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Review scientific paper

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# IMPACT OF CHARGING STATIONS FOR ELECTRIC VEHICLES ON THE POWER DISTRIBUTION NETWORK

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**Abstract:** The paper describes the impact of the load increase caused by the connection of electric vehicle (EV) charging stations in the power distribution network. The power distribution network model was created using the professional software tool DIgSILENT PowerFactory (DPF). Analyses were carried out for the cases of connecting a different number of EV charging stations to 0.4 kV busbars of distribution transformer stations (TS). The results of voltage conditions and loading of the most loaded distribution substations are shown. Increasing the load results in an increase in losses in the network, which is particularly significant today since the prices of electrical energy on the market are currently at historically high levels. Distribution System Operator (DSO) should pay attention to the problem of losses increase in the network, and in addition to classic solutions in strengthening the network, the DSO should also consider modern solutions such as the flexibility of new consumers.

**Keywords:** charging stations, electric vehicles, power distribution network, flexibility, losses

## INTRODUCTION

A rise in Earth's temperature of fewer than 2 degrees Celsius according to the Paris Agreement requires the transformation of the power system from a fossil fuel-based system to a system that promotes energy efficiency, and it is based on renewable energy sources. Electrification of large-dimension end users such as buildings, industrial facilities, and transport vehicles, and gradual decarbonization of the electrical sector are key preconditions for transformation. The transformation of the system leading to a system based on renewable energy sources cannot be achieved without overcoming barriers because a high share of renewable energy sources increases the requirements for a balance between supply and demand [1]. Flexibility helps achieve these requirements. The flexibility of the power system is defined as the ability of the system to manage changes and uncertainties of supply and demand in all relevant time frames reliably and cost-effectively. [2] To achieve the goal, flexibility must be used in all areas of the power system, from generation, transmission, distribution, and energy storage systems to the end users. Flexibility resources should be managed by a system operator, which has two main methods to obtain the services necessary for the reliable and secure operation of the system: adapting the operation of its network components to enable specific services, or where potential providers of ancillary services are market participants, they may be encouraged to provide ancillary services through energy markets and ancillary services [1]. Recently, the development of electric vehicles (EVs) has significantly affected the operation of the distribution network. Accelerated changes in the electrification and decarbonization of the power system lead to the decisions of the traditional approach in the system planning and operation to be reviewed. Such changes most frequently occur at the level of distribution network, where the traditional approach for the reinforcement of the network components through long-term plans may not economically be the most acceptable option. Dynamic changes in a network-end-user interaction resulting from the new technology integration suggest the need for a distinct approach. A cost-benefit analysis is imposed as a solution that compares classical network reinforcement solutions such as the construction of new TS, cables, and surface guides and new solutions such as the use of flexibility services without network reinforcement. Reference [3] shows an approach to the markets of flexibility services with electric vehicles. When defining the desired option, a compliance with the rules of network while meeting consumer demands is a fixed restriction within the problem.

Many papers describe various influences of electric vehicles on the power distribution network. Certain scientific papers deal with congestion problems in distribution networks due to the connection of the large number of EV charging stations. Paper [4] shows load reduction results due to predictive consumption management using the V2G (Vehicle to Grid) approach. The prediction procedure and technology for the control of conges low-voltage networks are described in

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reference [5]. An example of a solution for peak load reduction through e-mobility smart tariffs is described in the paper [6]. Reference [7] describes the results of a major development project focused on the flexibility of electromobility and how the operation of charging station infrastructure can be extended to allow the use of limited networks. The technology for EV charging control for consumption peak shifting is described in the paper [8].

The main problem described below in this paper is the effect of increasing load in the urban power distribution network. The rise as expected in the EV will be accompanied by an increase in the EV charging stations. The DSO must therefore analyse and assess the impact on the network before such an increase in load occurs. Impact of EV Charging on the Power Grid is emphasized in references [9], [10] and [11]. Reference [9] presents a study with power quality variables change during EV charging. Reference [10] shows impacts of integrated EVs and variable renewable energy (VRE) on entire power system operation with analysis of uncoordinated charging costs in comparison with coordinated charging costs for specified scenarios. Reference [11] has assessed impacts of three different types of charging current on power quality variables with respect to several EV penetration scenarios.

Chapter 1 presents Grid Model with its most important characteristics. Chapter 2 present results of Load Flow and Quasi-Dynamic simulation analyses and Chapter 3 concludes the results presented in the paper.

## 1. MODEL OF POWER DISTRIBUTION NETWORK

Analyses of load increase impact on the power distribution network due to increase in the number of EV charging stations were carried out using the example of Tomislavgrad power distribution network owned by the DSO JP Elektroprivreda Hrvatske zajednice Herceg Bosne d.d. Mostar.

Consumption of the distribution TS of the nominal transformation of 10 (20)/0.4 kV, which are part of the network, is performed by the electrical energy distribution from primary TS 110/35/10 (20) kV Tomislavgrad. TS Tomislavgrad consists of 10 medium voltage distribution feeders. TS Tomislavgrad over 35 kV busbar also supplies TS Zidine 35/10(20) kV, which consists of 3 medium voltage distribution feeders. 2 cable distribution feeders have been specifically analysed in Tomislavgrad: Latice Cable Outgoing and Plastika Cable Outgoing. A characteristic case of the highest network load in 2021 (24 December at 5 p.m.) has been analysed. The consumption of the remaining 8 MV distribution feeders in TS Tomislavgrad and the consumption of all other distribution feeders on TS Zidine were cumulatively considered. Data on guides and transformers were obtained by the relevant DSO. Figure 1 shows the distribution network modelled in the DIgSILENT PowerFactory (DPF) professional software tool [12].

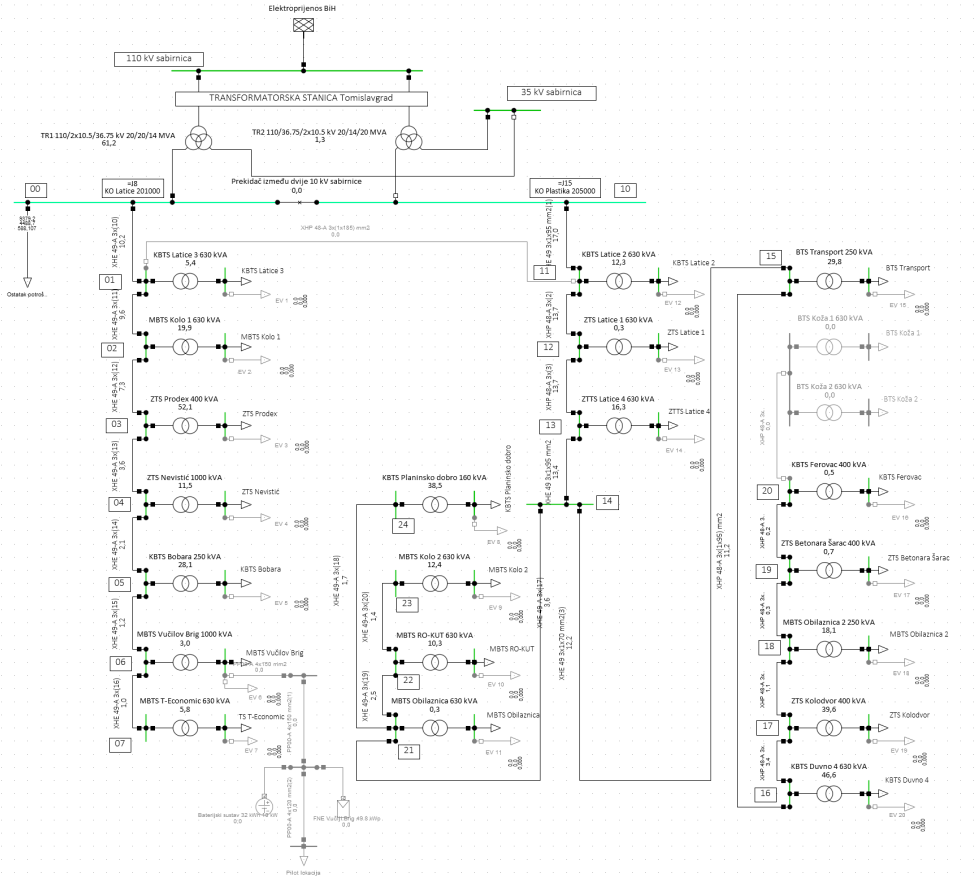



Figure 1: Power Distribution Network Model in DPF

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## 2. PERFORMED ANALYSES

In order the Newton-Raphson calculation of power flows to be implemented, it is necessary to know the consumption of the network observed. Calculations of power flow are usually used when analysing power systems in the steady-state operating conditions (without a short circuit in the network). A steady state implies conditions under which it is assumed that all parameters and variables are constant within the period of observation. Therefore, such situation reflects the system conditions for a specific moment in time. Usual practice is checking the conditions in the system for the worst-case scenario, which is often the highest load of primary substations or the maximum load of distribution substations when the highest load of network elements occurs and the highest voltage drops. The data of consumption were obtained from a reading system for automatic metering owned by the relevant DSO. Data is transferred using GSM/GPRS module of wireless communication to an 'Advance' - the central system, which collects, stores and integrates the data [13].

The analysis of power flows was performed in the case of the maximum load of TS Tomislavgrad and TS Zidine in 2021. The analysis of power flows was carried out in 2 cases: current operating state and future operating state. The future operating state will take into account the connection of the EV charging stations. Reproducing the system behaviour before connecting new consumers is an idea in order to detect possible weaknesses and propose a solution accordingly.

### 2.1. Maximum Network Load results without Charging Stations for Electric Vehicles

Figure 2 shows voltage amounts for the busbar of multi-voltage, voltage amounts for the low voltage busbar, and a load of TS 10 (20)/0.4 kV in the event of maximum load registered for TS Tomislavgrad and TS Zidine without connected EV charging stations. The results are presented for TS with the lowest voltage values at low voltage.

Due to the long air MV distribution feeders, the initial voltage at the 10 kV busbar in TS Tomislavgrad is 10.50 kV. Voltage

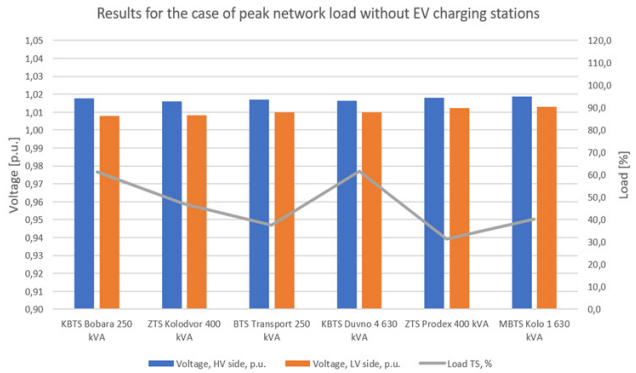



Figure 2: Maximum Network Load results without EV Charging Stations

is within the limits prescribed by network rules [14]: +/- 0.1 p.u. for the middle voltage of 10 kV, which is the voltage of multi-voltage distribution TS busbars and +0,05/-0.1 p.u. for the low voltage of 0,4 kV, which is the voltage of the low-voltage distribution TS busbars.

### 2.2. Maximum Network Load results with the EV Charging Stations

The results in the event of maximum load for TS Tomislavgrad and TS Zidine with EV charging stations of peak power of 100 kW (2 x 50 kW) connected at each low-voltage distribution TS busbar in 2 MV distribution feeders concerned are shown in Figure 3. The results are presented for TS with the lowest voltage values at low voltage.

Figure 3 shows that the voltage is within the network rules of the prescribed limits even when new consumers are connected to all low-voltage busbars of TS in the 2 distribution feeders concerned. That is the reason for the low network load compared to the lengths of MV cable outgoings and the characteristics of the conductors.

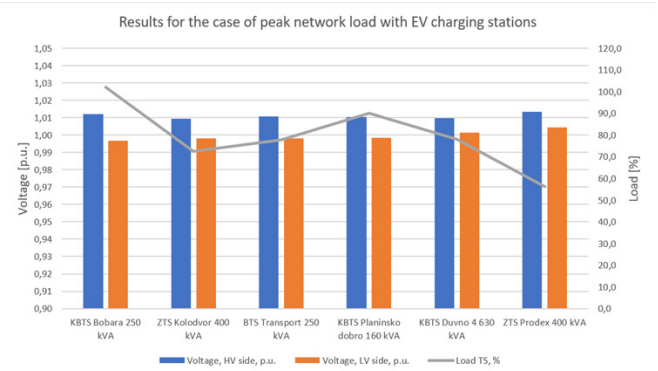



Figure 3: Results for the Case of Maximum Network Load with EV Charging Stations

### 2.3. Maximum Network Load results with the EV charging stations – increasing losses

The results in the event of maximum load for TS Tomislavgrad and TS Zidine with EV charging stations connected with distribution TS with the highest load are shown in Figure 3. 6 TS are presented; 1 TS has a load above 100%. It is known that transformers can be loaded for a certain duration without causing significant difficulties in the

transformers operation. Therefore, the short-term load of transformers in the worst scenario of 102% is not a significant problem. Also, Figure 3 shows the results when the EV charging stations operate at full power of 100 kW, which is the worst scenario. Further analyses will include the load curve of the EV charging stations made to minimize the cost of charging the EV charging stations when participating in a day-ahead market as described in reference [15].

This analysis was done using the simulation of Quasi-Dynamics. Each load of the substation was modelled using the operating and reactive power load curve. Substation load data were obtained from AMR/AMM system. The load of the EV charging station was modelled using the above-mentioned load curve as shown in Figure 4.

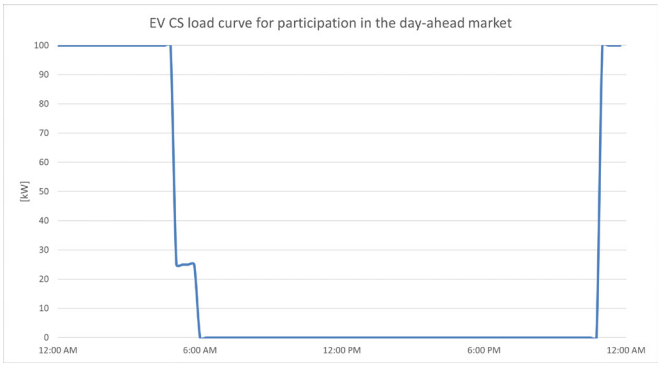



Figure 4: Curve of EV Charging Stations for the Day-Ahead Market Participation

Quasi-Dynamic simulation tool implements a time series of simulations of power flow compared to the classical calculation of power flows, which analyses the network under a specific set of working conditions. Calculations of power flow have shown that under the highest network load without EV charging stations connected and with connected EV charging stations under the peak power there are no voltage problems and the overloads of substations do not represent a significant problem. However, there is an increase in the network losses. In the JP Elektroprivreda Hrvatske zajednice Herceg Bosne d.d. Mostar case, electrical energy procurement to cover losses is part of the market's total electrical supply. Network losses need particular attention today due to historically high market prices. According to a reference market HUDEX [16], the prices of a band of electrical energy on 7 February 2022 for the following four quarters amounted to BL Q2-22: 183.21 €/MWh, BL Q3-22: 195.93 €/MWh, BL Q4-22: 209.74 €/MWh, BL Q1-23: 210.18 €/MWh where 199.59 €/MWh is an average price. Figure 5 shows the curve on 24 December 2021 for the network losses. Figure 6 shows the curve on 24 December 2021 for network losses when the EV charging stations are connected to the low-voltage busbars of distribution TS to 2 distribution feeders concerned.

In this case, the loss curve, as well as the load curve, shows growth in the hours from 11 p.m. to 5 a.m. when the EV charging stations operate at full power. Total losses without connected EV charging stations amount to 2.008 kWh. Total losses with connected EV charging stations amount to 2.211 kWh. Consequently, there was an increase in losses of 203 kWh. According to the above-average price of electrical energy, the increase in losses represents an additional cost (with no tax levies or any other costs included) in the amount of 41,50 € per day. This cost can be much higher, because the EV charging stations will be used not only when it is cost-optimal for the owners of the EV charging stations, but according to the requirements of the owners of the EV which can then increase consumption and losses in the network. In the long-term planning of distribution network development, the DSO should consider this cost before connecting the EV charging stations. The price of a new city's prefabricated concrete transformer substation, e.g., with a connection cable of 1 km in length is 80.000 €, and possible network reinforcements to minimize the losses are not the most economical option. One access to the EV load is described in reference [17] considering the electrical energy price. Future analyses will include smart tariff options and flexibility mechanisms as more cost-effective options that encourage better use of a well-built network. In addition, advanced network loss calculation methods described in references [18] and [19] can help predict losses.

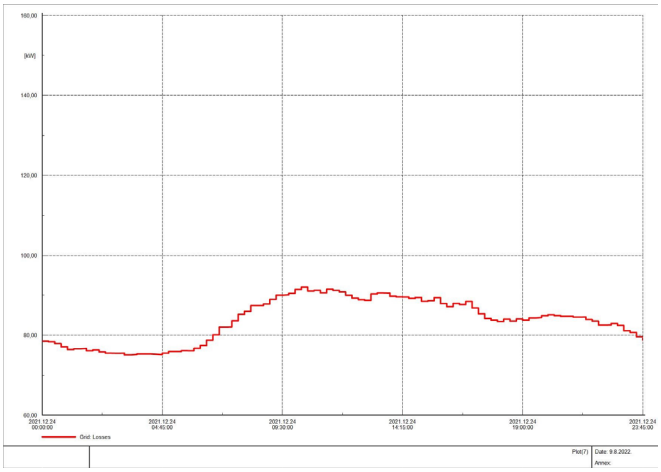


Figure 5: Curve of Network Losses without EV Charging Stations connected

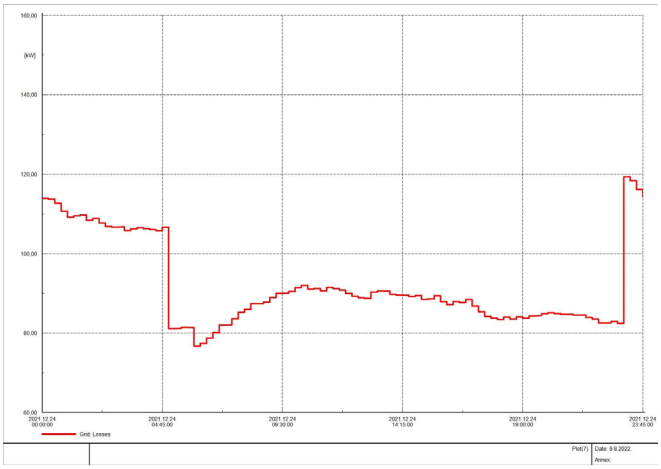


Figure 6: Curve of Network Losses with EV Charging Stations connected

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## 3. CONCLUSION

The paper describes a case study of a real cable distribution network with radial and ring topology in a radial drive is described. The expected increase in the use of EVs and the installation of the EV charging stations accordingly were simulated using the DIgSILENT PowerFactory, a professional software tool, using the example of the Tomislavgrad distribution network. The relevant DSO provided input and consumption data from the AMR/AMM automatic reading system while the future EV charging stations were modelled using defined load profiles. Several scenarios have been processed. The results have shown that there were no voltage problems even in the case of connection of 100 kW (2 x 50 kW) at the peak load of the EV charging stations to the low voltage busbars of distribution substations when the network is at its peak load. However, the problem of rising network losses was highlighted, especially due to historically high prices of electrical energy. Flexibility and smart tariffs may be a more cost-effective solution rather than traditional network reinforcement by building new network components in order to mitigate the problem.
The contribution and novelty of the work refer to the problem of the increasing influence of electric vehicle charging stations on the power distribution network. This particularly applies to the problem of increasing losses in the network. As a possible solution, it is proposed to consider new auxiliary services such as flexibility services instead of the traditional solution of strengthening the network by building new network components.

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## BIOGRAPHY

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**Tomislav Capuder** was born in 1983 in Zagreb. He graduated and has been awarded a PhD degree at the Faculty of Electrical Engineering and Computing, University of Zagreb. At the same Faculty, he was elected to scientific-educational title of Assistant Professor in 2016 and in 2020 to scientific-educational title of Associate Professor. During his doctoral and postdoctoral studies, he spent several months training at the University of Manchester in Great Britain. He is the winner of the Silver Award Josip Lončar for the best doctoral dissertation of the Faculty of Electrical Engineering and Computer Science and also he has been awarded several times for different development, professional and research activities. Research interests include electric vehicles, battery storage, advanced energy networks, energy markets and power system modelling and optimization with an emphasis on advanced distribution networks. He is the author of book chapters, 3 editorial books, more than 50 papers in the A category magazines and more than 80 papers in conference proceedings with international review, as well as over 100 expert studies and reports. He is the manager of several international and national scientific research and development projects and active organizer of international scientific and professional conferences in various roles (from the chairman of the Organizing Committee to the chairman of the program committee). He is a member of the scientific and professional associations HRO CIGRE, SDEWES, IEEE, and in the Croatian section of the IEEE he currently holds the position of President of the Energy Department.

**Drago Bago** graduated and completed postgraduate PhD studies from the Faculty of Electrical Engineering and Computing, University of Zagreb. Since 2000 he has been employed at JP Elektroprivreda Hrvatske zajednice Herceg Bosne d.d. Mostar in the Distribution Power Division and the Development Division. Now, he is a member of the Board and the Executive Director for Development in JP Elektroprivreda Hrvatske zajednice Herceg Bosne d.d. Mostar. He completed a professional study "Energy Efficiency" organized by the Institute of Energy Technology in Kjeller (Oslo), Norway and the Faculty of Electrical Engineering and Computing. He is an author and a co-author of several scientific and professional papers in the field of overvoltage protection for medium voltage lines, the correlation of events data from the power system and data from the system of professional organization IEEE. He is also a member of the Study Committee of the International Council on Large Electric Systems CIGRÉ in Paris, Study Committee C6 - Distribution Systems and Dispersed Generation. He is the President of the International Conference of CIRED for Bosnia and Herzegovina and president of Study Committee C6 BH K CIGRÉ - Distribution Systems and Dispersed Generation. He is a member of the Board of BH K CIGRÉ and a member of the Board BAKE – BH Council for Electrical Engineering. He is also a member of the Editorial Council of the magazine B&H Electrical Engineering and a member of the Croatian Association of Engineers – AMAC.

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