Available online at www.garmian.edu.krd

Passer Journal

Passer 5 (Issue 1) (2023) 85-93

http://passer.garmian.edu.krd/

Investigation of Voltage Profiles and Power Losses in Radial Distribution Feeders Based on Smart Meter Data (Raparin Substation as a Case Study)

Chra Fariq Raouf[1*], Asso Raouf Majeed[1]

[1]*Department of Electrical, College of Engineering, University of Sulaimani, Sulaimani, Kurdistan Region, Iraq.*

Received 19 January 2023; revised 26 February 2023;
accepted 1 March 2023; available online 6 March 2023

DOI: 10.24271/PSR.2023.382269.1235

ABSTRACT

In modern societies, electric energy usage has become an essential need in daily life. As a result, the number of customers and their appliances increases continuously, and the load (stress) on the distribution feeders increases accordingly. The distribution feeder is the final stage that delivers energy to the customers directly and contributes to about eighty percent of the power outages to the customers. Previously, conducting studies on distribution networks was difficult because of the difficulty in collecting data and sometimes due to the unavailability of accurate data. Nowadays, emerging smart meters (SM) in distribution networks provide a great opportunity to collect the data required for such studies.
In this study, the data was collected for ten feeders of the Raparin substation as a case study since they are provided with smart meters for the transformers and all the consumers. These feeders consist of 156 branches and 331 nodes. To deliver good power to the customers and obtain their satisfaction, it is necessary to monitor and control the operation of the distribution feeders.
Modeling and simulation for each feeder with different case studies are achieved during maximum and minimum load periods using ETAB software. Power flow using ETAB at maximum load is performed in order to find active and reactive losses with voltage profiles in each branch and at each node. At the same time, the power flow during minimum load is necessary to monitor the increase in voltage level so as that avoid undesirable events.

Keywords: Radial distribution feeder, Smart meters, Transformer loading, Capacitor bank.

1. Introduction

Power system generally consists of three main stages: generation, transmission, and finally, distribution. Distribution networks are responsible for delivering power to the consumers, and they are of two types which are radial and ring. The first one delivers power from one source only, and the power flows in one direction. Although it is simple in design and has low initial and operation costs, it is less reliable because when a fault occurs at the beginning of the main feeder, then all the customers will be interrupted. However, the second type possesses a higher degree of reliability because, in the case of any failure, the deteriorated consumers are fed from another source[1].

Power flow is considered one among several useful studies that are used in deciding the system's status under a steady state and the given load condition[2].

Power flow is essential in system design and future expansion as it gives detailed information about losses, voltage drop, current in each branch, and voltage magnitude and its angle at each bus. The conventional algorithms used to perform load flow study are[3]:

- Gauss seidel
- Newton Raphson
- Fast decoupled method

After many studies, researchers found that these algorithms do not suit distribution networks in terms of robustness, performance, and efficiency. For this reason, other methods have been discovered, such as the ladder technique, which is specifically designed for a radial system[4].

For this study, two inputs are required, which are line (branches) and bus data (transformer nodes). Bus data is conventionally collected by measuring the load of several buses, and in this situation, the result will not be accurate. But today, emerging new technologies to the distribution feeders, like smart meters, enable the system operators and the researchers to monitor and control the network as these meters provide historical data such as 3-ph voltages and currents, injected power, frequency, and power factor.

* Corresponding author
E-mail address: chra.rauf@univsul.edu.iq (Instructor).
Peer-reviewed under the responsibility of the University of Garmian.

A perfect distribution network must ensure the consumers' satisfaction in terms of reliability and good power quality; from this perspective, it is necessary to study and investigate the losses, voltage drop, power factor violation, frequency, transformer and line loadings, and total demand in a distribution network[5].

In recent years, many researchers have proposed and developed special algorithms for distribution networks as well as computer programs in order to model, simulate, and analyze these networks because they are characterized by the following points:

- Unlike transmission systems, distribution feeders are un-transposed.
- The configuration at most is radial or weakly meshed.
- The loads are single phases or unbalanced three phases.
- Consists of many nodes and branches.
- Wide-ranging of X/R ratio.

In 2017, Bhela & Veeramachaneni formulated a Coupled Power Flow problem (CPF) relying on smart meter data. This work proves the importance of the metered buses in the controllability and observability of the distribution grid[5].

In 2017, Alinjak. et al. modified the backward/forward sweep by applying the breadth-first search technique in constructing the indices matrix with a minimum searching number for connections between buses. The method is very applicable to unbalanced three-phase distribution networks[6].

In 2019, Anagnostopoulos, P. M., & Papathanassiou proposed a novel algorithm named ModDistFlow which derived from the conventional DistFlow equations. The proposed one is more accurate as it includes the active and reactive power losses in the calculation and is very suitable for distribution feeders with high penetration of DER[7].

In 2019, Jha & Dubey used branch flow equations to propose a convex iterative technique to solve optimal power flow in a distribution feeder. The authors addressed the issues related to the radial distribution feeders that cause the conventional optimal power flow (OPF) not to converge. They obtained OPF solutions by using second-order cone program (SOCP) iterations. The proposed method was tested on 13 and 123-bus IEEE test feeders[8].

In 2020, Ouali & Cherkaoui produced an algorithm that is simple to implement with the only use of linear equations based on Kirchhoff's formulation, with no need for any matrix construction, and based on backward and forward sweep PF to solve load flow problems in radial distribution feeders[9].

In 2021, Guo. et al. proposed a novel approach to identifying feeder topology by rebuilding a

weighted Laplacian matrix of distribution networks, then they estimated the line impedance of a single branch by developing nonlinear least absolute deviations (LAD) and least squares (LS) regression models based on a nonlinear inverse power flow method[10].

The objectives of this paper are:

- Highlighting the role of the smart meter in providing the essential data at each transformer node and at each end consumer.
- Possibility of reducing the stress on the distribution feeders through limiting the supplied current for the overloaded branches or, overall, the feeder consumers.
- Modeling and simulation of the detailed topology of each feeder with the detailed branches for evaluation of the power flow for finding the power losses, voltage profile, and power factor.
- Suggesting possible improvement in order to obtain better performance and operation of distribution feeders.

2. Case Study - Raparin substation

Raparin substation is located in Sulaimani city, and it is connected through two 33 KV lines from the Bakrajo substation. It has two 33/11 KV transformers, each with 31.5 MVA capacity, and each transformer feeds six feeders of 11 KV. Hence total installed capacity for this substation is 63 MVA with 12 feeders of 11 KV voltage. Ten substation feeders have been provided smart meters at each distribution transformer and every consumer since 2019.

3. Smart meter

The smart meter is a component of a smart grid that has the ability to meter as well as communication. It records the consumed energy and allows it to be read it remotely and displayed on a device that can be existed within the consumer's home, which is known as Customer Interface Unit (CIU). The meter can also receive information remotely, e.g., switch between post-paid and pre-paid modes, and can remotely update tariff information. It has two key features to perform:

(1) providing the consumer with energy consumption data that permits the consumers to avoid overconsumption and manage their load more economically.

(2) for sending data to the utility for peak-load requirements and load control and to develop pricing strategies on the basis of consumption information. A smart meter is provided with automated meter reading capability as well as two-way communication between consumers and utilities[11]. Other features of the smart meter are low voltage network monitoring that provides better service reliability, sophisticated energy loss detection, and any tampering of the system immediately reported to the central control system[12]. Currently, in Kurdistan Region (KR), three types of smart meters are installed along distribution feeders. Fig.1 shows the front view of the available smart meters.

Fig.1. (a) is a three-phase Current Transformer /Whole Current (CT/WC) smart meter, which means the meter is integrated with CT internally; this type is installed on the secondary side of the distribution transformers. Fig.1. (b) is also a three-phase CT smart meter that needs to install a CT with it. Both these meters have many enhancements, such as smart grid solutions, high data storage, data processing, and modular communication capabilities.

(a) (b) (c)

Figure 1: The available smart meters in KR.

Fig.1. (c) represents an advanced single-phase meter designed for residential use with an integrated 60 A compliant relay. It is able to operate in either prepaid or postpaid mode. This type is installed at the customer's end.

It can communicate with the CIU (Customer Interface Unit) wirelessly (Fig. 2). Also, it can communicate with the gateway and with the rest of the system as a complete AMI (Advanced Metering Infrastructure) system[13].

The smart meter project started in KR in 2019. In 2020, the chosen feeders were partially provided with smart meters, while in 2021, the project is nearly completed along the chosen feeders. Table.1 provides the number of the smart meters installed in each feeder in 2021.

Figure 2: Customer interface unit used by the consumers and communicates wirelessly with the smart meter.

Table 1: Technical information for ten feeders.

Feeder ID	**F100**	**F101**	**F102**	**F103**	**F105**	**F105A**	**F106**	**F108**	**F109**	**F110**
SM [1]	994	1420	1774	824	595	1477	1501	1100	1675	927
Demand (MW) [2]	5.19	5.49	6.42	4.75	4.83	4.85	4.0	5.3	5.7	4.58
Length (KM) [3]	7.036	5.570	7.861	6.073	8.590	5.591	4.550	14.044	7.871	3.973

[1] represents the total number of smart meters installed along the feeder

[2] represents the total demand during peak load

[3] represents the total wire used in the feeder.

Table. 2 gives details of the number of nodes and branches for the ten feeders.

Table 2: Number of nodes and branches for each feeder.

Feeder ID	**F100**	**F101**	**F102**	**F103**	**F105**	**F105A**	**F 106**	**F108**	**F109**	**F110**
No. of nodes	31	31	36	37	35	27	25	37	41	31
No. of branches	12	8	26	13	16	11	10	24	21	15

Table. 3 gives the measured current of the residential appliance directly from the SM by the household consumers using the customer interface unit shown in Fig. 2.

Table 3: Residential appliances with their currents in Ampere (A).

Item	**Split**	**Boiler**	**Refrigerator**	**Freezer**	**Iron**	**Cloth washing machine**	**Oven**	**Lighting**	**T.V & satellite**
(A)	10	14.8	1.3	0.78	8.8	8.8	6.3	3.2	1.2

In order to show the role of SM in decreasing the load on the feeders, the data was collected for six years (from 2016 to 2021) for feeder 100 as an example, and the annual average load was calculated for each year, and the result is presented in Fig.3. (a)

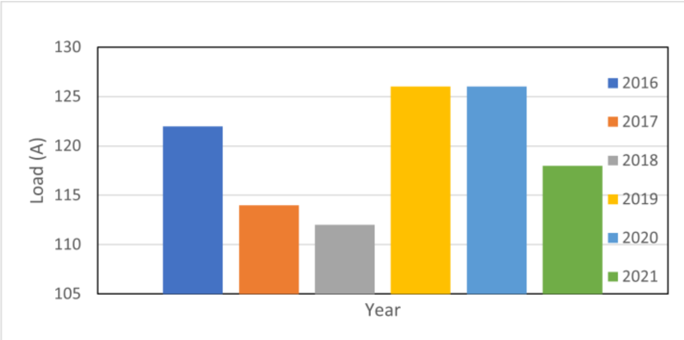

Figure 3: (a) Annual average load for feeder 100. It represents the amount of the load consumed every year (from 2016 to 2021).

Fig.3. (b) represents the total hours the consumers supplied in January (the most severe month) for each year (from 2016 to 2021) on the same feeder.

From these results, the role of the smart meter appears clearly in

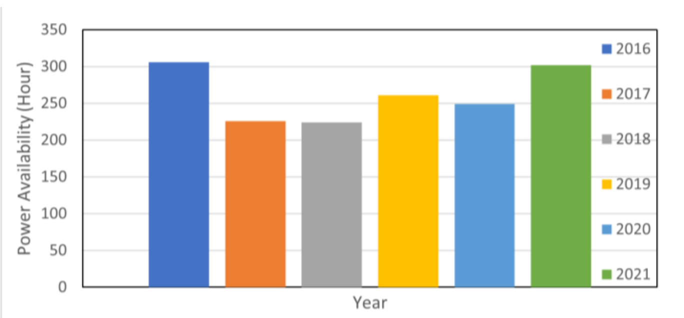

Figure 3: (b) Supply hours in January for every year (from 2016 to 2021) for feeder 100. The mentioned month was selected as an example since most of the failures occur in January.

reducing the feeder's load. In the years 2017 and 2018, the supply availability was the least. Naturally, their annual average load will be the minimum. The comparison can be made between 2019, 2020, and 2021. In 2019 and 2020, the supply hours were less than in 2021, but the annual average load in 2021 was the least among them. This reduction belongs to two main reasons: the first reason is that the power system operators can control the load and limit it to a specific value (to 40 A at normal conditions and 30 A during peak load) and force the consumer to reduce the consumption otherwise the relay of the meter will trip. The second reason is the consequence of the first reason; the consumers will manage their load more economically and efficiently in order to avoid power outages. Other applications of the smart meter, such as the detection and prevention of tampering and illegal use of electricity, also have an impact on load reduction.

4 Load flow case studies

The load flow is performed by using the historical data recorded by SM. Load flow is performed at maximum load to determine the feeder's active and reactive losses, voltage level, and voltage drop at each branch of the feeder. The load flow at minimum load value is also performed to observe the voltage level rise at minimum load. The model of the ten feeders is entered according to the ETAB software. Fig.4 shows, as an example, the modeling of feeder 103 with details of nodes and branches.

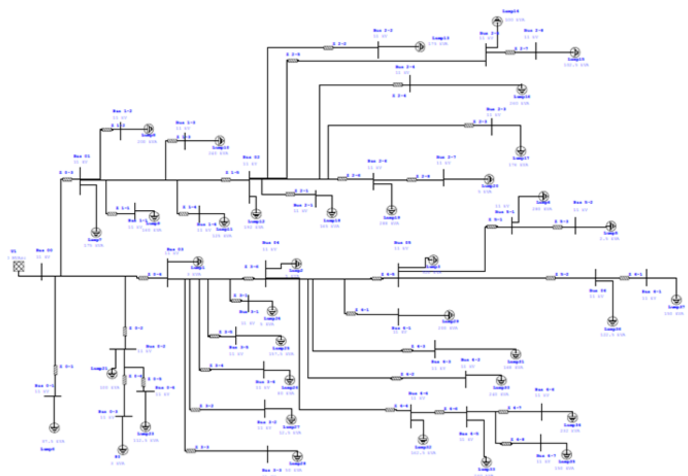

Figure 4: Single line diagram for feeder 103 as shown by ETAB.

4.1 Power flow results

The results obtained from load flow are active and reactive losses at each branch, bus operating voltage at the beginning and end of the branch, and voltage drops at each branch. All ten feeders are modeled and studied. Table 4. shows the results obtained for feeder 103 and Fig.5. represents the voltage profile during maximum and minimum load for the same feeder.

The summary of the results for other feeders is listed in Table 5

.

Table 4: Load flow results for feeder 103.

Branch ID	KW losses	KVAR losses	Bus Operating voltage (KV)		Voltage drops in %
			From sending bus node	To receiving bus node	
Z 0-1	0.0	0.0	11.00	11.00	0.01
Z 0-2	0.1	0.1	11.00	10.99	0.05
Z 0-3	6.6	8.8	11.00	10.96	0.41
Z 0-4	11.1	14.8	11.00	10.93	0.63
Z 0-5	0.0	0.0	10.99	10.99	0.01
Z 0-6	0.0	0.0	10.99	10.99	0.00

Z 1-1	0.0	0.0	10.96	10.96	0.01
Z 1-2	0.0	0.0	10.96	10.96	0.01
Z 1-3	0.0	0.0	10.96	10.96	0.02
Z 1-4	0.0	0.0	10.96	10.96	0.01
Z 1-5	0.8	1.0	10.96	10.95	0.08
Z 2-1	0.0	0.0	10.95	10.95	0.01
Z 2-2	0.0	0.0	10.95	10.95	0.01
Z 2-3	0.0	0.0	10.95	10.95	0.01
Z 2-4	0.0	0.0	10.95	10.95	0.02
Z 2-5	0.0	0.0	10.95	10.95	0.02
Z 2-6	0.0	0.1	10.95	10.95	0.02
Z 2-7	0.0	0.0	10.95	10.95	0.00
Z 2-8	0.0	0.0	10.95	10.95	0.00
Z 3-1	0.0	0.0	10.93	10.93	0.00
Z 3-2	0.0	0.0	10.93	10.93	0.00
Z 3-3	0.0	0.0	10.93	10.93	0.01
Z 3-4	0.0	0.0	10.93	10.93	0.01
Z 3-5	0.0	0.0	10.93	10.93	0.02
Z 3-6	7.4	9.8	10.93	10.88	0.48
Z 4-1	0.0	0.0	10.88	10.88	0.01
Z 4-2	0.0	0.0	10.88	10.88	0.02
Z 4-3	0.0	0.1	10.88	10.88	0.04
Z 4-4	0.5	0.7	10.88	10.87	0.10
Z 4-5	1.0	1.4	10.88	10.86	0.17
Z 4-6	0.0	0.1	10.87	10.87	0.01
Z 4-7	0.0	0.0	10.87	10.87	0.01
Z 4-8	0.0	0.0	10.87	10.87	0.00
Z 5-1	0.0	0.0	10.86	10.86	0.02
Z 5-2	0.0	0.1	10.86	10.86	0.02
Z 5-3	0.0	0.0	10.86	10.86	0.00
Z 6-1	0.0	0.0	10.86	10.86	0.00
Total	28.0	37.2			

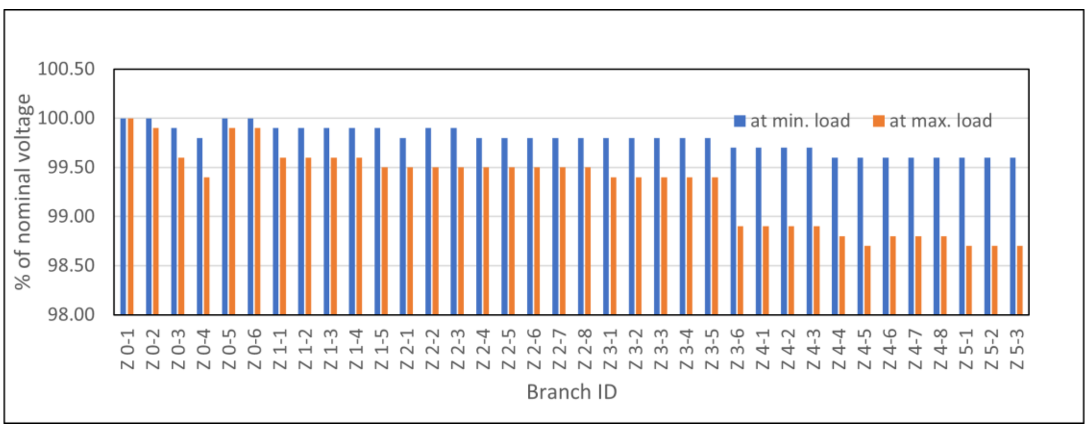

Figure 5: Voltage profile for feeder 103 during maximum and minimum load periods at the end of each branch. The voltage values are expressed as a percentage of the nominal voltage.

Table 5: Summary of results for the ten feeders.

Feeder ID	Total KW losses	Total demand (MW)	Losses as % of the feeder demand
100	230.3	5.190	4.4
101	136.9	5.486	2.5
102	231.7	6.419	3.6
103	28.0	4.750	0.6

105	26.2	4.827	0.54
105 A	42.7	4.852	0.89
106	27.6	4.043	0.7
108	480.5	5.312	9
109	251.2	5.660	4.4
110	23.4	4.577	0.5
Total	1478.5	51.116	2.89

4.2 Transformer loading

A distribution transformer can provide a service to one or more consumers according to the type of consumer. Each transformer's maximum and minimum periods differ from the others[4]. The figures (6, 7, and 8) below show the active and reactive energy consumption recorded by the smart meter for three different nodes at the same times every 30 minutes.

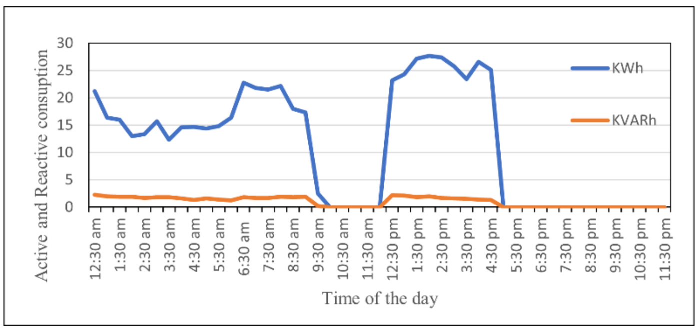

Figure 6: Daily load consumption at node 02 of feeder 100 recorded by a smart meter during 24 hours (March 1 st, 2022). The zero values represent the load-shedding periods.

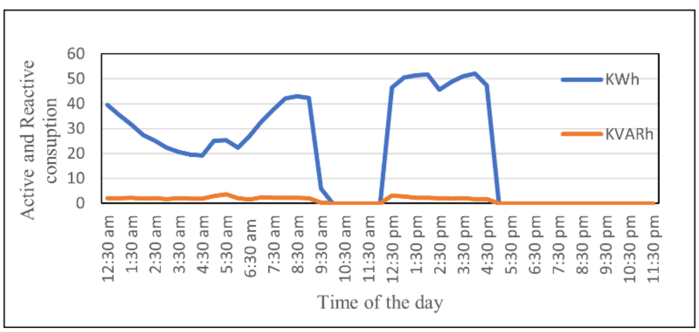

Figure 9: Daily load consumption at node 04 of feeder 100 recorded by a smart meter during 24 hours (March 1st, 2022). The zero values represent the load-shedding periods.

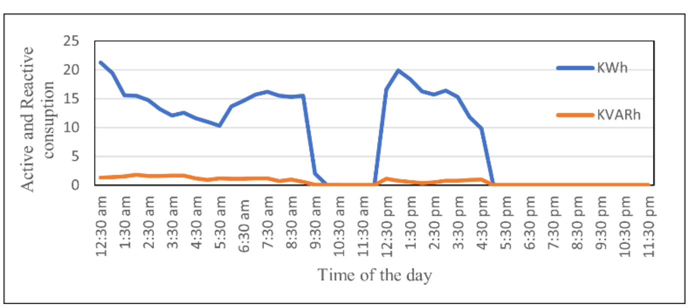

Figure 8: Daily load consumption at node 03 of feeder 100 recorded by a smart meter during 24 hours (March 1 st, 2022). The zero values represent the load-shedding periods.

Table 6: The number of overloaded transformers of each feeder.

Feeder ID	F 100	F101	F102	F103	F105	F105A	F106	F108	F109	F110
No. of overload Transformers	7	7	8	2	5	5	4	8	5	3

4.3 Power factor investigation

In general, most of the loads used by consumers are inductive in nature, such as fans, water pumps, air conditioners, and refrigerators. This type of load draws a lagging current, due to which a reasonable amount of power losses occur[4]. In order to minimize power losses, it is possible to add a leading reactive component that acts opposite to the lagging reactive component and cancels a great part of the lagging current impact. In this part, it monitored the voltage drop and power losses at the branch and placed a Capacitor Bank (CB) at the branches with a high percentage of voltage drop.

Fig.9 represents power factor values recorded by a smart meter at node 05 of feeder 100 as an example. It shows that the power factor changes between 0.7 and 0.95. According to this data, different case studies for power factors were performed. Table.7. represents the case when the power factor equals 0.75. It gives the value of losses before installing the bank capacitors, the location and the size of the bank, total inserted MVAR. Also, it gives the losses after putting the capacitors and the percentage reduction in active and reactive losses. Fig.10 shows the voltage profile for feeder 102 before and after adding capacitor banks.

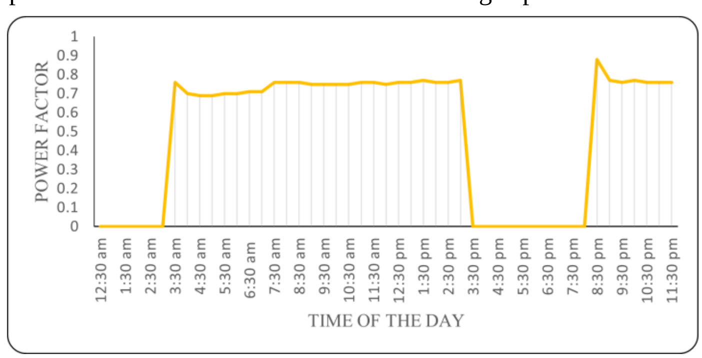

Figure 7: Load power factor of node 01 of feeder 100 during 24 hours recorded by the smart meter. The zero value represents the load-shedding periods.

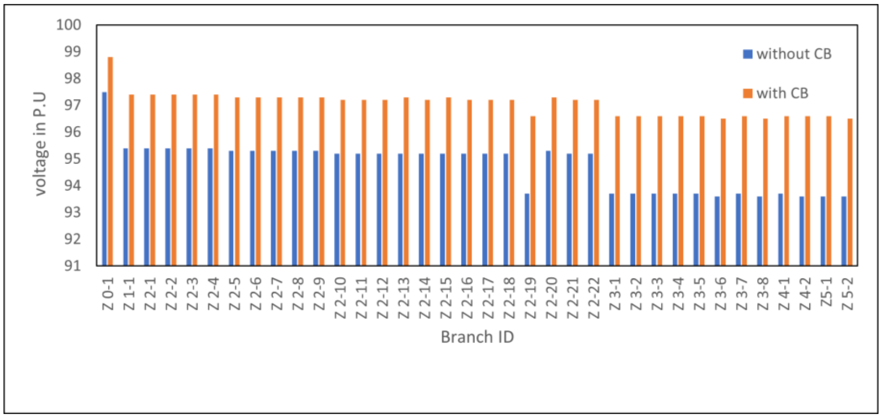

Figure 10: Improvement of voltage profile for feeder 102 as a result of adding capacitor banks. The result shows the improvement included the whole branches, while the banks were placed at four nodes (as indicated in table.7).

Table 7: Case study when power factor=0.75.

Feeder ID	**Losses without CB KW+jKVAr**	**Point of connection**	**Total VAR required (MVAR)**	**Losses with CB KW+jKVAR**	**Reduction in losses (%)**	
					Active losses	**Active losses**
100	233+j 311	• 2*300 at bus 01 • 2*300 at bus 02 • 2*300 at bus 03 • 2*300 at bus 05 • 2*300 at bus 07 • 1*300 at bus 5-7 • 1*300 at bus 5-4	3.6	124+j166	47	47
101	138+j184	• 3*300 at bus 01 • 3*300 at bus 02 • 2*300 at bus 03 • 2*300 at bus 04 • 2*300 at bus 05	3.6	80+j106	42	42
102	234+j312	• 5*300 at bus 01 • 5*300 at bus 02 • 4*300 at bus 03 • 1*300 at bus 04	4.5	133+j178	43	43
103	28+j37	• 1*300 at bus 01 • 1*300 at bus 03 • 1*300 at bus 04 • 1*300 at bus 05	1.2	21+j28	25	24
105	26+j35	• 1*300 at bus 03 • 3*300 at bus 04	1.2	20+j26	23	26
105A	42.9+j57.1	• 8*300 at bus 02	2.4	27+j36	37	37
106	27.7+j36.9	• 4*300 at bus 01	1.2	21.4+j28.5	23	23
108	496+j660	• 2*300 at bus 02 • 3*300 at bus 04 • 1*300 at bus 06 • 1*300 at bus 07 • 3*300 at bus 08 1*300 at bus 05	3.3	243+j324	51	51
109	254+j339	• 3*300 at bus 03 • 3*300 at bus 04 • 3*300 at bus 05 • 2*300 at bus 07 • 1*300 at bus 09 1*300 at bus 10	3.9	134+j179	47	47
110	23.5+j31.3	• 4*300 at bus 05	1.2	17.7+j23.8	25	24

5. Discussion

The load flow of the ten feeders provides detailed information about each section of any feeder regarding the losses, as well as the voltages at the transformer nodes. This paper focused on and introduced the different outcomes of the load flow based on the collected data of the SM on some typical feeders selected from the studied ten feeders. For example, (feeder 103) illustrates the outcomes that are tabulated in Table.4 shows the power losses of all sections of the feeder and most of the power losses available at the main branches, such as Z_{0-4} and Z_{3-6}, the other branches have a small loss that can be ignored. Fig.5. shows the voltage level at the same feeder during minimum and maximum load.

Table.5 provides the summary of the study for each feeder, total losses, total demand, and the losses as a percentage of total demand. Figures 6, 7, and 8 show the transformer loading at different nodes of feeder 100 as an example. The zero values represent the load-shedding period. Table.6 gives the number of overloaded transformers on each feeder. Table.7. shows the location and size of the capacitor banks required to minimize the losses for each feeder. For example, feeder 100 needs to add 12 units, each with 300 KVAR, at the nodes specified in the table in order to reduce losses by 47 percent. Fig.10. shows the improvement in voltage profile after adding capacitor banks for feeder 102 as an example; taking the last branch as an example, it is found that the voltage level at the end of the branch Z_{5-2} is improved from 93.6 to 96.5 %.

Conclusion

In this study, modeling, simulation, and load flow analysis have been carried out for ten feeders of the Raparin substation using collected data from the installed smart meters. The branch-to-branch active and reactive losses with voltage drop were found. A load flow study during minimum load is also important to observe the voltage level and make possible improvements. Monitoring the transformer loading is another important objective to reduce failures and increase the reliability of the network, then, in turn, gain customer satisfaction. The addition of capacitor banks will help in improving, reducing losses, and enhancing the voltage profile. Overvoltage condition is also investigated, and it is found that proper selection of the size and the location of the capacitor banks, leaving them switched ON during minimum load period, will not cause an over-voltage problem of the other nodes. According to the results obtained in this study, the following points are concluded:

- The installed smart meters at the transformers have an impact on reducing the load during the peak loads and provide the opportunity to supply more consumers or reduce load-shedding periods.
- Feeder 108 has losses near 0.5 MW which is equal to 9 % of total demand and needs immediate action for improvement.
- Each feeder has a number of transformers that are overloaded and need to be replaced with a greater capacity
- Adding a capacitor bank can solve some of the problems, like minimizing losses and improving the voltage profile.

Authors contribution

Smart meters as an application are new in KR distribution networks. Introducing a methodology for getting the most benefit from the stored data and management of the data collection procedure is essential for local power distribution authorities and academic researchers to achieve detailed and comprehensive studies of the different distribution networks and monitor the performance of the distribution performance and quality.

In this paper, we presented some useful outcomes of many problems and highlighted aspects such as the period of load shedding per feeder. This reflects the low availability of electricity that needs to be solved.

Conflict of interests

None

Acknowledgments

The authors of this study would like to thank the engineers of the Sulaimani electricity distribution directorate as well as the electricity control and dispatch office for their cooperation in providing suitable data for the smart meters.

References

1. Ahmed, A. H., & Hasan, S. Optimal allocation of distributed generation units for converting conventional radial distribution system to loop using particle swarm optimization. Energy Procedia, *153*, 118-124. (2018).
2. Al-bayaty, H., Kider, M. S., Jasim, O. N., & Shakor, A. Electrical distribution grid of Kirkuk City: A case study of load flow and short circuit valuation using ETAP. Periodicals of Engineering and Natural Sciences (PEN), *10*(3), 311-322. (2022).
3. Ghiasi, M. A comparative study on common power flow techniques in the power distribution system of the Tehran metro. Tehnički glasnik, *12*(4), 244-250. (2018).
4. Kersting, W. H. Distribution system modeling and analysis. In Electric Power Generation, Transmission, and Distribution: The Electric Power Engineering Handbook (pp. 26-1). CRC press. (2018).
5. Bhela, S., Kekatos, V., & Veeramachaneni, S. Enhancing observability in distribution grids using smart meter data. IEEE Transactions on Smart Grid, *9*(6), 5953-5961. (2017).
6. [6] Alinjak, T., Pavić, I., & Stojkov, M. Improvement of backward/forward sweep power flow method by using modified breadth-first search strategy. IET Generation, Transmission & Distribution, *11*(1), 102-109. (2017).
7. Anagnostopoulos, P. M., & Papathanassiou, S. A. A power flow method for radial distribution feeders with der penetration. Journal of Technology Innovations in Renewable Energy, *8*, 1-12. (2019).
8. Jha, R. R., & Dubey, A. Exact distribution optimal power flow (d-opf) model using convex iteration technique. IEEE Power & Energy Society General Meeting (PESGM) (pp. 1-5). IEEE. (2019, August).
9. Ouali, S., & Cherkaoui, A. An improved backward/forward sweep power flow method based on a new network information organization for radial distribution systems. Journal of electrical and Computer Engineering. (2020).
10. Guo, Y., Yuan, Y., & Wang, Z. Distribution grid modeling using smart meter data. IEEE Transactions on Power Systems, *37*(3), 1995-2004. (2021).
11. Dileep, G. A survey on smart grid technologies and applications. Renewable energy, *146*, 2589-2625. (2020).

12. Gandhi, K., & Bansal, H. O. Smart Metering in electric power distribution system. In 2013 International Conference on Control, Automation, Robotics and Embedded Systems (CARE) (pp. 1-6). IEEE. (2013, December).

13. EDMI official site https://www.edmi-meters.com/offerings/meters/

14. Tahir, M. J., Bakar, B. A., Alam, M., & Mazlihum, M. S. Optimal capacitor placement in a distribution system using ETAP software. *Indones. J. Electr. Eng. Comput. Sci*, *15*(2), 650-660. (2019).