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Analysis of Voltage and Load profiles of a rural distribution Feeder in Madhya Pradesh

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***Abstract*— In rural India, power supply reliability and quality in distribution feeders often suffer. A major challenge is low voltage issues, worsened by increased demand from agricultural loads, especially irrigation pump sets. These heavy loads, typically during peak agricultural periods, strain local distribution infrastructure, causing voltage drops, inefficiencies, and reduced productivity. This paper examines the impact of agricultural loads on the Kuwa feeder in Thikri tehsil, Barwani district, Madhya Pradesh, focusing on voltage sags, fluctuations, and instability. Detailed voltage and load analysis highlights the causes of low voltage problems and their impact on power delivery reliability. Based on the analysis, voltage conditions have been evaluated, revealing normal operating conditions eliminating undesirable conditions of overvoltage, voltage fluctuations and reverse power flow to the grid. The study focuses on the importance of regular voltage monitoring and analysis to ensure consistent power quality and to design sustainable solutions.**

Keywords: rural feeder, voltage issues, renewable sources, load analysis

I. INTRODUCTION

Agriculture is a critical sector in India, employing over 50% of the workforce, but faces challenges like unreliable power, water scarcity, and climate variability. The lack of consistent electricity hampers productivity, especially for irrigation and other essential agricultural activities. Decentralized solar generation offers a promising solution by providing farmers with reliable, cost-effective, and sustainable energy. Solar power systems, deployed at the point of use (e.g., on farms or irrigation pumps), can reduce dependence on the grid and diesel generators, improving agricultural efficiency while lowering environmental impacts [1].

In rural India, the agricultural cycle significantly influences the demand and consumption patterns of electricity, particularly during the Kharif (monsoon) and Rabi (winter) cropping seasons. These two critical agricultural seasons not only shape the farming activities but also introduce distinct fluctuations in both voltage and load across rural electricity grids. The Kharif season, with its dependence on monsoon, typically demands high irrigation-related energy usage, especially for pumping water, while the Rabi season, being less dependent on rainfall, sees a different load distribution as farmers prepare their fields and manage winter crops.

These seasonal variations often cause voltage fluctuations and load imbalances in the local grid, which can lead to inefficiencies and power outage [2]-[4].

Whenever there is a change in load, the system voltage level changes. With the drop in voltage level, the reactive power demand increases. If the reactive power demand is not met, then it leads to further decline in bus voltage. Hence to maintain the voltage profile within permissible limits becomes essential [13].

The analysis highlights voltage variations, underlines the need for vigilant monitoring and mitigation strategies. The primary sector benefiting is agricultural, as solar power plants are integrated into agricultural setups, such as solar-powered irrigation systems. This provides a sustainable and cost-effective energy source for agricultural activities.

In this paper a case study is performed on Kuwa 33kV feeder and analysis has been presented forth variation of voltage and load profiles during agricultural months.

The remainder of the paper is organized as follows:

Section I introduction to agricultural issues and seasonal variations,

Section II presents importance of voltage management,

Section III discusses the importance of load analysis,

Section IV discusses the case study on Kuwa feeder ,

Section V and VI as results and conclusion respectively.

II. IMPORTANCE OF VOLTAGE ANALYSIS

Voltage analysis helps utilities maintain optimal voltage levels across the distribution network. By identifying variations and patterns in voltage, utilities can address issues that might lead to equipment damage, power quality problems, and service interruptions [7][8]. Key reasons for performing voltage analysis include:

i. Maintaining Power Quality: Consistent voltage

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levels are essential for delivering high-quality power. Voltage analysis helps ensure that voltage stays within acceptable ranges, reducing the risk of power quality issues like voltage sags, swells, and harmonics that can harm sensitive equipment.

ii. Preventing Equipment Damage: High or low voltage can strain transformers, switches, and other grid components, leading to premature wear and failures. By analyzing voltage levels on feeders, utilities can take action to protect infrastructure and extend the life of equipment.

iii. Improving System Reliability: Voltage analysis enables utilities to detect patterns that could indicate potential issues, such as seasonal or demand-based voltage fluctuations. Addressing these patterns proactively can improve overall grid reliability and minimize the risk of service interruptions [5] –[7].

Daily and hourly voltage analysis provides insights into short-term and long-term voltage variations. This analysis helps utilities address immediate issues, such as load-related voltage drops during peak hours, and also plan for long-term trends that may require infrastructure upgrades.

Daily and Hourly Voltage Analysis is essential for the following reasons:

i. Managing Voltage Fluctuations with Demand Patterns: Voltage levels tend to drop during peak demand due to increased current flow. Daily and hourly analysis helps utilities monitor these fluctuations and take corrective measures as needed.

ii. Voltage Regulation: Monitoring voltage hourly allows utilities to identify when voltage dips below or rises above optimal ranges, enabling timely adjustments to maintain stable power quality.

iii. Supporting Demand Response Programs: Voltage analysis supports demand response by adjusting voltages during peak times to reduce the overall system demand [8].

III. SIGNIFICANCE OF LOAD ANALYSIS

The reasons for performing load analysis on feeders are multifaceted, focusing on optimizing system performance, preventing issues, and ensuring that the infrastructure can meet current and future power requirements. Some of the key reasons for conducting load analysis include:[9][10]

i. Matching Supply and Demand: For a power distribution system to be balanced and to avoid overload conditions or under- utilization, the electricity supplied must meet the demand at any given moment. Analyzing load on feeders not only helps one understand when and where electricity is being used but also helps to manage supply as well.

ii. Minimizing outages and failures in equipment: Load analysis helps to identify parts of the feeder that are prone to get damaged due to overloading and stress as feeder nears its capacity, which can be achieved by studying load patterns.

iii. Improving System Reliability and Stability: Load analysis successfully provides insights into the working of feeders under various conditions. Henceforth, engineers can design and implement control measures to enhance the reliability and stability of the network, especially during high-demand periods.

iv. Cost Reduction and Efficiency: By understanding load characteristics, optimization in the use of generation assets and waste reduction can be done. Additionally, better management of load can reduce the need for costly upgrades in the short term [9]-[12]

Furthermore, the emphasis is laid upon daily and hourly load analysis, which contributes towards total load analysis by the measurement of these following components.

i. *Understanding and Managing Demand Patterns*: Electricity demand varies significantly by the hour and day due to daily routines and furthermore, the weather changes that affect heating or cooling needs. These seasonal and day-of-week variations are included as well.
By analyzing these patterns daily and hourly, authorities can understand when and where peak demand occurs. This knowledge allows them to allocate resources effectively and prevents unexpected overloads on the grid, especially during high-demand periods.

ii. *Peak Load Management*: To ensure that demand does not exceed the capacity of the distribution system, hourly load analysis highlights, the time of peaks on each day, allowing authorities to take proactive measures to manage demand, such as:

- Implementing demand and response programs to shift non- essential usage away from peak hours.
- Scheduling maintenance in order to avoid disruptions during high- demand times.
- Activating backup power sources or peaking power plants to ensure reliable service during peak demand periods.
Effective peak load management improves reliability, minimizes the risk of outages, and optimizes the use of generation resources.

iii. *Supporting Demand Forecasting and Long-Term Planning*: Accurate electricity demand forecasting is essential for planning strategic future infrastructural investments. By analyzing daily and hourly data, authorities can forecast:

- Short-term changes in demand (due to weather or events).
- Long-term growth trends that provide insights for future decisions on upgrading equipment or expanding capacity.
Without detailed daily and hourly analysis, forecasts would be less accurate, leading to inefficiencies, such as overbuilding or under-utilization.

iv. *Voltage Regulation:* Demand fluctuations affect voltage levels across the grid. High demand can cause voltage drops, while low demand can result in over voltages. Maintaining proper voltage levels is essential for:

- Preventing equipment damage essentially with sensitive equipment.
- Ensuring power quality and for the stable operation of appliances in homes and businesses.
Hourly load analysis help authorities to regulate voltage levels subjective to changing load conditions and maintaining consistent power quality throughout the day.

v. *Real-Time Fault Detection and Grid Reliability:* Abnormalities in daily or hourly load patterns can signal authorities about issues such as faults, overloads, or equipment malfunctions and provides various other assistances as:

- Detect and respond to faults more quickly.
- Schedule maintenances based on actual data, extending the lifespan of transformers, switches, and various other components.
- Real-time monitoring and analysis will not only improve grid resilience but minimizes disruptions.

IV. CASE STUDY- ANALYSIS OF KUWA FEEDER

In this section we analyze voltage readings across May and October- key periods for agricultural activities in India - to identify deviations from the standard 19 kV per phase. The analysis highlights voltage variations, underlining the need for vigilant monitoring and mitigation strategies. Additionally, we assess solar power generation and reactive power availability, comparing data from other feeders.

Kuwa is a village located in Thikri tehsil of Barwani district in Madhya Pradesh. It is situated 9km away from sub-district headquarter Thikri and 45km away from district headquarter Barwani. Kuwa is surrounded by Umarban tehsil towards North, Raipura Tehsil towards South, Dharampuri tehsil towards East, Manawar tehsil towards North. The 33kV KUWA feeder emanates from 132kV Extra High Voltage Substation Barhi.

The 33kV feeder is stepped down to:

1. 11kV Kuwa DL: The feeder has a length of 41.1654kms and has 96 transformers. It has a kVA rating of 2855 kVA.
2. 11kV Kuwa AG: The feeder has a length of 34.1004kms and has 32 transformers. It has a kVA rating of 1508 kVA.
3. 11kV Keolari DL: The feeder has a length of 14.167kms and has 14 transformers. It has a kVA rating of 496kVA and current rating of 21 Amperes.

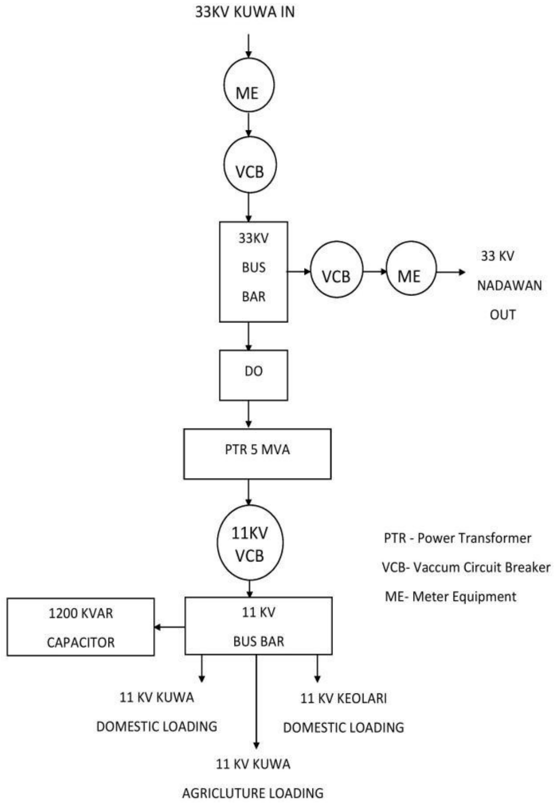

Figure 1. Single line diagram of KUWA feeder

V. RESULTS AND DISCUSSION

A. Voltage Analysis

The comprehensive analysis of voltage readings across the months of March, May and October provides crucial insights into the stability and reliability of power distribution systems. May represents the peak summer month. March is the time of Rabi crop harvesting while October is significant as the harvesting month of Kharif crops and the start of winter in India. Voltage levels are an essential aspect of electrical grid performance, have been meticulously monitored to identify deviations from the standard voltages. The data, encompassing hourly and daily readings for each phase (V_R, V_Y, and V_B), highlights significant voltage variations that suggest potential issues such as overloading, faults, outages, or equipment malfunctions.

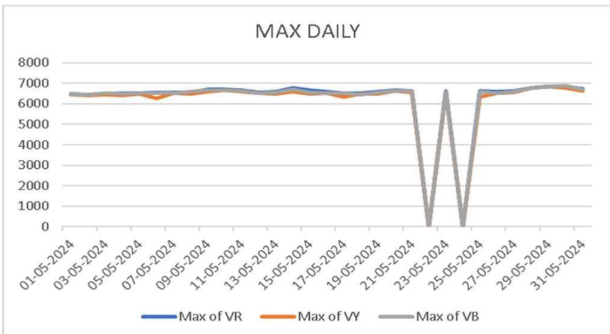

Figure 2. 11kV Agri-KUWA feeder: Daily Maximum voltages on each phase

Figure-2 indicates voltage maximum profile of May-24 shows that for every day of the month, maximum of each phases is equal to the supply phase voltage is 6500 V.

For 11kV agricultural feeder at Kuwa, it is observed that the month of May needs a constant rated supply for majority of the day. The drop in the requirement on 23rd and 25th May, are either due to power cut or shutdown due to local reasons like market day etc.

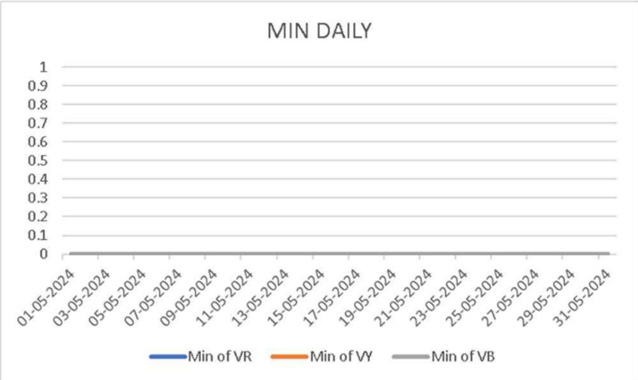

Figure 3. 11kV Agri-KUWA feeder: Daily Minimum voltages on each phase.

Figure-3 indicates voltage minimum profile shows that the voltage across the all phases is zero at some point on every day of the month.

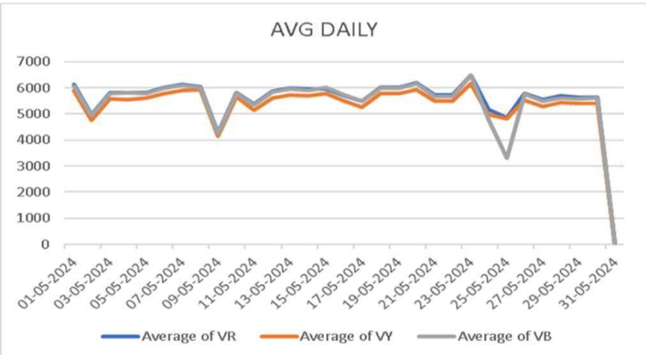

Figure 4. 11kV Agri-Kuwa feeder: Daily average voltages on each phase

Figure-4 indicates voltage average profile shows that the voltage across the all phases is near to the rated voltage of the phase with a variation of +6% to -9%. For 11kV agricultural feeder at KUWA, the voltage requirement is constant and thus we need to maintain rated supply at the feeder. The plot shows that there is optimum utilization of the source and the efficient use of the energy.

B. Load Analysis

As a feeder is a critical part of the infrastructure that carries power from substations to distribution networks, each feeder handles a specific portion of the electrical load, depending on the area and types of consumers it serves. To manage the demand efficiently, utilities perform load analysis on these feeders, which involves monitoring, evaluating, and understanding the patterns of power consumption over time.

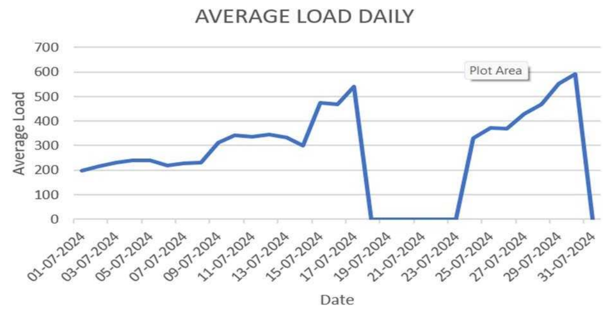

Figure 5. Kuwa Agricultural 11KV - Average Load Daily

Figure. 5, shows a steady increase from the start of July, peaking around mid-month. After a period of zero load, it rises gradually towards the end of the month before dropping again. The highest daily load is observed around 30th July 2024, reaching an average of close to 600 units. A period of zero load between 18th to 23rd July 2024 may indicate scheduled maintenance, data inconsistency, or outages, which could impact agricultural operations if prolonged. The load resumes after the zero period and reaches another peak by the end of the month before a sudden drop.
The fluctuations and peaks likely reflect high demand due to irrigation cycles, with peak usage times aligning with water needs in agricultural operations.

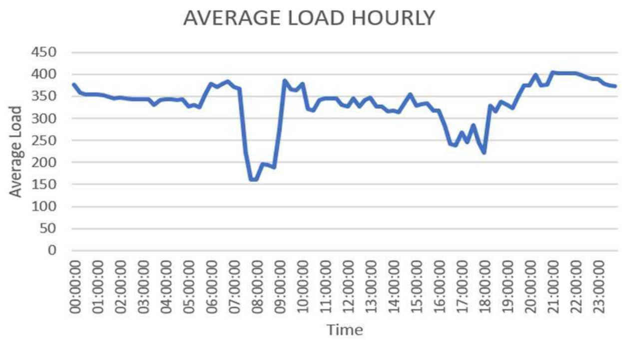

Figure 6. Kuwa Agricultural 11KV - Average Load Hourly

Figure. 6, Hourly load remains relatively stable throughout the day, with specific peaks and dips. The peak occurs around 9:00 PM, reaching just above 400 units, with another high around 9:00 AM. Significant dips occur around 8:00 AM and 6:00 PM. Load stabilizes in the evening, possibly reflecting extended operational hours due to agricultural machinery usage.
Peaks in the morning and evening correspond to active irrigation or machinery operations, while the mid-day dip may represent a lull in agricultural activity.

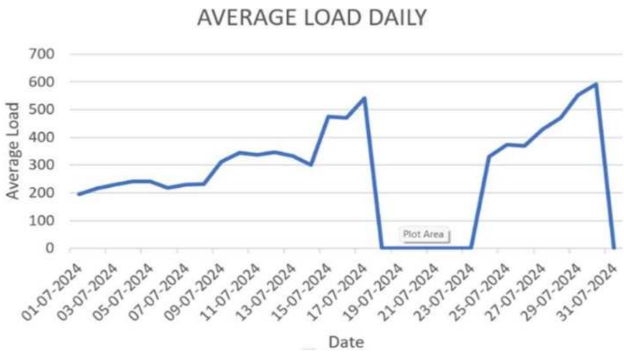

Figure 7. Kuwa 11KV (Non-Agricultural) - Average Load Daily

Figure. 7, The daily load shows a gradual increase, peaking around 18th July 2024, similar to the agricultural feeder.
A zero-load period is also seen from 19th to 24th July 2024. Peak Load Reaches close to 600 units around 30th July 2024. Zero Load The absence of load from 19th to 24th July suggests either maintenance or system-wide power interruptions.
This pattern indicates demand cycles likely associated with residential or commercial usage, affected similarly by downtime across both feeders.

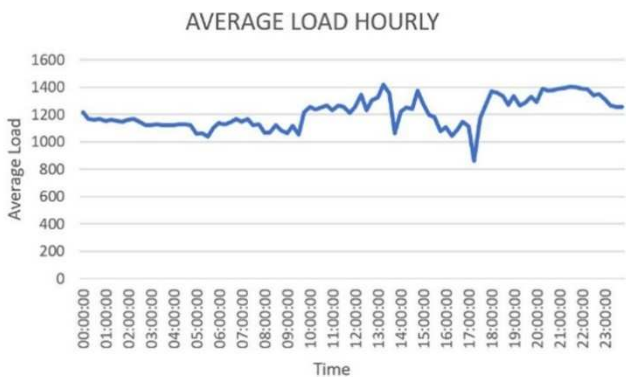

Figure 8. Kuwa 11KV (Non-Agricultural) - Average Load hourly

Figure. 8, Overall Trend: The hourly load remains fairly stable, with peaks and dips reflecting demand patterns.
Peak Load: The load peaks around 9:00 PM, slightly below 1400 units.
Drops in load are observed in the morning and late evening hours. The load rises again in the evening, though not as significantly as in the agricultural feeder.
This feeder follows patterns typical of residential/commercial usage, with increased morning and evening demand and a mid-day reduction.

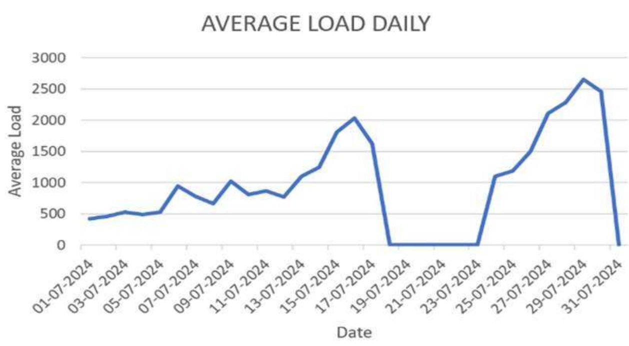

Figure 9. Keolari 11KV - Average Load Daily

Figure.9, From 1st July to around 12th July, the load is stable but relatively low, indicating minimal demand.
A notable increase in load begins around 16th July, peaking near 30th July before dropping at the month's end.
Zero Load Period: From 19th to 23rd July, there is no recorded load, likely due to data inconsistencies or maintenance affecting data continuity.
The sharp rise and peak towards the end of the month suggest seasonal or periodic demand increases, potentially related to higher appliance usage.

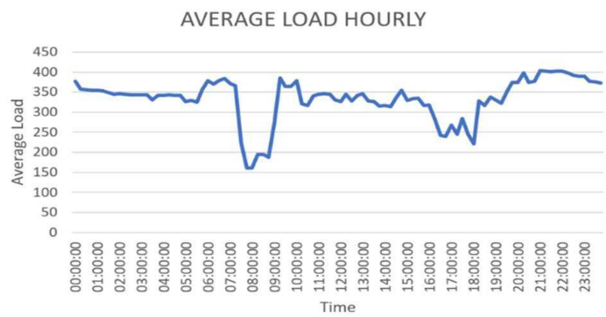

Figure 10. Keolari 11KV - Average Load Hourly

Figure.10, The load peaks around 1:00 PM, indicating high appliance usage in the afternoon, possibly for cooling, lighting, or other residential/commercial uses.
Evening Peaks: Some peak values also occur around late-night hours, likely reflecting additional evening activities.
Voltage Influence: High voltage values might contribute to these peak loads; as higher voltage allows for greater load capacity.
The afternoon peak aligns with active hours in residential or commercial settings, while evening peaks correspond to night-time activities. High voltages further support these peak loads, accommodating higher appliance use.

VI. CONCLUSION

This study underscores the importance of thorough voltage and load analysis in maintaining a resilient and efficient distribution system, particularly in rural areas where power demands vary significantly due to agricultural cycles. Voltage management at the distribution level is essential not only to safeguard equipment but also to enhance overall power quality and reliability.

The analysis of voltage and load for the Kuwa feeders reveals significant stability issues. Voltage drops, ranging from 3 kV to 6.5kV, indicate overloading and potential equipment malfunctions, especially during peak demand. These fluctuations, exceeding a 9% drop from the nominal 19 kV, highlight the need for continuous voltage monitoring and proactive measures to ensure a stable power supply.

The load analysis shows key demand patterns, with agricultural feeders peaking during irrigation times and non-agricultural feeders following typical daily usage trends. Zero-load periods likely reflect maintenance or outages, which could cause disruptions if prolonged. Peak demand times, such as early mornings and evenings, require careful load management. Overall, better monitoring, maintenance, and system optimization are needed to improve reliability and prevent service interruptions.

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