Seasonal Performance Analysis of 11 kV Agricultural Distribution Feeder Using MATPOWER

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Abstract-*This paper presents a comprehensive performance analysis of an 11kV agricultural distribution feeder, namely the Sawangi feeder, supplied from a 33/11 kV substation. Agricultural feeders are characterized by highly variable and seasonal loads, primarily consisting of induction motor-driven irrigation pumps, which significantly affect voltage regulation, power factor, and system losses. In this study, a detailed feeder model comprising 46 nodes and 31 distribution transformers is developed using MATPOWER in the MATLAB environment based on real field data and satellite mapping. The analysis is carried out under different seasonal conditions, namely monsoon (August), winter (January), and summer (April), to evaluate the impact of load variation on feeder performance. Time-based load profile analysis is performed over a 24-hour period to examine variations in voltage, current, active power, and power factor. The results indicate that the feeder experiences significant voltage drop, increased losses, and reduced power factor during peak load conditions, particularly in the winter season due to intensive irrigation demand. Based on the analysis, several improvement techniques such as reactive power compensation using capacitor banks, proper conductor selection, and load balancing are proposed to enhance feeder performance. The study provides valuable insights into the operational behavior of agricultural feeders and suggests practical measures for improving power quality and system efficiency.*

Key Words: 11kV Agricultural Feeder, Load Flow Analysis, MATPOWER, Voltage Profile, Power Factor, Distribution System, Power Losses, Seasonal Load Variation.

1.INTRODUCTION

Electric power distribution systems play a vital role in delivering electrical energy to end users, with agricultural feeders being particularly important for irrigation and rural development. These feeders primarily supply power to induction motor-driven pump sets, which are inherently inductive in nature and operate with low power factor and high starting current. As a result, agricultural feeders often face challenges such as voltage drop, increased line losses, and reduced system efficiency [2],[4].

A key characteristic of agricultural feeders is their seasonal and time-varying load behaviour. During peak irrigation seasons such as winter (Rabi) and summer (Zaid), a large number of pumps operate simultaneously, leading to heavy loading conditions.

In contrast, during the monsoon season (Kharif), the load is relatively lower due to reduced irrigation requirements. Additionally, peak demand typically occurs during daytime hours, causing further stress on the feeder and resulting in poor voltage regulation, especially at the tail-end nodes of long radial feeders.

To effectively analyse and address these issues, it is essential to perform a detailed performance evaluation using reliable simulation tools. MATLAB-based MATPOWER is widely used for load flow analysis of distribution systems, enabling accurate assessment of voltage profile, power flow, and system losses under varying load conditions [1],[3].

In this study, the 11 kV Sawangi agricultural feeder, supplied from a 33/11 kV substation, is modelled and analysed using MATPOWER based on real field data. The analysis is carried out for different seasonal conditions to evaluate key performance parameters such as voltage variation, current profile, power factor, and system losses. Based on the findings, suitable improvement techniques are proposed to enhance feeder performance and power quality [6].

1.1 Problem Statement

The 11 kV Sawangi agricultural feeder, supplied from the 33/11 kV Chauka substation, exhibits several operational challenges due to its long radial structure and the nature of connected agricultural loads. The feeder primarily supplies induction motor-driven pump sets, which are highly inductive and operate with low power factor, leading to increased reactive power demand.

Field observations and data analysis indicate that the feeder experiences significant voltage drop during peak load hours, particularly between 10:00 AM and 4:00 PM, when a large number of irrigation pumps operate simultaneously. This issue is more severe at the tail-end nodes of the feeder due to its extended length of 15.06 km. [2]

In addition, the feeder shows seasonal variations in loading conditions, where:

- During monsoon (August) - feeder is lightly loaded with relatively stable voltage
- During winter (January) - feeder is heavily loaded, resulting in major voltage drop and higher losses
- During summer (April) - moderate to high loading with noticeable performance degradation

These conditions lead to:

- Poor voltage regulation
- Low power factor
- Increased line losses
- Reduced overall system efficiency

Therefore, a detailed performance analysis of the feeder under varying seasonal and loading conditions is required to identify critical issues and suggest suitable improvement measures. [7]

1.2 Objective Formation

The primary objective of this research is to perform a detailed performance analysis of the 11 kV Sawangi agricultural feeder using MATPOWER in the MATLAB environment. The study aims to develop an accurate simulation model of the feeder based on real field data, including its network configuration, load distribution, and transformer details. Furthermore, the research focuses on analysing feeder performance under different seasonal conditions, namely August, January, and April, to capture the impact of varying load demand on system behaviour.

The work also aims to evaluate key performance parameters such as voltage profile, current variation, active power demand, power factor, and system losses under different loading scenarios. In addition, a time-based load profile analysis is carried out to understand the variation in feeder performance over a 24-hour period.

Based on the analysis, the study seeks to identify critical operational issues such as voltage drop, increased losses, and poor power factor, and to propose suitable improvement techniques for enhancing overall feeder efficiency and power quality.

2. System Description

The present study focuses on the performance analysis of the 11 kV Sawangi agricultural feeder, which is supplied from the 33/11 kV Chauka substation. This feeder serves a rural agricultural area and primarily supplies power to irrigation pump loads, making it highly dependent on seasonal and time-based variations.

Fig. 1: Satellite view of 11 kV Sawangi Agricultural Feeder

The feeder operates at a nominal voltage level of 11 kV and has a total length of approximately 15.06 km. Due to its long radial configuration and dispersed load distribution, the feeder is prone to voltage drop and power quality issues, particularly at the tail-end nodes.

For accurate analysis, a detailed network model of the feeder has been developed based on actual field data. The feeder consists of 46 nodes, representing various load points and junctions along the network. These nodes are interconnected through distribution lines characterized by their respective electrical parameters such as resistance and reactance [2].

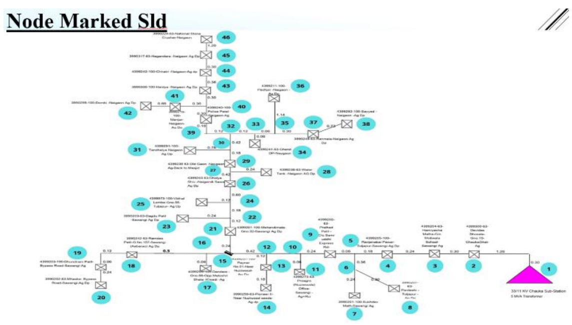

Fig. 2: Single Line Diagram of 11 kV Sawangi Feeder

The system includes a total of 31 distribution transformers, which step down the voltage to supply agricultural consumers. Among these, 16 transformers are rated at 63 kVA, while the remaining 15 transformers are rated at 100 kVA, reflecting the variation in load demand across different locations on the feeder.

The feeder is modelled as a radial distribution system, which is typical for agricultural networks. The substation is considered as the slack bus, maintaining a constant voltage reference, while the remaining nodes are treated as load buses.

The connected load mainly consists of induction motor-based agricultural pump sets of ratings such as 3 HP, 5 HP, and 7 HP, which are aggregated to represent the total feeder load. The overall load on the feeder is considered to be in the range of 1.6 MW to 2 MW, depending on seasonal and operational conditions.

Due to the nature of these loads and the feeder configuration, the system exhibits significant variation in performance parameters such as voltage, current, power factor, and losses. Hence, a detailed simulation-based analysis is essential to evaluate feeder behaviour under different loading scenarios [8].

2.1 Modeling and Simulation of the Feeder

The performance analysis of the 11 kV Sawangi Agricultural Feeder is carried out using MATPOWER Version 8.1 in the MATLAB environment. MATPOWER is an open-source MATLAB-based power system simulation package widely used for steady-state power flow and distribution system analysis . In the present work, AC power flow analysis based on the Newton–Raphson method is adopted to evaluate feeder performance under varying seasonal loading conditions.

The feeder originates from the 33/11 kV Chauka Substation and is modelled as a radial distribution network consisting of 46 nodes and 31 distribution transformers. The complete feeder configuration is developed using actual field data, satellite mapping, and single-line diagram representation. The feeder operates at a nominal voltage level of 11 kV with a total feeder length of approximately 15.06 km [1].
The MATPOWER case structure (mpc) is created programmatically using MATLAB scripts. The simulation model includes:

- mpc.bus → bus and load data
- mpc.branch → feeder section impedance data
- mpc.gen → slack bus and source data

The feeder parameters are extracted from Excel-based datasets and automatically converted into MATPOWER-compatible matrices. The electrical parameters considered for simulation include conductor resistance, reactance, diversity factor, power factor, and nominal voltage.

The parameter variation analysis indicates that the feeder uses ACSR DOG-100 sq.mm conductors with resistance and reactance values of approximately 0.3 Ω/km and 0.4 Ω/km, respectively.

The system is modelled with a diversity factor of 1.3 and an operating power factor close to 0.98 lagging, representing practical agricultural loading conditions.

The loads connected to the feeder mainly consist of agricultural pump sets of ratings such as 3 HP, 5 HP, and 7 HP. These loads are aggregated at different buses and modelled as constant PQ loads. The total feeder loading varies between 1.6 MW and 2 MW depending on seasonal irrigation demand [3].

2.2 Load Flow Analysis Using MATPOWER

Load flow analysis is carried out on the developed feeder model using MATPOWER to assess the steady-state performance of the system under varying operating conditions. This analysis enables evaluation of key electrical parameters such as bus voltage magnitude, line current, active and reactive power flow, power factor, and system losses.

The study is performed under different seasonal loading conditions to capture the variation in feeder behaviour. Three representative scenarios are considered:

- August (Monsoon Season) – Light load condition
- January (Winter Season) – Heavy load condition
- April (Summer Season) – Moderate load condition

In addition to seasonal analysis, a time-based load profile study is conducted over a 24-hour period to examine the variation of system parameters with time. This is particularly useful for identifying peak load conditions, which typically occur during daytime hours when agricultural pump usage is highest [1].

The load flow results provide detailed insights into:

- Voltage profile across all nodes
- Current distribution along the feeder
- Active power demand variation
- Power factor behaviour under different loading conditions
- Total system losses

These observations help in identifying critical operating conditions such as significant voltage drop at tail-end nodes, increased current flow during peak hours, and reduction in power factor due to inductive loads. The analysis forms the basis for proposing suitable techniques to improve feeder performance [9].

3. PROPOSED IMPROVEMENT TECHNIQUES

Based on the performance analysis of the 11 kV Sawangi agricultural feeder, issues such as voltage drop, low power factor, and increased losses are observed during peak loading conditions. These problems are mainly due to the inductive nature of agricultural loads and the long feeder length. Since this study is based on simulation and analysis, the following improvement techniques are proposed to enhance feeder performance.

3.1 Reactive Power Compensation Using Capacitor Banks

The inductive nature of agricultural pump loads results in high reactive power demand, leading to poor power factor and voltage drop. To mitigate these issues, installation of shunt capacitor banks at suitable locations is recommended.

Capacitor banks provide local reactive power support, thereby reducing reactive current flow in the feeder. This results in improved voltage profile, enhanced power factor, and reduced line losses. The required reactive power compensation can be estimated us,

$$Q_c = P (\tan \phi 1 - \tan \phi 2)$$

3.2 Proper Conductor Selection

The long feeder length contributes significantly to voltage drop and power losses due to conductor resistance. Therefore, the use of conductors with lower resistance and higher current-carrying capacity is recommended. This improvement can reduce I^2R losses, enhance voltage regulation, and improve overall system efficiency, especially under heavy loading conditions.

3.2.1 Voltage Magnitude Analysis

The voltage profile from Bus 1 (source) to Bus 46 (tail end) was obtained for all three simulation cases. The minimum permissible voltage on an 11 kV feeder is 10.34 kV (- 6%) and the maximum is 11.66 kV (+6%) as per Indian Electricity Grid Code.

Table 3.2.1 – Voltage Summary: Key Nodes (Actual Values)

Bus #	Case1: DOG PF=0.98, DF=1.3 (kV)	Case2: DOGUP PF=0.98, DF=1.3 (kV)	Case3: DOG PF=0.95, DF=1.2 (kV)
Bus 1 (Source)	11.000	11.000	11.000
Bus 5	10.835	10.868	10.813
Bus 10	10.824	10.857	10.791
Bus 15	10.791	10.824	10.758
Bus 20	10.780	10.824	10.747
Bus 25	10.769	10.813	10.725
Bus 30	10.725	10.780	10.681
Bus 35	10.714	10.769	10.670
Bus 40	10.703	10.758	10.659
Bus 46 (Tail)	10.692	10.758	10.648
Voltage Drop (V)	308 V	242 V	352 V

Note: PF – Power Factor, **DF –** Diversity Factor.

The tail-end voltage at Bus 46 remains above the statutory minimum of 10.34 kV in all three cases, confirming that the feeder operates within permissible limits under the simulated loading conditions.

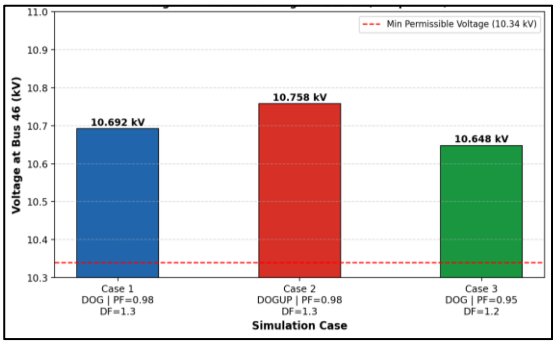

Fig. 3.2.1 – Tail-End Voltage at Bus 46: Comparison Across All Cases

The DOGUP conductor improves the tail-end voltage by 66 V (0.006 pu) over the existing DOG conductor under identical PF and DF conditions.

3.2.2 Power Flow Analysis

Branch power losses (I^2R active losses and I^2X reactive losses) were computed by MATPOWER for each simulation case. Table 6.3 presents the total feeder losses converted to actual values, and Figure 6.2 provides a side-by-side bar chart comparison.

Table 3.2.2 – Total Feeder Power Loss Summary

Parameter	Case1: DOG PF=0.98, DF=1.3	Case2: DOGUP PF=0.98, DF=1.3	Case3: DOG PF=0.95, DF=1.2
Active Loss P (I^2R)	36 kW	28 kW	42 kW
Reactive Loss Q (I^2X)	40 kVAr	30 kVAr	40 kVAr
Total Load P Served	1.89 MW	1.89 MW	1.99 MW
Loss as % of Generation	1.87%	1.46%	2.07%
Max Branch Loss (Br 1-2)	17 kW	13 kW	20 kW
Voltage Drop (Bus 1→46)	308 V	242 V	352 V

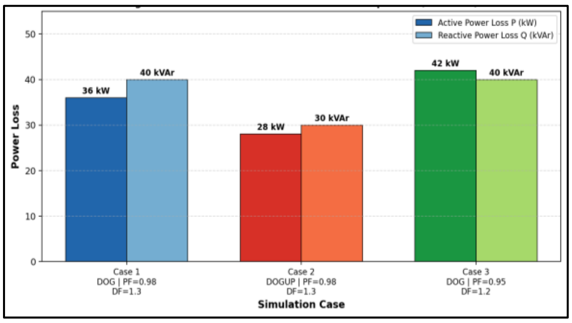

Fig. 3.2.2 – Active and Reactive Power Loss Comparison: All Three Cases

Replacing the existing ACSR DOG conductor with AAAC DOGUP reduces active power loss by 8 kW (22.2%) and reactive power loss by 10 kVAr (25.0%) under the same loading conditions. Branch 1–2, which carries the entire feeder current, accounts for the highest individual branch loss in all cases and benefits most from conductor upgradation [4],[9].

4. RESULTS AND DISCUSSION

The performance of the 11 kV Sawangi agricultural feeder is evaluated using load flow analysis in MATPOWER under different seasonal and time-based loading conditions. The results are analyzed in terms of voltage profile, current variation, active power demand, and power factor behavior.

4.1 Voltage Profile Analysis

The variation of voltage with respect to time for different seasons is shown in Fig. 3.

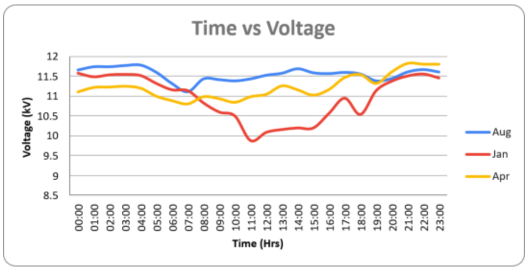

Fig. 3: Voltage Profile under Different Seasonal Conditions

The results indicate that the voltage remains relatively stable during the monsoon season (August) due to lighter loading conditions. However, during the winter season (January), a significant voltage drop is observed, especially during peak hours between 10:00 AM and 4:00 PM. This is attributed to the simultaneous operation of multiple irrigation pump sets.

In the summer season (April), a moderate voltage drop is observed, reflecting intermediate loading conditions. The voltage drop is more pronounced at the tail-end nodes of the feeder due to its radial structure and long length.

4.2 Current Profile Analysis

The variation of feeder current with time is illustrated in Fig. 4.

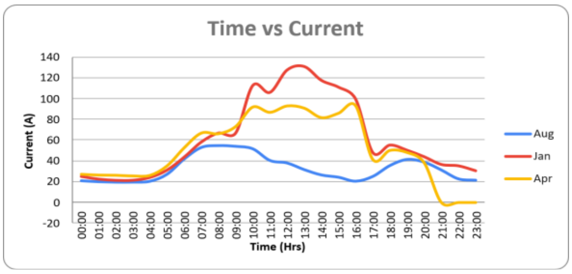

Fig. 4: Current Variation for Different Seasonal Conditions

It is observed that the current is lowest during the monsoon season due to reduced load demand. In contrast, the current reaches its maximum value during the winter season, particularly during peak irrigation hours.

This increase in current leads to higher losses and increased stress on the feeder. The summer season shows moderate current levels, corresponding to medium load demand.

4.3 Active Power Analysis

The active power demand variation is presented in Fig. 5.

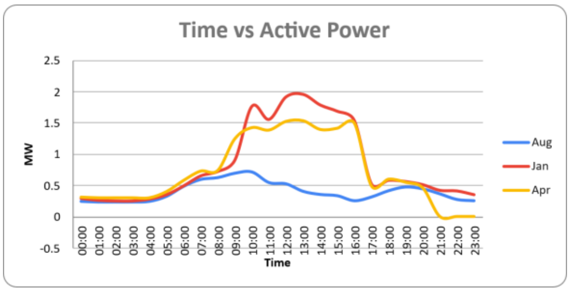

Fig. 5: Active Power Variation for Different Seasons

The results show that the maximum power demand occurs during the winter season, reaching values close to 2 MW, indicating heavy loading conditions.
During the monsoon season, the power demand is significantly lower due to reduced irrigation requirements. The summer season exhibits moderate power demand, reflecting partial agricultural activity.

4.4 Power Factor Analysis

The variation of power factor with time is shown in Fig. 6

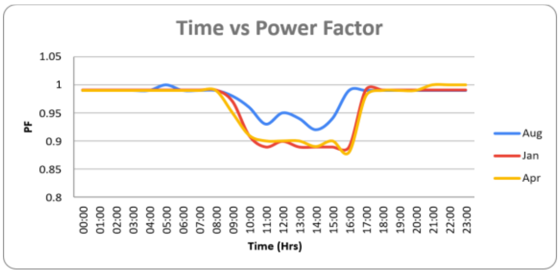

Fig. 6: Power Factor Variation under Different Load Conditions

It is observed that the power factor decreases during peak load conditions due to the inductive nature of pump loads. The lowest power factor is observed during the winter season, while relatively better values are seen during the monsoon season.

The reduced power factor contributes to increased reactive power demand, higher current flow, and additional system losses.

4.5 Overall Performance Discussion

From the above analysis, it is evident that the performance of the feeder is significantly influenced by seasonal and time-based load variations. The feeder experiences:

- Significant voltage drops during peak loading conditions
- Increased current flow and system losses
- Reduction in power factor due to inductive loads

Among the three scenarios, the winter season represents the worst-case condition, while the monsoon season represents the best-case scenario in terms of feeder performance.

These results clearly highlight the need for appropriate improvement techniques to enhance voltage regulation, reduce losses, and improve overall system efficiency.[3],[4]

5. CONCLUSION

This paper presented a detailed performance analysis of the 11 kV Sawangi agricultural feeder supplied from the 33/11 kV Chauka substation using MATPOWER in the MATLAB environment. A realistic feeder model was developed based on actual field data, and the analysis was carried out under different seasonal conditions monsoon, winter, and summer to evaluate the impact of load variation. The results revealed that the feeder experiences significant voltage drop, increased current flow, higher system losses, and reduced power factor during peak loading conditions, particularly in the winter season due to intensive irrigation demand.

The time-based load profile analysis further highlighted that maximum stress occurs during daytime hours, affecting overall feeder performance. Based on these observations, improvement techniques such as reactive power compensation using capacitor banks and proper conductor selection were proposed to enhance voltage regulation, improve power factor, and reduce losses. Although these methods were not implemented practically, the study provides valuable insights into feeder behaviour and offers effective recommendations for improving the efficiency and reliability of agricultural distribution systems.

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