.33	66.87
21	2025-04-13	74.92	85.77	66.97
23	2025-04-15	69.73	77.80	57.68
24	2025-04-16	74.03	84.36	65.43
25	2025-04-17	74.67	85.01	65.98
26	2025-04-18	74.22	84.68	65.59
27	2025-04-19	74.51	85.13	65.73
28	2025-04-20	74.19	84.79	65.40
29	2025-04-21	74.66	85.63	65.76





Daily Efficiency Metrics

26. Overall: All three efficiency metrics show similar daily patterns.
27. Downtime Impact**:** Sharp drop to 0% around March 25, 2025, followed by quick recovery.
28. Typical Levels**:** operational_rte highest (around 85%), ess_rte around 75%, rte_incl_aux around 67%.
29. Mid-April Dip: Slight decrease in all efficiencies around April 14, 2025.

7-Day Rolling Average of Efficiency Metrics

30. Smoothed Trends: Confirms daily patterns with smoother transitions, maintaining relative efficiency levels.

Efficiency Metrics Summary Statistics

31. Mean: ess_rte 70.33%, operational_rte 79.79%, rte_incl_aux 62.76%.
32. Minimums: All at 0.00% due to downtime.

Correlation Matrix of Efficiency Metrics

33. Perfect Correlation: All efficiency metrics are perfectly correlated (1), indicating they move in unison.

Days with Efficiency Below 70%

34. Downtime: March 25, 2025, showed 0% efficiency.
35. Other Instances**:** rte_incl_aux consistently below 70% from April 11th; ess_rte also below 70% on some April days.

Distribution of Efficiency Metrics

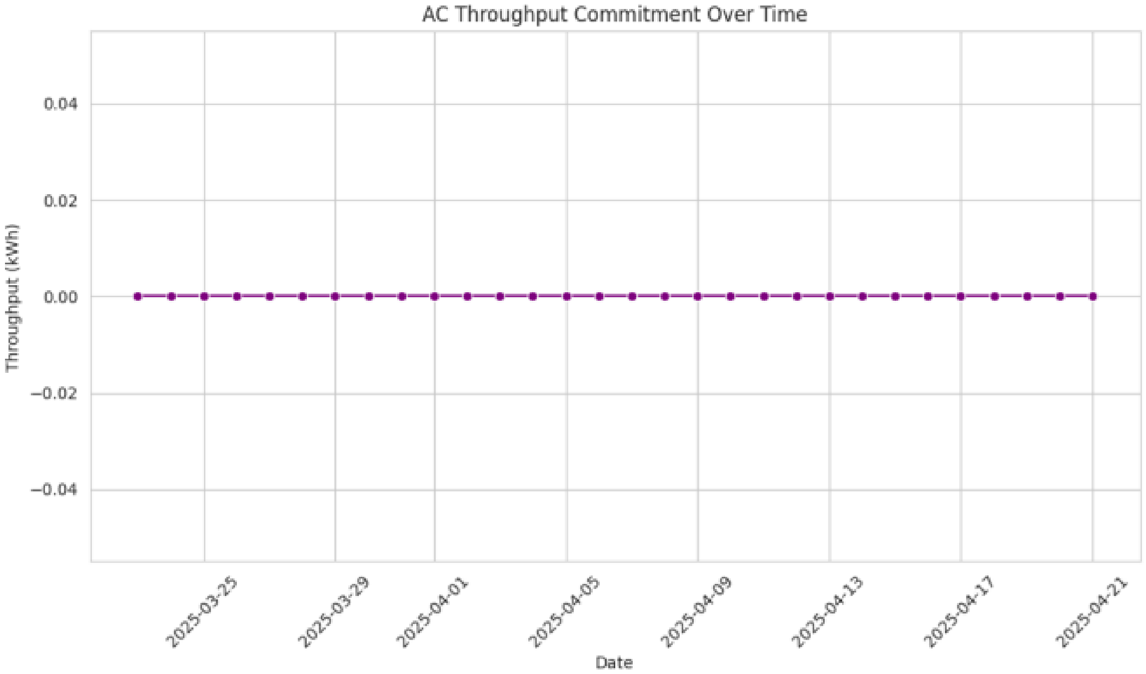
36. Two Peaks: Distributions show peaks at 0% (downtime) and higher ranges (operational efficiency).
37. Distinct Ranges**:** operational_rte 80-90%, ess_rte 70-80%, rte_incl_aux 60-70%.

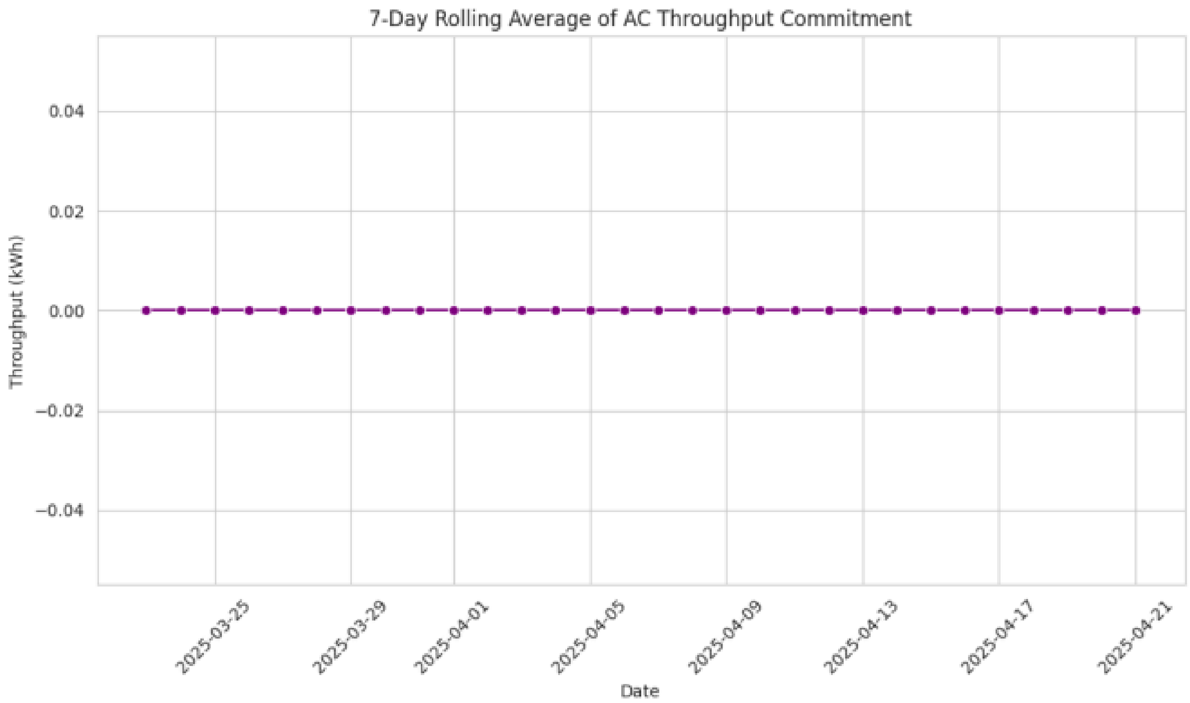
Efficiency Metrics vs Throughput Commitment

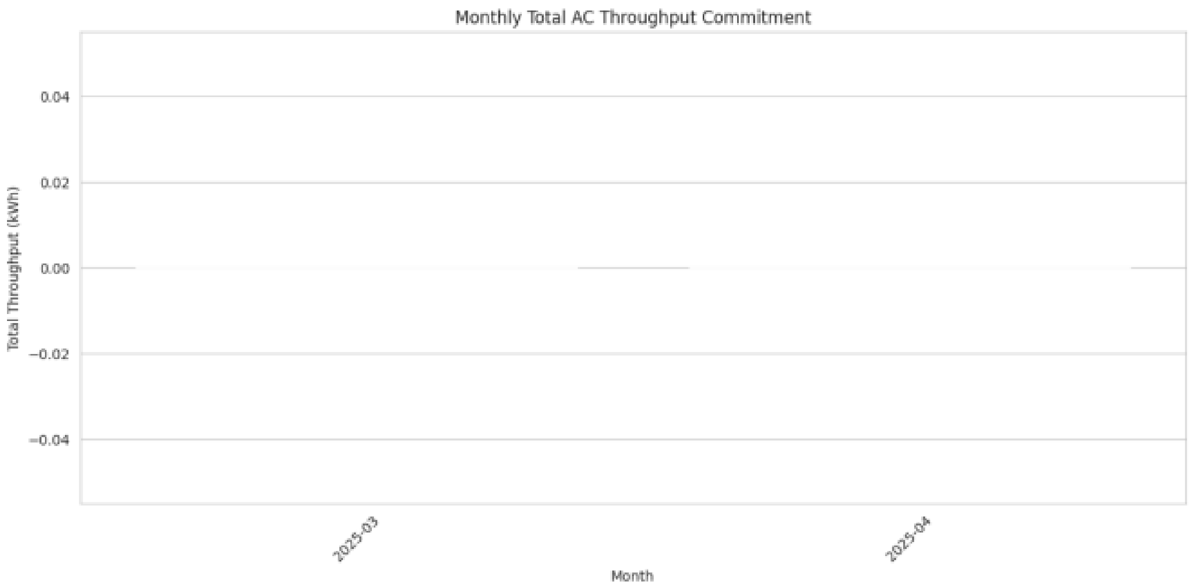
- No Clear Relationship: Efficiency remains high even at very low throughput commitment, suggesting no strong correlation.

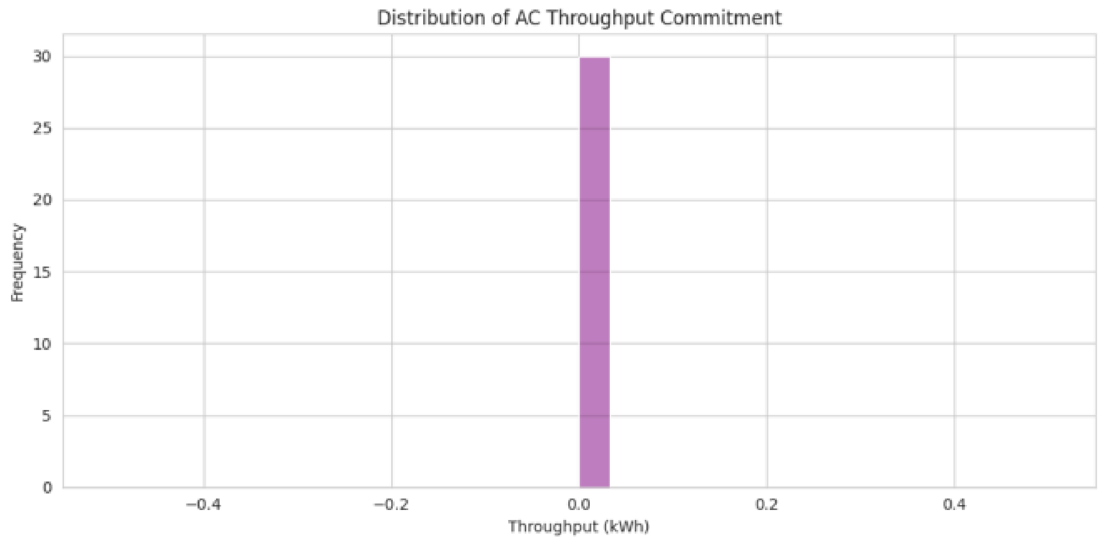
Conclusion: The BESS shows consistent efficiency, with operational_rte being highest. A significant downtime event impacted all metrics in late March. While efficiencies generally remain high and are perfectly correlated, rte_incl_aux consistently performs below 70%. No clear relationship with throughput commitment was observed.

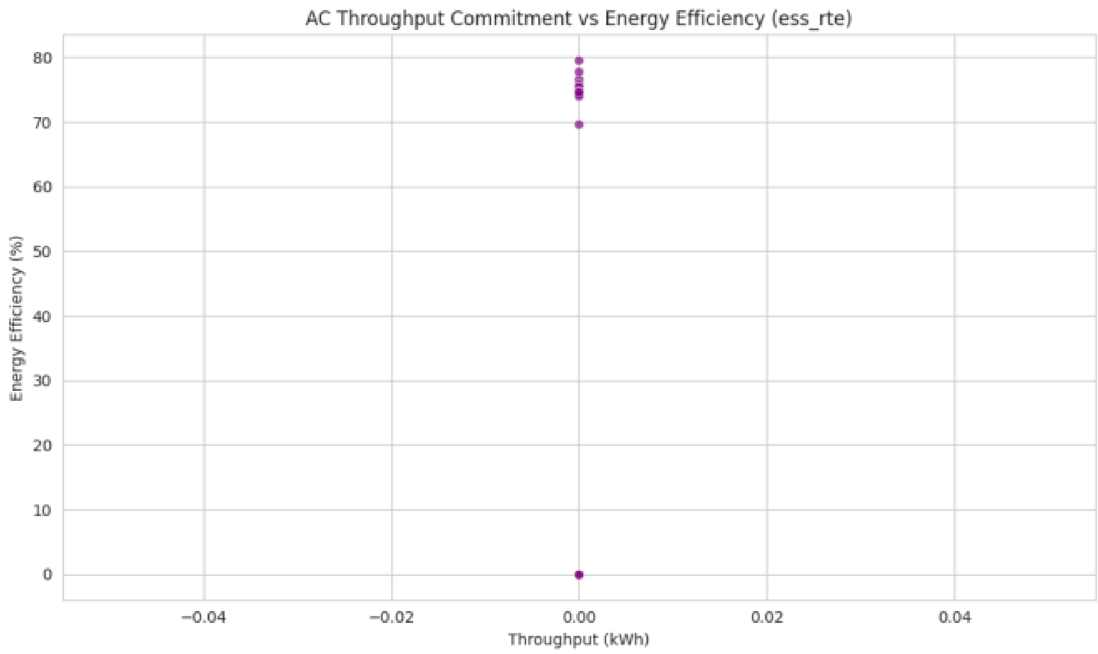
38. Throughput Commitment




7-Day Rolling Average of AC Throughput Commitment
0.04
0.02
0.00
−0.02
−0.04
Throughput (kWh)
2025-03-25
2025-03-29
2025-04-01
2025-04-05
2025-04-09
2025-04-13
2025-04-17
2025-04-21
Date


Monthly Total AC Throughput Commitment
0.04
0.02
0.00
−0.02
−0.04
Total Throughput (kWh)
2025-03
2025-04
Month


Distribution of AC Throughput Commitment
Frequency
Throughput (kWh)
0
5
10
15
20
25
30
−0.4
−0.2
0.0
0.2
0.4


AC Throughput Commitment vs Energy Efficiency (ess_rte)
Energy Efficiency (%)
Throughput (kWh)
0
10
20
30
40
50
60
70
80
−0.04
−0.02
0.00
0.02
0.04

```
Number of days with zero throughput: 30
          date  ac_throughput_commitment
0   2025-03-23                         0
1   2025-03-24                         0
2   2025-03-25                         0
3   2025-03-26                         0
4   2025-03-27                         0
5   2025-03-28                         0
6   2025-03-29                         0
7   2025-03-30                         0
8   2025-03-31                         0
9   2025-04-01                         0
10  2025-04-02                         0
11  2025-04-03                         0
12  2025-04-04                         0
13  2025-04-05                         0
14  2025-04-06                         0
15  2025-04-07                         0
16  2025-04-08                         0
17  2025-04-09                         0
18  2025-04-10                         0
19  2025-04-11                         0
20  2025-04-12                         0
21  2025-04-13                         0
22  2025-04-14                         0
23  2025-04-15                         0
24  2025-04-16                         0
25  2025-04-17                         0
26  2025-04-18                         0
27  2025-04-19                         0
28  2025-04-20                         0
29  2025-04-21                         0
Correlation between throughput and charge+discharge energy:
nan
```

Battery Cycling Analysis

- Daily Equivalent Battery Cycles: The battery showed high daily cycling (0.9 then 0.75 equivalent cycles) from late March to mid-April 2025, with a downtime around March 25.
- Monthly Total Equivalent Cycles: March 2025 had ~6.0 total equivalent cycles, significantly increasing to ~17.5 in April 2025.
- Conclusion: Total equivalent cycles were 24.05. Despite a late March downtime, consistent daily cycling in April led to higher monthly totals.

Equivalent Cycles with SOC and Energy Throughput

39. Equivalent Cycles vs Average SOC: Daily equivalent cycles were consistently low (near 0) across various average SOC values, suggesting minimal activity or calculation issues.
40. Equivalent Cycles vs Total Energy Throughput: Similarly, daily equivalent cycles were near 0 despite varying energy throughput, indicating low daily usage.

41. Monthly Equivalent Cycles and Average SOC Trends: Monthly total equivalent cycles increased significantly from a negative anomaly in March to a positive value in April, correlating with improved average SOC.
42. Conclusion: Daily cycling is low, but monthly trends show increased total cycles in April with improved average SOC, despite a data anomaly in March.

Charge/Discharge Behavior

43. Charge and Discharge Energy Trends: A brief downtime around March 25, 2025, was observed, followed by stable operation with charge energies around 112-125 kWh and discharge around 97 kWh. A slight reduction occurred in mid-April.
44. Daily Net Energy Flow: Most days saw more charging than discharging (net negative flow), with a sharp drop in net flow around April 13-14, 2025.
45. Monthly Energy Totals: April 2025 had significantly higher total charge and discharge energies than March.
46. Daily Energy Loss: Energy loss primarily occurred during charging (around 13-15 kWh), while discharge loss was negligible.
47. Conclusion: The BESS experienced a brief downtime, then stable operation with charging consistently incurring losses and the system generally charging more than discharging daily. Monthly energy throughput increased from March to April.

Efficiency Assessment

48. Daily Efficiency Metrics: All efficiency metrics (operational, ESS, and including auxiliary) showed similar daily patterns, with a sharp drop to 0% around March 25, 2025, and subsequent recovery. Operational RTE was highest (~85%), followed by ESS RTE (~75%), and RTE incl. aux (~67%).
49. Correlation Matrix: All efficiency metrics were perfectly correlated (1).
50. Low Efficiency Days: March 25, 2025, had 0% efficiency. RTE incl. aux was consistently below 70% from April 11th, and ESS RTE also dropped below 70% on some April days.
51. Efficiency vs Throughput Commitment: No clear relationship was observed; efficiency remained high even at very low throughput commitment.
52. Conclusion: The BESS shows consistent efficiency, with operational RTE performing best, but experienced downtime in late March. While efficiencies are generally good and perfectly correlated, RTE incl. aux frequently falls below 70%, and no clear relationship with throughput commitment was found.

Throughput Commitment

53. Overall: The AC Throughput Commitment was consistently zero from March 23 to April 21, 2025, both daily and monthly.
54. Conclusion: Due to the uniform zero values, no meaningful trends, distributions, or correlations could be established for throughput commitment. The data suggests no active throughput commitment or it was not recorded during this period.

55. Descriptive Statistics

```
--- Descriptive Statistics ---
       average_soc  equivalent_cycles  ess_rte  operational_rte  rte_incl_
aux
count        30.00              30.00    30.00            30.00          3
0.00
mean         67.42               0.80    70.33            79.79          6
2.76
std          13.06               0.22    19.18            21.75          1
7.23
min           0.00               0.00     0.00             0.00
0.00
25%          68.95               0.79    74.55            85.16          6
5.82
50%          68.98               0.89    75.51            85.80          6
7.75
75%          71.29               0.89    75.76            86.04          6
7.97
max          73.66               0.89    79.49            88.13          7
3.42
```

Descriptive Statistics

56. Average SOC: Mean 67.42%, with most values (25th-75th percentile) between 68.95% and 71.29%. Min 0% due to downtime.
57. Equivalent Cycles: Mean 0.80 cycles, with a tight cluster between 0.79 and 0.89 cycles during operational periods. Min 0%.
58. Efficiency Metrics:
1. ess_rte: Mean 70.33%, stable at 74.55%-75.76% when operational.
2. operational_rte: Highest mean at 79.79%, stable at 85.16%-86.04% when operational.
3. rte_incl_aux: Lowest mean at 62.76%, stable at 65.82%-67.97% when operational.
4. All efficiency metrics show a minimum of 0% due to downtime.

Conclusion: Descriptive statistics confirm a period of downtime (min 0% for all metrics). When operational, the battery maintained a healthy average SOC and consistent equivalent cycles. Operational_rte is highest, while rte_incl_aux is lowest, indicating the impact of auxiliary losses.

Performance and Efficiency Analysis of 2 MW Solar Power Generation Plant (Oct 2024 - Mar 2025)

Data Overview: The dataset provides daily readings from October 1st, 2024, to March 31st, 2025, including:

1. **Inverter Specifications:** Capacity, module count, module rating, and installed DC capacity for 5 individual inverters.
2. **Daily Generation Data:**
    1. Individual generation readings for each of the 5 inverters (e.g., Inverter 1, Inverter 2... Inverter 5). *Assumed unit: MWh/day given the values (e.g., 2600).*
    2. Total daily inverter generation (sum of individual inverters).
    3. Daily Irradiation (kWh/m²).
    4. Daily Solar Meter Reading (likely overall plant output or billed energy).
    5. Daily "B/W Inverter Generation and Billed Generation" (likely a discrepancy or loss metric, given the negative values).

Descriptive Statistics

1. Summary statistics of inverter generation, irradiation, and meter readings.

2. Total generation (daily and monthly).
3. Mean and standard deviation per inverter.

```
📊 Summary Statistics:
        Irradiation_kWh_per_m2  Solar_Meter_kWh
count               189.000000       189.000000
mean                 10.480169     17682.539683
std                  28.738672     49164.443581
min                   0.096000       200.000000
25%                   4.334000      7400.000000
50%                   5.801000      9400.000000
75%                   7.175000     11600.000000
max                 214.350000    400800.000000

⚡ Daily Total Inverter Generation:
0    Inverter 1Inverter 2Inverter 3Inverter 4Invert...
1                            320kW320kW320kW320kW320kW
2                                                 4091
3                                                 2750
4                                              2250.05
Name: Total_Inverter_Generation, dtype: object
```

Observations:

1. **Irradiation:**
    1. Most days have values between **4.3 to 7.2 kWh/m²**, which is expected.
    2. The **mean (10.48)** is inflated due to a **max value of 214.35**, which is **physically unrealistic** for daily irradiation. It may be a **data entry error**.
2. **Solar Meter kWh:**
    1. Normal readings range between **7,400 to 11,600 kWh** per day (Q1–Q3).
    2. The **mean (17,682 kWh)** is heavily influenced by an extreme **max value of 400,800**, which again is **likely erroneous**.
    3. Standard deviation (49,164 kWh) is extremely high → also due to outliers.

Daily Total Inverter Generation Issue

This output indicates a **data quality issue**:

What's Wrong:

1. **Row 0 and 1** contain **headers or metadata**, not numerical data.
2. This implies the actual data starts from **row 2 or 3**, not row 0.
3. That's why Total_Inverter_Generation is being computed incorrectly — the first two rows are **strings**.