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A systematic approach for analysing and improving operating conditions in distribution grids

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Abstract. This paper presents a systematic approach for analysing and improving operating conditions in the distribution grids. It is based on collecting and processing data on the grid topology, grid elements, and their yearly loading profile. The data validation is performed by comparing the measured results with the grid model calculated ones. Afterwards, the grid model is applied to evaluate possible solutions for improving grid operation considering voltage profile and losses. These solutions include proper tap setting for individual transformers and the introduction of adequately sized and placed storage devices and reactive power compensators. The usage of the proposed methodology is demonstrated in the case of an actual distribution grid.

Key words. distribution grid, analysis, improved operation, systematic approach.

1. Introduction

The most important task in each distribution grid company is the provision of reliable energy supply, where the voltage parameters compline with the standard EN 50160. The commitments resulting from the legislative package Clean energy for all Europeans [1] and the European green deal [2] represent additional challenges for grid companies and must be adequately addressed. The increasing share of renewable sources and charging infrastructure for electro mobility accommodated in the distribution grids [3], [4], environmental commitment and obsoletion of fossil carbon in energy production, and the introduction of energy flexibility services [3] are some of these challenges. The Advanced Distribution Management System (ADMS) and similar tools can help distribution grid companies to address these challenges. Unfortunately, the ADMS [5] cannot be introduced without a priori knowledge of grid topology, grid elements, including their settings and parameters, and load and production profiles. This paper focuses on the analysis and data validation that must be performed before introducing ADMS and can also be used to improve distribution grid operation.

The paper proposes a systematic approach for analysing and improving distribution grid operation. It consists of several stages. At the first stage, presented in section 2, grid topology and data of individual grid elements are used to build a grid model afterwards used in load flow calculations based on the backward-forward sweep (BFS) method [6], [7]. When model-based load flow calculations are performed considering measured load and production profiles, errors in data related to the grid topology, individual elements and profiles (for load and production) can be identified. After clearing all errors, validated data and grid model for load flow calculations are obtained. At the second stage, presented in section 3, the validated model is used together with yearly profiles of loads and generation units to evaluate grid operation and propose improvements in grid operation. The evaluation includes the analysis of the voltage profiles and losses in the discussed distribution grid. The third stage, presented in section 4, proposes improvements in grid operation, focused on sizing and placement of distributed generation, energy storage systems and different reactive power compensators in the distribution grid. Additionally, improved tap settings can be proposed for individual transformers.

In section 5, the proposed systematic approach is applied in the case study of an actual operating distribution network, while the conclusions are drawn in section 6.

2. Analysis and validation of data

The distribution grid model, suitable for load flow calculations, requires data related to grid topology and parameters of grid elements. This data is often exported from Graphical Information System (GIS). In some cases, GIS data does not match the actual situation in the grid, i.e. mismatch in conductor type and its cross-section or wrong tap setting. After the grid model is established, measured voltage, active and reactive power profiles for different feeders, loads and generation unis are required. In order to validate the grid model and measured profiles, the results of measurements are compared with those obtained by load flow calculation for the established grid model. During this process following situations could appear:

1. If the feeder profile of active and reactive power does not match the sum of active and reactive power on all grid elements, some smart meters are probably incorrectly connected or synchronised.
2. If the power profiles match, but there exist differences between the measured and load flow calculated voltage profile, it is very likely that data of some conductors in the model does not match the ones in the grid. In this case all calculated voltages following the conductor element with incorrect data are affected.
3. If the measured and calculated voltage profiles show a mismatch in one or several randomly distributed distribution transformers in the grid, the tap setting data for the affected transformers is likely incorrect.

After setting data of all grid elements in the model to those of actual grid elements, a proper matching between the measured and calculated voltage and power profiles should be achieved. The model can be considered validated and is ready to be used in further analysis.

3. Analysis of grid operation

The validated grid model is applied in the analysis of grid operation, which is afterwards used in section 4 to propose improvements in grid operation. The analysis should be performed over a longer time interval in the duration of at least one year, where measured power and voltage profiles are available. In this paper, the analysis was performed over a year considering 15 min average measured values of voltage, and active and reactive power profiles. The goals of the analysis were:

1. Identification of nodes where voltage profile limits could be violated.
2. Identification of energy flows in the form of active and reactive power in individual grid lines.
3. Assessment of grid losses.

4. Proposal for improvements in grid operation

The analysis of grid operation, presented in section 3, is used in section 4 to propose improvements in grid operation. Calculations with the grid model that considers yearly voltage profiles for individual grid nodes as well as profiles of active and reactive and losses for individual grid lines were used to identify the following possibilities for improvements in grid operation:

1. Identification of grid suitability for the implementation of energy storage systems, their locations and size.
2. Identification of nodes suitable for introducing reactive power compensators, their locations and size.
3. Identification of nodes suitable for introducing distributed generation units, their type and size.

All three presented stages, Analysis and validation of data (section 2), Analysis of grid operation (section 3), and Proposal for improvements in grid operation (section 4), were applied and tested in the case study of an actual distribution grid presented in section 5.

5. Case study

In the tested rural distribution grid, a 31.5 MVA transformer 110 kV/20 kV supplies 126 transformers 20 kV/0.4 kV with a power range from 50 to 1600 kVA. The share of distributed generation in the form of hydro units with induction and synchronous generators and photovoltaic (PV) units, with a power range from several kW to several MW, is substantial. Some feeders contain mostly cables, while the others contain mostly overhead lines, which makes (capacitive and inductive) reactive power compensation even more challenging. Melting snow and rain in a partially Alpine landscape causes a substantial increase in hydro generation over several days to several weeks. The increasing interest in including several additional MW of PV powers into the grid makes the grid operation even more challenging. In order to coop with the aforementioned challenges, a systematic approach was developed. In order to address the aforementioned challenges, a systematic approach was developed. It was tested in the case of the discussed grid, connected to substation Mozirje, and is presented in this paper.

GIS model of the discussed distribution grid with marked transformer substation 110/20 kV Mozirje, main feeder supplying distribution substation Ljubno, feeders Logarska dolina, Citrija and Rastke, critical points CP1 and CP2, compensation devices CD1, CD2 and CD3, and distribution transformers 20/0.4 kV, is shown in Fig. 1.

The GIS model was the starting point for building a grid model suitable for BFS method-based load flow calculations. The measured profiles for voltage, active and reactive and power were available for all feeders, distribution transformers and generation units over one year.

The initial comparison of measured and calculated voltages on the 0.4 kV side of distribution transformers has shown that the tap setting data for some transformers was incorrect, as shown in Fig. 2. The problems related to incorrect data in GIS were solved during data validation.

Figs. 3 to 5 show yearly active power profiles for feeders Logarska dolina, Citrija and Rastke. The results presented clearly show that feeders Lagraska dolina and Rastke contain a substantial share of distributed small hydropower generation units, the production of which is highly influenced by precipitations in the duration of several days to several weeks. Thus, the usage of storage units for smoothing active power generation profiles could be pretty costly due to the required high capacity and power of the storage systems.

The reactive power profiles for the feeders Logarska dolina, Citrija and Rastke are shown in Figs. 6 to 8. The feeder Logarska dolina contains a substantial share of cables. Therefore, the capacitive reactive can be effectively compensated by inductor compensator. In feeders Citrija and Rastke, containing majority of overhead lines, the inductive reactive power is dominant. It can be effectively compensated by capacitor banks. The locations, sizes and setting steps for reactive power compensation units were proposed.

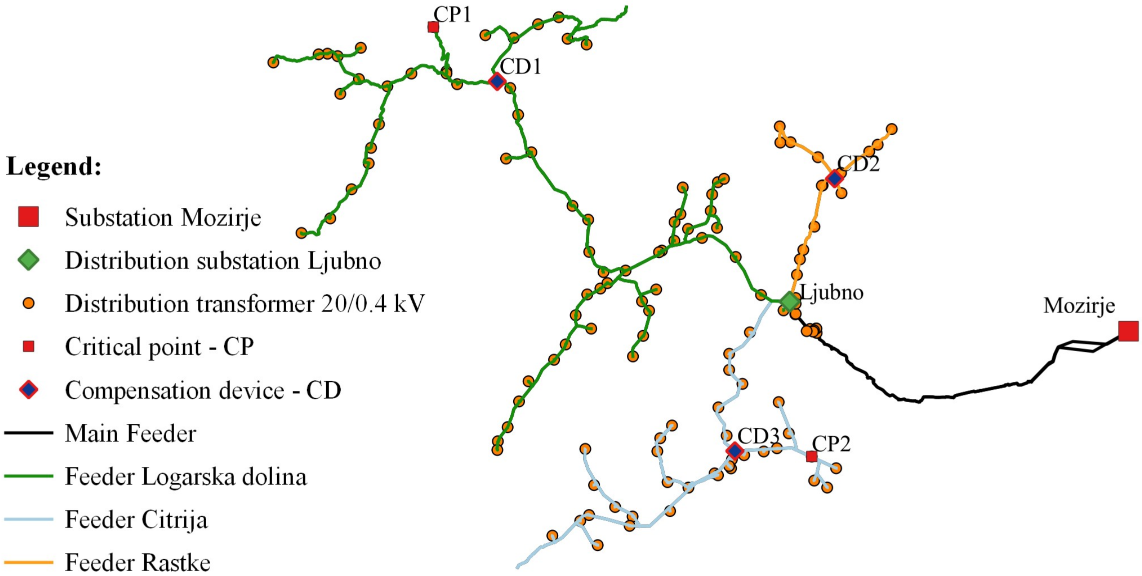

Fig. 1. GIS model of the discussed distribution grid

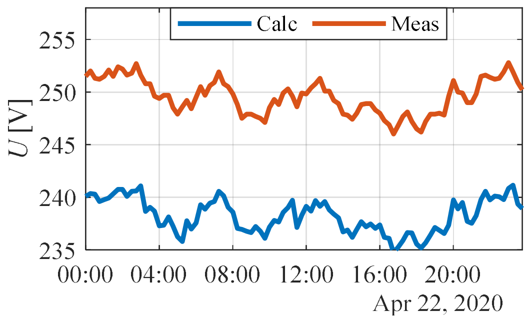

Fig.2. A mismatch between the measured (Meas) and calculated (Calc) voltage at 0.4 kV side of a distribution transformer

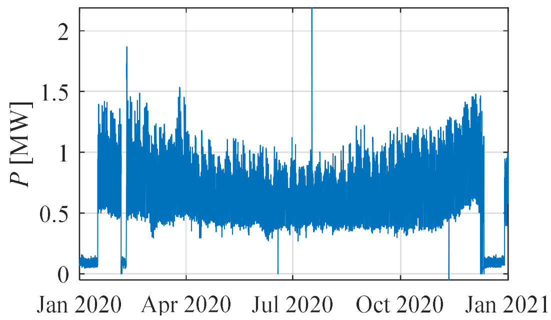

Fig.4. Yearly active power profile for the feeder Citrija

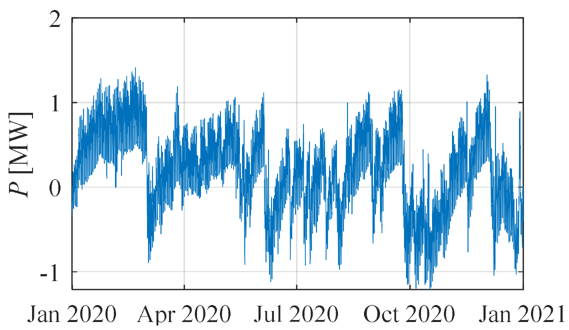

Fig.3. Yearly active power profile for the feeder Logarska dolina

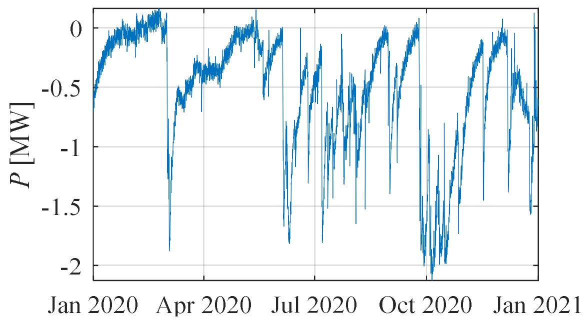

Fig.5. Yearly active power profile for the feeder Rastke

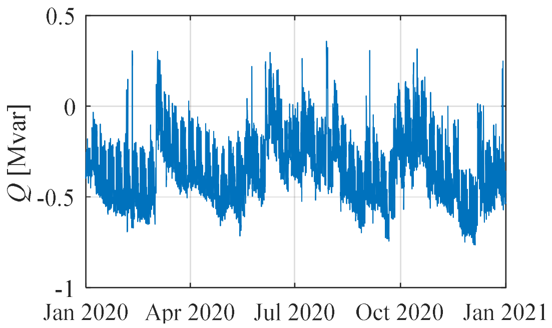

Fig.6. Yearly reactive power profile for the feeder Logarska dolina

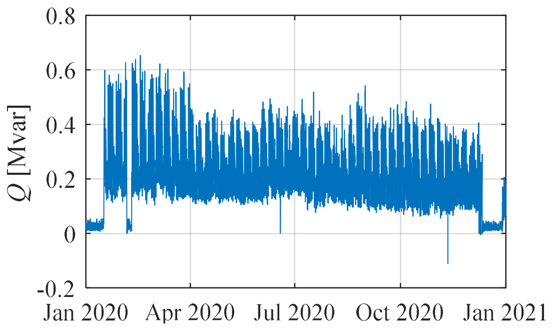

Fig.7. Yearly reactive power profile for the feeder Citrija

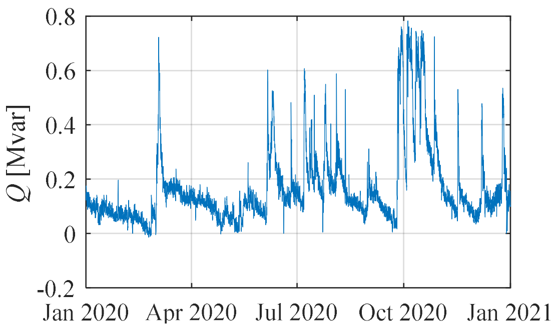

Fig.8. Yearly reactive power profile for the feeder Rastke

Fig. 9 shows the character of reactive power in individual lines. The analysis of yearly reactive power profiles shows that the introduction of centralized or decentralized compensation units, with adaptation in several steps, can improve voltage profile and reduce losses in individual feeders.

The performed analyses show, that the discussed gird can host additional 6.5 to 7 MW of PV power.

6. Conclusion

The paper proposes a systematic approach for analysing and improving distribution grid operation. At the first stage, which is indispensable also for introducing ADMS, the grid-related data, profiles, and grid model used in load flow calculations are analysed and validated. At the second stage, the validated model, gids data and profiles (load and generation) are used to determine voltage, loading and loss profiles. At the third stage solutions for improving the operation of the discussed distribution grid are prepared. The proposed systematic approach was applied in a real distribution grid case study, providing clear guidelines for improving its operation.

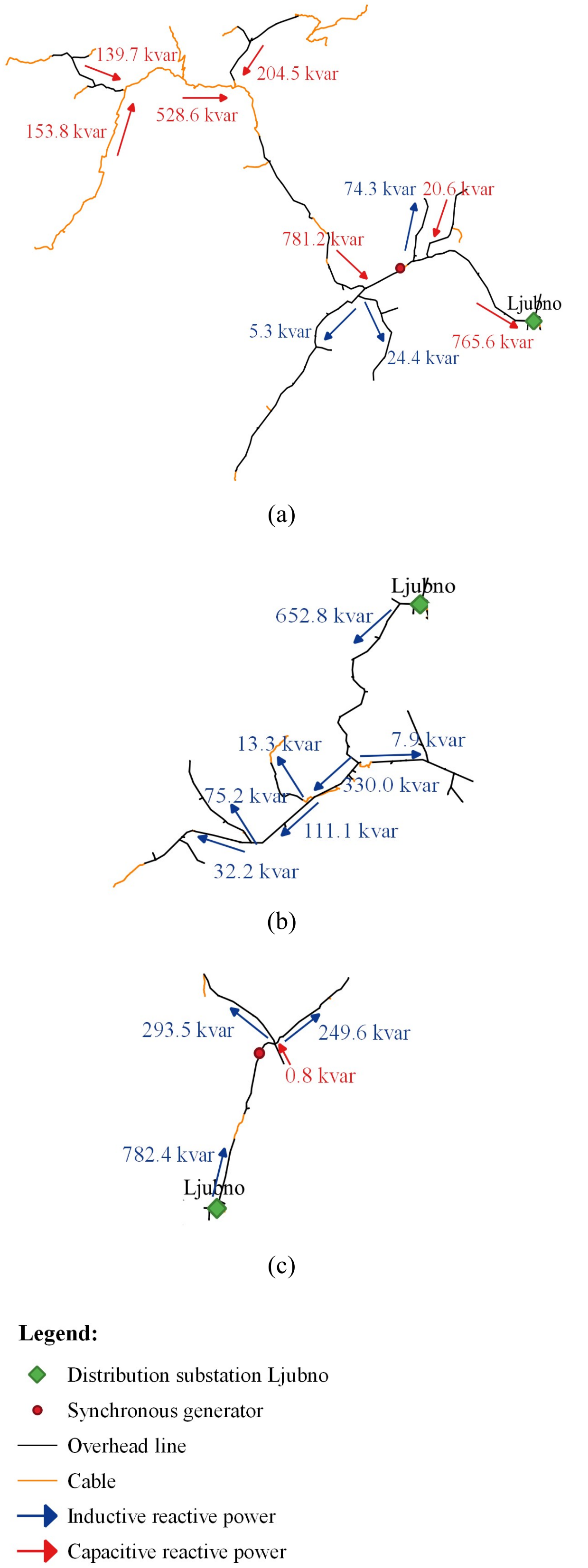

Fig.9. Distribution of reactive power in feeders Logarska dolina (a), Citrija (b) and Rastke (c) in the cases of maximal reactive power demand

References

[1] European Commission, Directorate-General for Energy, Clean energy for all Europeans, Publications Office, 2019, https://data.europa.eu/doi/10.2833/21366.

[2] European Commission, Communication from the Commission: The European Green Deal, Brussels, 11.12.2019, COM (2019) 640.

[3] Ruchi Gupta et al, "Spatial analysis of distribution grid capacity and costs to enable massive deployment of PV, electric mobility and electric heating", Applied Energy. Vol. 287, 1 April 2021, https://doi.org/10.1016/j.apenergy.2021.116504.

[4] Felipe Gonzalez Venegas, Marcc Petit and Yannick Perez, "Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services", Renewable and Sustainable Energy Reviews. Vol. 145, July 2021, https://doi.org/10.1016/j.rser.2021.111060.

[5] Merkebu Z. Degefa, Santiago Sanchez and Ravishankar Borgaonkar, "A Testbed for Advanced Distribution Management Systems: Assessment of Cybersecurity", IEEE 2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Espoo, Finland, 18-21 October 2021, pp. 5, doi: 10.1109/ISGTEUROPE52324.2021.9640184.

[6] Ulas Eminoglu and M Hakan Hocaoglu, "Distribution systems forward/backward sweepbased power ow algorithms: a review and comparison study", Electric Power Components and Systems, Vol. 37, No. 1, pp. 91-110, 2008. https://doi.org/10.1080/15325000802322046.

[7] G. W. Chang, S. Y. Chu in H. Wang, "An Improoved Backward/Forward Sweep Load Flow Algorithm for Radial Distribution Systems", IEEE Transactions on Power Systems, Vol. 22, No. 2, pp. 882-884, 2007.