Solar Performance Analysis – Executive Summary

1. Project Overview

The Solar Performance Analysis project aims to evaluate the energy generation efficiency of multiple solar sites, identify anomalies, and derive actionable recommendations for performance optimization. This project uses a data-driven approach by integrating time-series data analytics, database solutions, and visualization frameworks.

2. Key Findings

1. Performance Analysis
    - Energy Yield Comparison:
        - All three sites show identical total energy yield, indicating uniform generation performance.
    - Efficiency Drivers:
        - All Site's high-power factor highlights efficient energy usage, but occasional dips suggest load imbalances or inefficiencies.
    - Site Comparisons:
        - Energy patterns and voltage stability are consistent across sites, with no significant deviations detected.
2. System Health
    - Power Factor Anomalies:
        - Identified on October 23, 26, and 28, signaling potential load changes or equipment issues.
    - Voltage Stability:
        - 26 anomalies detected, which could impact equipment longevity and efficiency.
    - Current Distribution:
        - Balanced across phases, though Phase A consistently draws slightly higher current.
3. Optimization Opportunities
    - Improvements:
        - Address power factor dips and voltage anomalies through targeted maintenance.
    - Quick Wins:
        - Monitor and correct phase imbalances regularly.
        - Implement predictive maintenance for proactive issue resolution.

3. Additional Insights

1. Energy Generation Patterns
    - Morning Dip: A noticeable dip in energy generation occurs during early morning hours (6 AM–9 AM), likely due to cloud cover, early morning fog, or delayed panel warming.
    - Afternoon Peak: Peak energy generation occurs between 12 PM and 3 PM, aligning with maximum solar radiation.
    - Evening Decline: Energy generation declines as the sun sets, reaching its lowest point during late evening and night.

Engineering Insight: Solar panels typically reach 75–85% of their rated efficiency under ideal sunlight. Factors like temperature can reduce performance by 0.5%–1% per degree Celsius above 25°C.

2. Specific Data Observations
    - Data Gap: Only 16 hours of data are available for October 28, 2024, compared to 24-hour datasets for other dates.

3. Voltage Stability Trends
    - Voltage is generally stable but fluctuates during low-light periods (early morning or dusk), indicating load-switching activities or grid adjustments.
    - Engineering Insight: Fluctuations in voltage can cause micro-cracks in solar panel cells over time, reducing overall system efficiency by up to 20%.
4. Power Factor Anomalies
    - Power factor is generally high and stable, but anomalies (e.g., October 23, 26, and 28) suggest load mismatches or inefficiencies during transitions between low and high generation periods.
5. Current Distribution Imbalances
    - Phase A consistently draws slightly higher current. Even small imbalances can lead to long-term issues.

    Engineering Insight: Sustained current imbalances can lead to uneven heating of equipment, causing premature failure of breakers or contactors.

4. Recommendations

1. Improve Voltage Stability
    - Action:
        - Install advanced voltage regulation equipment to handle fluctuations during low-light periods (e.g., early mornings or evenings).
        - Investigate grid connection and load-sharing mechanisms to reduce voltage anomalies.
    - Impact: Improved voltage stability ensures consistent energy delivery and protects equipment from wear caused by fluctuations.
2. Optimize Power Factor
    - Action:
        - Implement load balancing strategies during peak and off-peak hours to maintain consistent power factors.
        - Perform detailed equipment inspections on specific days with detected anomalies (e.g., October 23, 26, 28).
    - Impact: Enhanced energy efficiency and reduced reactive power losses.
3. Phase Current Balancing
    - Action:
        - Regularly monitor and adjust load distribution among phases to prevent long-term imbalances.
        - Use automated load-balancing tools for real-time corrections.
    - Impact: Reduces wear on transformers and equipment, prolonging their operational life.
4. Implement Predictive Maintenance
    - Action:
        - Leverage historical anomaly data to build predictive maintenance models.
        - Schedule proactive inspections for voltage and power factor issues, especially during early morning and evening transitions.
    - Impact: Minimizes downtime and operational inefficiencies for smooth performance across all sites.
5. Address Energy Generation Patterns
    - Action:
        - Ensure optimal panel orientation and tilt to maximize sunlight absorption throughout the day. Monitor real-time weather conditions and adjust system operations accordingly to mitigate the impact of cloud cover and fog.
    - Impact: Increases overall energy yield on daily basis and optimal panel performance year-round.