Technical challenges of integrating electric vehicles in the distribution grid

Cupan, Filip

SVEUČILIŠTE U RIJECI

TEHNIČKI FAKULTET

Diplomski sveučilišni studij elektrotehnike

Diplomski rad

Tehnički izazovi integracije električnih vozila u distribucijskoj elektroenergetskoj mreži

Rijeka, srpanj 2024.

Filip Cupan

0069083304

SVEUČILIŠTE U RIJECI

TEHNIČKI FAKULTET

Diplomski sveučilišni studij elektrotehnike

Diplomski rad

Tehnički izazovi integracije električnih vozila u distribucijskoj elektroenergetskoj mreži

Mentor : izv. prof. dr. sc. Rene Prenc

Komentor : izv. prof. dr. sc. Vedran Kirinčić

Rijeka, srpanj 2024.

Filip Cupan

0069083304

SVEUČILIŠTE U RIJECI
TEHNIČKI FAKULTET
POVJERENSTVO ZA DIPLOMSKE ISPITE

Rijeka, 16.03.2024.

Zavod: Zavod za elektroenergetiku

Predmet: Zaštita i automatika električnih postrojenja

ZADATAK ZA DIPLOMSKI RAD

Pristupnik: **Filip Cupan (0069083304)**

Studij: Sveučilišni diplomski studij elektrotehnike (1300)

Modul: Automatika (1331)

Zadatak: **Tehnički izazovi integracije električnih vozila u distribucijskoj elektroenergetskoj mreži / The technical challenges of integrating electric vehicles in the distribution electrical grid**

Opis zadatka:

U radu će se opisati tehnički aspekti izazova povezanih s integracijom električnih vozila u distribucijsku elektroenergetsku mrežu i ukazati na potencijalne probleme i njihova rješenja. Dat će se značajke pasivne, te potom aktivne distribucijske mreže sa obnovljivim izvorima električne energije i konačno aktivne mreže sa još uključenim električnim vozilima, odnosno punionicama. Objasnit će se koncept vehicle-to-grid, te njegove prednosti i mane. Usporedit će se dio mrežnih pravila distribucijskog sustava vezan uz priključak električnih vozila u Hrvatskoj i svijetu te ukazati na razlike. Također, isto će biti napravljeno i za pravilnike, odnosno standarde priključenja, te nacionalne akcijske planove za prihvat velikog broja takvih vozila u budućnosti.

Rad mora biti napisan prema Uputama za pisanja diplomskih / završnih radova koje su objavljene na mrežnim stranicama studija.

Zadatak uručen pristupniku: 20.03.2024.

Mentor:
izv. prof. dr. sc. Rene Prenc

Predsjednik povjerenstva za diplomski ispit:
prof. dr. sc. Dubravko Franković

Komentor:
izv. prof. dr. sc. Vedran Kirinčić

SVEUČILIŠTE U RIJECI

TEHNIČKI FAKULTET

Diplomski sveučilišni studij elektrotehnike

IZJAVA

U skladu s člankom 10. Pravilnika o diplomskom radu i diplomskom ispitu na diplomskim sveučilišnim studijima Tehničkog fakulteta u Rijeci, izjavljujem da sam samostalno izradio diplomski rad prema zadatku br. 90 za srpanj 2024. godine.

Rijeka, srpanj 2024.

____

Filip Cupan

0069083304

PROŠIRENI SAŽETAK

U ovom radu istražuju se tehnički izazovi integracije električnih vozila u distribucijskoj elektroenergetskoj mreži gdje se ujedno ukazuje na pozitivne i negativne značajke. Kroz rad opisane su glavne značajke aktivne distribucijske mreže s obnovljivim izvorima energije i električnim punionicama za električna vozila, Vehicle to grid (V2G) tehnologija i priključenje električnih vozila na distribucijsku mrežu u Republici Hrvatskoj, Ujedinjenom Kraljevstvu, Nizozemskoj i Njemačkoj.

Prvo poglavlje predstavlja uvod u rad gdje se spominju utjecaji zašto se mnoge države nalaze pred nadolazećim tehničkim izazovima u distribucijskoj mreži. Zbog povećane decentralizacije, digitalizacije, dekarbonizacije prometnog i toplinskog sektora javljaju se mnogi tehnički izazovi u distribucijskoj mreži. Ekološki izazovi nameću elektrifikaciju transportnog sektora, ali i razvoj fleksibilnosti usluga prema različitim sudionicima u elektroenergetskom sustavu kao što su pametna punjenja i V2G tehnologija. Proizvođači automobila prisiljeni su smanjiti emisije CO_2 flote novih vozila na 95 g/km te se time potiču bržom dekarbonizacijom vozila. Integracija obnovljivih izvora energije također predstavlja tehnički izazov iz razloga, zato što je cilj što više električne energije dobiti iz obnovljivih izvora energije kako bi se provela efikasna dekarbonizacija transportnog sektora. Opterećenje distribucijske mreže električnim vozilima zahtijeva dodatna neizbježna ulaganja u infrastrukturu. Punjenje električnih vozila može dovesti do gubitaka aktivne snage, preopterećenja transformatora ili vodova te negativno utjecati na kvalitetu usluge koju primaju krajnji korisnici.

Drugo poglavlje kroz šest točki opisuje tehničke izazove za distribucijsku elektroenergetsku mrežu. Svih šest navedenih točki treba uzeti u obzir jer su od krucijalne važnosti zbog povećane integracije električnih vozila u distribucijskoj mreži. Pogotovo zato što je važno osigurati stabilnu distribucijsku mrežu, dovoljan broj punionica za električnih vozila, smanjiti negativne utjecaje na distribucijske transformatore, dovoljnu količinu električne energije i faktor harmoničkog izobličenja u granicama.

Treće poglavlje opisuje glavne značajke aktivne distribucijske mreže s obnovljivim izvorima energije i punionicama za električna vozila. Aktivna distribucijska mreža omogućuje dvosmjeran tok energije koji je potreban radi integracije obnovljivih izvora energije, ali ujedno i radi integracije V2G tehnologije. Distribuiranom proizvodnjom potiče se proizvodnja električne energije iz obnovljivih izvora energije, dok korištenjem V2G tehnologije električna vozila mogu poslužiti kao skladišta električne energije te time kada je potrebna električna energija predati je u mrežu. Opisane su pojedine značajke na koje utječe kombinacija distribuirane proizvodnje i V2G tehnologije kao što su razina napona u mreži, regulacija toka snage, termički utjecaji na opremu i razine struje kvara.

Četvrto poglavlje detaljnije opisuje V2G tehnologiju. Također, opisane su prednosti V2G tehnologije kao što su: regulacija frekvencije i napona, promjenjivost opterećenja u mreži, podrška u integraciji obnovljivih izvora energije. Opisani su i negativne značajke kao što su trošenje baterije i utjecaji na elemente distribucijske mreže i opremu. Posebno treba naglasiti trošenje baterije jer kada vlasnici električnih vozila daju električnu energiju u mrežu može uzrokovati degradaciju baterije jer zdravlje baterije ovisi o broju ciklusu punjenja i pražnjenja.

Peto poglavlje predstavlja priključenje električnih vozila u distribucijsku mrežu u Republici Hrvatskoj, Ujedinjenom Kraljevstvu, Nizozemskoj i Njemačkoj. Priključenje punionica za električna vozila istraženo je kroz razne dostupne dokumente. U navedenom poglavlju istaknute su neke od činjenica koje prisiljavaju države u razvitak i dodatno ulaganje u distribucijsku mrežu. Za svaku pojedinu državu istaknute su sve dostupne informacije koje oblikuju priključenje punionica za električna vozila na distribucijsku mrežu.

U šestom poglavlju opisan je zaključak cijelog rada. Zaključak rada je da se mnoge države nalaze pred velikim ulaganjem u distribucijsku elektroenergetsku mrežu radi integracije električnih vozila i obnovljivih izvora energije koje je neizbježno radi provođenja dekarbonizacije transportnog sektora i energetskog sektora. Pametnim punjenjima i upravljanjem opterećenja može se značajno smanjiti dodatno ulaganje i to je nešto što mnoge države uključujući i Republiku Hrvatsku trebaju istražiti i implementirati radi smanjenja dodatnih troškova.

Technical challenges of integrating electric vehicles in the distribution grid

Filip Cupan
Student
Universtiy of Rijeka, Faculty of engineering
Rijeka, Croatia
fcupan@gmail.com

Rene Prenc
Department of Electric Power systems
Universtiy of Rijeka, Faculty of engineering
Rijeka, Croatia
rene.prenc.@riteh.uniri.hr

Vedran Kirinčić
Department of Electric Power systems
Universtiy of Rijeka, Faculty of engineering
Rijeka, Croatia
vedran.kirincic@riteh.uniri.hr

Michele Rojnić
Department of Electric Power systems
Universtiy of Rijeka, Faculty of engineering
Rijeka, Croatia
michele.rojnic@riteh.uniri.hr

***Abstract*— This paper explores technical requirements of the distribution network for integrating electric vehicles (EV), while also pointing out their positive and negative features. The concept of Vehicle to Grid (V2G) is described and its recent implementation in action plans for some EU countries. Charging point connections in Croatia, Netherlands, UK and Germany are compared through available information in the regulations concerning distribution network planning and operation of each country and also other public documents that serve as guidelines. Special emphasis was placed on possible providing of ancillary services.**

Keywords— electric vehicles, emobility, distribution electrical grid, charging stations, V2G, anciallery services

I. INTRODUCTION

Distribution electrical power grids are facing a challenging environment characterized by increased decentralization, digitalization, and decarbonization of the transportation and heating sectors [1]. The integration of a large number of battery electric vehicles (BEVs) poses significant challenges for the operation and planning of the distribution network. However, electric vehicles also present an opportunity to offer flexibility services to various participants in the electricity market by using smart charging technology and vehicle-to-grid (V2G) capabilities. Environmental challenges necessitate the electrification of the transportation sector. BEVs have the potential to significantly reduce CO_2 emissions in this sector, while simultaneously lowering emissions of other atmospheric pollutants such as particles and NO_x, as well as reducing noise levels. The aforementioned reasons have prompted many governments and cities to adopt pro-EV measures, such as stricter CO_2 emission standards and low-emission zones, which compel car manufacturers to improve the fuel efficiency of internal combustion engines and develop new electric models. Car manufacturers in Europe must adhere to an average fleet emission of 95 g/km of CO_2 emissions from 2020/21 onwards [2].This measure represents, on average, a 21 % reduction in CO_2 emissions compared to 2018 values. These factors have driven a rapid growth in the electric vehicle market, with over 3.2 million EVs sold in 2020, representing a 43 % increase from 2019.

On the other hand, in the distribution electrical power grid, there are already existing challenges related to the integration of distributed renewable energy sources, such as wind farms and photovoltaic (PV) panels, new schemes for empowering consumers, such as energy communities, and cross-sector electrification, such as heating and transportation. The integration of electric vehicles has an important impact on distribution networks around the world [3]. This impact can include issues with load flows and voltage fluctuations. Additional load from BEVs in a standard grid-to-vehicle (G2V) operation mode can increase active power losses and create congestion in the distribution network infrastructure [4]. Overloading transformers or lines can cause equipment degradation and damage. Voltage issues affect the quality of service delivered to end-users, which needs to be maintained within the appropriate range (EN50160 standard in Europe). Charging BEVs can lead to voltage drops and phase imbalances outside of these grid requirements defined by the Grid Code of each country. However, the integration of renewable energy sources is a step towards sustainable mobility. Distributed generation (DG) can reduce urban areas' dependence on fossil fuels, while ensuring an adequate amount of electrical energy for BEV needs. Many EU countries including Croatia face a number of issues that need to be addressed for BEV integration. Some of the key challenges include ensuring an adequate number of charging stations, especially in Croatia, a tourist destination where more tourists each year are arriving with their BEVs. However, to achieve this, substantial investment in the distribution grid infrastructure is necessary. It is important to develop regulations on smart charging that contribute to alleviating some of these potentially burdening investment costs and to develop a charging strategy, especially during peak load hours. For example, users could be incentivized to charge their vehicles at a lower electricity price during off-peak hours or when the highest amount of electricity is generated from renewable energy sources.

This paper will describe technical aspects of integrating electric vehicles into the distribution power grid and highlight potential issues and their solutions. It will outline the features of passive, and then active distribution networks with renewable energy sources, and finally active networks with included electric vehicles and charging stations. The concept of vehicle-to-grid will be explained, along with its advantages and disadvantages. A comparison will be made for the part of distribution network planning & operation rules and regulations related to the connection of electric vehicles in Croatia and other countries in the world, pointing out the similarities and differences. The same will be done for connection standards and national action plans for accommodating a large number of such vehicles in the future.

II. TECHNICAL CHALLENGES FOR THE DISTRIBUTION POWER GRID

The widespread use of BEVs has several impacts on the distribution electric power grid:

A. *Increased demand for electric power & energy*

Due to the increasing share of electric vehicles, there is also a higher consumption of electric energy during their charging time, which can coincide with peak evening hours.

B. *Charging infrastructure*

The development of charging infrastructure is necessary, including charging stations in public places, workplaces, and home chargers. Electricity providers and governments must invest in expanding charging infrastructure to accommodate the growing electric vehicle market.

C. *Managing the load of the electric power grid*

It is crucial to avoid overloading the grid during high electricity demand periods coinciding with charging of electric vehicles. Smart charging technologies enable the optimization of charging schedules, allowing electric vehicles to charge during low electricity demand periods or when the production of electricity from renewable sources is high.

D. *Grid stability*

There are three types of frequency regulation in a power system: primary, secondary and tertiary (the last two including also power exchange between neighbouring countries). BEVs can participate in secondary regulation by supplying energy to the grid when consumption exceeds production, or viceversa, by charging the battery. This is an example of an ancillary service, where BEV owners can receive compensation not for supplied energy, but for available power [5]. However, it is not yet implemented in practice as is the case with standard stand-alone battery energy storage systems (BESS).

E. *Negative effect on distribution transformers*

High usage of electric vehicles can lead to localized overloads of distribution transformers, especially in areas with a dense concentration of EVs. Upgrading and strengthening distribution infrastructure is necessary to accommodate the increased load from charging BEVs. Additionally, in the case of overloaded distribution transformers with various EVs fed via converter interfaces, harmonic currents can cause transformer heating, thus increasing losses in the iron core. These losses will increase the overall heat dissipation and worsen the kVA rating (capacity) of the transformer [6].

F. *Impact of current and voltage harmonics on electrical grid*

The increase in high-frequency components of voltage and current relative to the fundamental 50 Hz harmonic is defined as harmonic distortion. Total Harmonic Distortion (THD) is a measure of waveform distortion of voltage and current.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} \times 100\% \qquad (1)$$

$$THD_v = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1} \times 100\% \qquad (2)$$

In [7], the authors state that during slower charging of electric vehicle batteries, THD_i and THD_v are lower, but during fast charging, they become higher. During this process, converters placed in charging stations inject harmonics into the distribution grid. In [7], the authors demonstrated through Monte Carlo simulation that as the number of charging stations increases, THD_i decreases. By implementing harmonic filters, THD_i is reduced, thereby improving grid power quality. According to the Distribution Grid Code in the Republic of Croatia, mitigation of the harmonic distortion is solely the responsibility of the customer. The harmonic distortion factor is determined at the connection point by observing a one-week period, and the obtained value must be strictly less than 8 % to meet the grid connection requirements in order to limit the cumulative impact of users on the planned level of total harmonic distortion [8].

III. MAIN FEATURES OF AN ACTIVE DISTRIBUTION NETWORK WITH RENEWABLE ENERGY SOURCES AND CHARGING STATIONS FOR ELECTRIC VEHICLES

The need to evolve from a passive distribution grid to an active one by introducing bidirectional energy flows indirectly enables achieving the goal of decarbonization of the transportation sector. At the same time, the grid must handle the increased number of electricity consumers and ensure their safety of supply with minimal costs. Additionally, it's crucial to balance the integration of renewable energy sources and charging stations for EVs. With vehicle-to-grid technology, EVs combined with DGs could be utilized for storing clean electrical energy in their batteries, which can supplement the grid in peak consumption hours. This is a good example of peak shifting, but with clean energy, which otherwise cannot be regulated by intermittent sources. EVs with V2G operation mode combined with DGs have the following impacts on the distribution network:

A. *The voltage level in the grid*

In some nodes of the grid, electric vehicles can cause a significant decrease in voltage below the allowed limit (during charging), and viceversa (V2G). However, since power converters can operate with a variable power factor, EVs can be set to provide stable voltage in areas where it is needed.

B. Power flow regulation

Power flow regulation is of crucial importance because, if unchecked, it can cause overload of the elements in the grid, potentially leading to damage. Power flow can be regulated using SCADA systems as a real-time support for managing production and network capacity, limiting local production of DGs and even consumption of EVs to prevent local grid overload [9]. Limiting the consumed power of EVs is another example of ancillary service, also called demand response. However, albeit technically viable, this concept is yet to be incorporated in the grid, due to high costs of developing a strong communication infrastructure.

C. Thermal impact on equipment

Continuing on the previous subchapter, reverse power flow from the distribution towards the transmission grid can lead to excessive voltage near the point of common coupling (PCC). Excessive voltage, if unregulated, may cause insulation breakdown, and this in turn leads to high temperatures due to accompanying short circuit currents [10]. This occurs because distributed generation exceeds local load and exports power to the upstream grid. Regarding electric vehicles, high currents during charging may also lead to equipment heating, with level 1 chargers having currents of 12 to 16 amps, level 2 chargers having currents of 15 to 80 amps, and level 3 chargers having currents of 60 to 615 amps, especially on Tesla V4 superchargers [11].

D. Fault current levels

Fault current is the amount of current flowing through the network usually caused by the occurrence of a short-circuit (SC). DGs and EVs produce contributing SC currents, that superimposed on the upstream grid SC current, may lead to exceeding the nominal rating of the network equipment (circuit breakers, busbars, etc.). However, since both technologies use converters (with the exception that some DGs use synchronous generators without a converter interface) that limit SC contribution, this can only have an impact on feeders consisting of more DGs and EVs in V2G mode. In that case, this issue can be addressed by using Fault Current Limiter (FCL) devices. FCL increases the network impedance temporary during the SC occurrence, thereby not allowing the SC current to rise to unacceptable levels. Another more conventional solution to this problem is the additional investment in distribution equipment with higher ratings [9].

As a concept, V2G technology entails many upgrades in a distribution system for electric vehicle charging stations, especially the communication lines. Additional investments in the active distribution grid depend mainly on the charging strategy. In [12], the authors emphasized the importance of implementing a proper charging strategy, namely Smart Load Management (SLM). Smart Load Management achieves voltage stabilization in the grid and reduces power losses, even during the connection of a large number of electric vehicles to charging stations. SLM is designed to organize the charging of electric vehicles based on the performance of the distribution grid. The authors also concluded that it is necessary to divide the charging zones based on the peak load value of the grid, and depending on that, the cost of charging an electric vehicle will vary according to the time of charging.

Renewable energy sources in tandem with electric vehicles constitute an important element for the sustainability of electrical power systems. Energy obtained from renewable sources for charging the electric vehicles also means lower CO_2 emissions and a greener footprint. With renewable energy sources, there is a push for decentralization of the power system as a whole and an improvement of the security of supply of the active distribution grid, ensuring less sensitivity to changes in electricity prices. In other words, with flexible and controllable charging of electric vehicles, renewable energy sources can be exploited optimally. Fig. 1 depicts the aforementioned G2V and V2G concept combined with using DGs [13]. In countries like France, regulations require that all parking lots with 80 to 400 parking spaces must cover their parking spaces with solar panels [14].

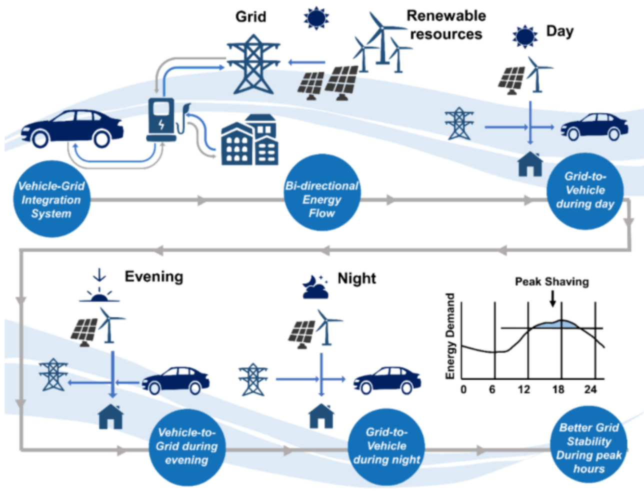

Fig. 1. Possible combined usage of EVs and DGs in the distribution grid [13]

IV. VEHICLE TO GRID (V2G)

Vehicle-to-Grid is a concept that enables bidirectional flow of electric power between electric vehicles and the distribution power grid. This is an example of a charging strategy where charging station users can participate in the market as buyers and sellers of electric energy. Due to the increasing demand for electric energy, it is necessary to increase energy production to maintain security of supply (and also stability, if EVs are included in secondary frequency regulation). During periods of high demand for electric energy (evening hours), electric vehicle owners can supply energy to the grid to fill gaps in renewable energy production or provide support. In addition to V2G, Vehicle-to-Everything (V2X) is often mentioned, which includes Vehicle-to-Home (V2H) and Vehicle-to-Building (V2B), depending on where the electric energy from the vehicle's batteries intends to be utilized. V2G technology offers many benefits such as:

A. Frequency and voltage regulation

During periods of high network load, frequency and voltage fluctuations occur. To maintain grid stability, it is necessary to keep the frequency and voltage within stable limits. The ratio of produced to consumed electric energy must be equal for grid stability (since the total grid storage for now is negligible). When the grid is overloaded, there is a global drop in frequency accompanied by local drops in voltage, and when the demand for electric energy is low and the production of electric energy is high (with uncontrollable renewable sources, like wind), there is an increase in frequency and voltage, which is also undesirable. V2G technology can help in reducing frequency fluctuations and maintaining grid voltage during these periods.

B. Variability of loads in the grid

Batteries in electric vehicles have the capability to charge at different power levels, allowing them not only to decrease or increase charging speed to minimize the impact on the grid, but also to provide rapid power injection into the grid when the grid load is at its peak. Thus, demand response enables not just peak shaving, but also peak shifting with a goal to flatten the power consumption curve.

C. Support for the integration of renewable energy sources

V2G technology indirectly stimulates the integration of renewable energy sources by enabling increased production of green electric energy (less need for power curtailment) and storing that clean energy in the batteries of electric vehicles, as well as returning it to the grid when demand for energy is higher.

V2G technology, besides offering many benefits to the grid, also has its drawbacks:

D. Battery Wear

The health of the battery depends on:

- Number of charge and discharge cycles,
- Temperature,
- Depth of discharge (DoD) and
- Charging speed.

V2G technology significantly affects the previously mentioned features. Many car manufacturers provide recommendations to their electric vehicle customers for battery care. For example, Volkswagen advises its customers to maintain the battery within a range of 20 % to 80 % during short driving distances in the summer, and 40 % to 80 % in the winter. They also recommend avoiding fast chargers and suggest using slower chargers. Therefore, if energy were to transfer from the electric vehicle battery to the grid via a fast charger, battery degradation will likely occur. In this case, BEV owners may risk losing their battery warranty if the battery health falls below 80 % after 8 years or 160,000 kilometers in the case of a Volkswagen vehicle [15]. Since battery technology is evolving every day, the previously mentioned battery health preservation issue may become unnecessary in the future.

E. Impact on the distribution network elements and equipment

In [16], it was concluded that BEVs have a significant impact on the distribution network elements and equipment. Level 2 and 3 chargers provide higher charging speeds because they require higher voltage. The requirement for higher voltage chargers puts much more strain on distribution equipment, thus shortening its lifespan (the insulation degrades faster). From this, it can be stated that constant investment in both distribution power and communication infrastructure is necessary. For these reasons, V2G is not yet a viable option in practice, and the current legislation is focused only on G2V technology.

V. Development of EV infrastructure in Croatia and the rest of Europe and its connection to the grid

In Europe, including Croatia, and worldwide, the development of electromobility is aligned with the efforts of urban environments to reduce CO2 and other exhaust emissions, as well as noise levels caused by traffic. Over the past few years, a series of legislative directives have been adopted within the European Union that all member states must comply with, regulating the development of infrastructure for alternative fuels. Meanwhile, there has been an increase in financial incentives (such as subsidies for vehicle and solar panel purchases) and non-financial incentives (such as the ban on fossil fuel vehicles in city centers) for the use of EVs. The energy sector of the Republic of Croatia is facing significant challenges and investments due to global and European trends. A large portion of funds from the automotive industry is being invested in the development of electromobility (batteries, autonomous driving). As electromobility continues to develop, there is a decrease in the price of electric vehicle charging equipment, and a significant expansion of its market. In March 2024, Volvo produced its last car with a diesel engine and aims to become an electric brand by the end of this decade [17]. From 2035 onwards, all new cars on the market should not emit CO_2, meaning that all cars will be electric or hydrogen-powered. Just a few of the aforementioned trends herald significant challenges in the energy sector of the Republic of Croatia. Directive 2014/94/EU, the Alternative Fuels Infrastructure Directive (AFID), explores electromobility and proposes future plans. Here are some highlighted messages for all participants in the electromobility market [18]:

- 10 % of the market share of energy from renewable sources must be allocated as fuel for use in transportation,
- Member states should ensure that the construction of publicly accessible charging points provides adequate coverage to enable electric vehicles to operate at least in urban/suburban agglomerations and other densely populated areas,
- Implementing intelligent metering systems for charging electric vehicles would contribute to the stability of the power grid by enabling battery charging from the grid during periods of reduced electricity demand,
- Member states ensure freedom for operators of public charging points, with the approval of suppliers, to freely procure electricity from any supplier within the European Union (charging

point operators may provide charging services to their customers on a contractual basis),

- All publicly accessible charging points must provide their customers with the option of charging without entering into a contract with an electricity supplier or operator,
- Intelligent metering systems, as established in Directive 2012/27/EU of the European Parliament and of the Council, enable the generation of real-time data necessary to ensure the stability of the electricity grid and promote the rational use of charging services by providing accurate and transparent information on the price and availability of electrical energy,
- The use of intelligent metering systems enables the optimization of charging, resulting in benefits for both the electricity grid and consumers (especially by complying with the aim of charging during periods of lower demand).

On April 13, 2024, the AFID was replaced by the Alternative Fuels Infrastructure Regulation (AFIR). With this replacement, more concrete plans regarding charging stations and the prescribed power requirements for meeting all demands (slow & fast) were introduced. AFIR is essentially a revision of AFID [19]. The revision was made because the current capacity for electromobility in the European Union will not meet the demand for charging stations. Some of the plans outlined by AFIR include:

- The output power of public charging stations must be proportional to the number of registered BEVs, with a power output of 1.3 kW for every light-duty BEV and 0.8 kW for every light-duty plug-in hybrid electric vehicle (PHEV),
- By 2025, the output power of charging stations must be equal to or greater than 400 kW, with at least one charger having a power output greater than 150 kW for light-duty vehicles, and they must be available every 60 kilometers,
- By 2027, the output power of charging stations must be equal to or greater than 600 kW, with a minimum of 2 chargers having a power output greater than 150 kW for light-duty vehicles,
- By 2025, for heavy-duty vehicles, the output power of charging stations must be equal to or greater than 1400 kW, including at least one charger with a minimum power of 350 kW (charging stations must be set up in both directions),
- By 2027, for heavy-duty vehicles, the output power of charging stations must be equal to or greater than 2800 kW, including two chargers with a minimum power of 350 kW each (charging stations must be set up in both directions),
- By 2030, for heavy-duty vehicles, the output power of charging stations must be equal to or greater than 3600 kW, including two chargers with a minimum power of 350 kW each (charging stations must be set up in both directions).

The regulatory framework of the Republic of Croatia, like all other European Union member states, adopts the duties from AFID and AFIR. Currently, based on the Directive on the deployment of alternative fuels infrastructure, there is only one document called the National Policy Framework for the Establishment of Infrastructure and Development of the Market for Alternative Fuels in Transport (NN 34/2017, dated April 6, 2017) [20]. For actual decisions regarding the necessary infrastructure, only input plans are currently available. They predict the so-called Scenario L, which represents the consumption of electric energy as follows: 5% on highways, 25 % on urban and interurban roads and 70 % at home charging points. The following plans according to the aforementioned framework are:

- 2020 - A minimum of 296 charging points (of which 222 are AC with a minimum power of 11 kW, and 74 are DC charging stations with a minimum power of 50 kW) at 164 charging stations,
- 2025 – A minimum of 602 charging points (434 AC with a minimum power of 11 kW and 168 DC with a minimum power of 50 kW) at 348 charging stations,
- 2030 – A minimum of 806 charging points (554 AC with a minimum power of 11 kW and 252 DC with a minimum power of 50 kW) at 479 charging stations.

Also, the same framework states that electric vehicle charging stations can be of low power, up to 22 kW, using a type 2 connector in accordance with the HRN EN 62196-2:2017 standard, or high power, greater than 22 kW (typically 50 kW), using a CCS or CHAdeMO connector in accordance with the EN62196-3 standard (for charging with direct current for vehicles from Japanese manufacturers), Fig. 2 [21]. Additionally, low-power charging stations can have an installed power as low as 3.7 kW, but these are intended for private households and not for commercial charging. In conclusion, the current National Framework for the Establishment of Infrastructure and Development of the Alternative Fuels Market in Transport does not meet the requirements of the AFIR and the growing needs of electromobility in Croatia, and thus a new plan will be soon required for the establishment of infrastructure and development of the alternative fuels market for transportation.

Fig. 2. Types of connection [21]

Electromobility in the Republic of Croatia is currently in the phase of infrastructure development, which is expanding in a technologically uneven manner. Although the prescribed provisions of the EU Directive and AFIR on the deployment of alternative fuels infrastructure are being followed in practice (albeit not preceded by a newer framework), there are no precisely defined technical requirements for connecting charging stations to the power distribution grid. However, by observing the construction laws (NN 20/17) [22] and energy laws (NN 102/15) [23], as well as other regulations governing this area. The Regulation on Simple and Other Buildings and Works (NN 112/2017) [24] states that electric vehicle charging stations are considered as simple structures. This in turn allows their construction without a building permit , thus significantly shortening the commissioning time. Connecting charging stations to the power grid is covered by the Methodology for Determining the Fee for Connection to the Electrical Network (NN 28/06) and the Decision on the Amount of Fees for Connection to the Power Grid and Increasing Connection Capacity (NN 52/06) [25] [26]. When connecting standard charging stations, the following should be taken into account:

- Connection to the low-voltage (LV) grid (for installed power up to 30 kW and over 30 kW) amounts to €179.17 per kW,
- Connection to the medium-voltage (MV) or high-voltage (HV) grid amounts to €179.19 per kW plus the additional costs for covering needed network upgrades (the so-called technical conditions).

The aforementioned prices apply to the entire territory of the Republic of Croatia, while in the city of Zagreb, the prices for connection to the low-voltage, medium-voltage, and high-voltage grids are €225.63/kW (all prices mentioned are exclusive of value-added tax). The connection of an electric vehicle charging station requires a technical solution depending on the characteristics of the station, its installed power, the construction site, and the nearby electrical grid. It can already be concluded in advance that fast charging stations will require connection to the MV grid, often implying additional costs for DSO's grid upgrade. Most property owners which typically want to buy a low-power charger will simply ask the DSO for more kW atop of the their existing household electrical installations and they will not require a new connection to the grid. However, there are cases where increasing the power will require modifications in the electrical grid even for a low-power station.

Low-power chargers located in Europe's rural areas will typically connect via a T-connection to the existing overhead grid (separate LV feeders are rarely required). On the other hand, in urban areas such as parking lots in cities, shopping centers, highway rest areas, etc., which commonly install high-power charging stations (of 50 kW or more), T-connection is used to the existing underground grid, and sometimes it is upgraded to a LI-LO connection (Line-In & Line-Out), as is shown in Fig. 3 [27].

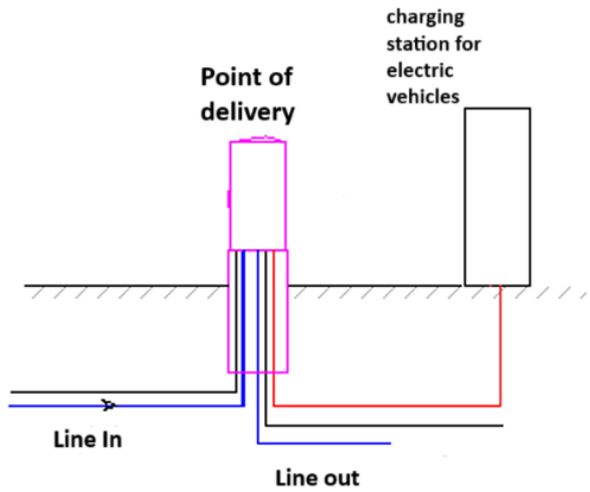

Fig. 3. LI-LO connection from the underground network [27]

In some cases a new LV feeder will be necessary, due to the fact that other feeders' capacity is full (Figure 4) [27]. More often than not, the owner of such a charging power station will simply connect to the MV network, cover the higher initial installation costs (in comparison with the connection to the LV grid), but will in return pay a lower price for consumed electrical energy.

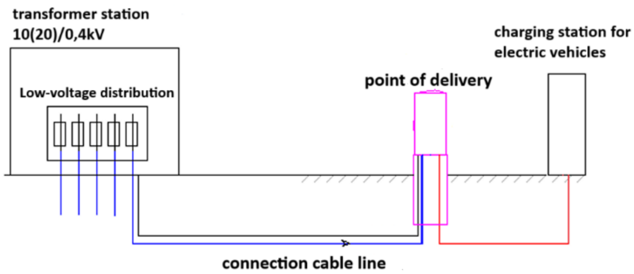

Fig. 4. A separate feeder laid from the transformer station towards the EV charging station [27]

The needs of electromobility in the Republic of Croatia branch in two main segments of infrastructure for charging electric vehicles: destination charging and transit charging. Destination charging involves the installation of chargers on public lighting poles, in households, business parking lots, public garages and shopping centers. Additionally, since Croatia is a tourist country, it also involves installing chargers at private renters, hotels, and campsites. In the coming years, the subsidizing of chargers is planned as part of the "E-Tourism Project" [28]. Destination chargers do not need to be of high power, but it is important that they provide charging power of up to 11 kW. Transit charging involves the construction of ultra-fast chargers in intercity and urban traffic areas, as well as on highways. The idea is to enable ultra-fast charging in 10 to 20 minutes maximum [28].

The Republic of Croatia as of yet has no regulations on smart charging for comparison with other countries such as the UK. Smart chargers enable monitoring and control of the charging process. By using smart chargers, the burden on the power grid is reduced by automatically adjusting the consumed kW towards the electric vehicles according to amount of grid load, meaning that in case of an imminent overload of the feeding line and/or transformer, the charger's power will simply drop. According to the regulations on smart chargers introduced for the UK on July 30, 2022, every charger sold in UK for home or public use must include smart features [29]. Basic smart features of the charger include:

- Connectivity - this fundamental requirement mandates that every electric vehicle charger must have an integrated data connection that measures and sends information about energy consumption during the charging cycle. It also allows the charging station to slow down or postpone charging, especially if there is high demand for electricity. This enables grid stability.
- Charging during off-peak hours - all chargers are programmed to avoid charging during peak hours. In the UK, peak hours are defined between 8 am and 11 am and from 4 pm to 10 pm. The EV user can increase the charging power in these periods, but will be penalised at a higher rate per kWh consumed, which is defined for the duration of peak network load. Electricity suppliers will offer lower electricity rates during off-peak hours. Electric vehicle owners can thus manage their costs, potentially resulting in significant savings.
- Controlled charging time - to avoid simultaneous charging, the UK government requires that all chargers have a charging delay time of up to 30 minutes. This equalizes the demand for electricity and also ensures the stability and safety of the power grid.

All the mentioned features of smart chargers are designed to preserve the operation of the power grid. Another set of requirements in UK, enacted on December 30, 2022, concerns privacy and security [30]. Each charger must ensure that the data sent is protected and encrypted to prevent cyber attacks or reduce the possibility thereof. All sent data will be stored for the next 12 months. Electric vehicle chargers must be manufactured to have a certain level of protection against damage or any negative impact to the power grid, such as overloading the network. As for the number of allowed chargers per household, it is not defined, allowing for the installation of multiple chargers at one location or within one household.

The Netherlands, which is a leading example of a successful EV integration policy, has 154,219 public charging stations, making up over 30 % of charging stations in Europe [31]. The Netherlands shapes its electric vehicle charging infrastructure according to the document called "Uniform Standards for Charging Stations", in which the guidelines are categorized by importance, and some of them are briefly described below [32]:

- Application – Before installing the charging station, it is preferable to submit an application for the charging station that corresponds to the electric vehicle driver and the municipality. For each new location, the contractor must offer a site inspection for the installation of the charging station and propose 2 dates for the inspection. The inspection must be conducted before submitting the request for connection to the grid. In case of deviation from the desired location during the inspection, it must be coordinated with the network operator in case it is necessary to increase the length of the cable, then it is necessary to resubmit the request.
- Construction – Before the construction of the charging station, several conditions need to be met, such as: the charging station must be placed within X meters from the electric vehicle driver's address; in case there is already a charging station nearby, an assessment should be made to determine if the request for a new charging station is necessary. Local authorities determine the maximum walking distance X to the charging station. All construction works related to the charging station must possess all necessary building permits. The contractor bears the costs. Connection to the grid and all construction-related works for the charging station must be completed within 24 hours or one day. Before installing the charging station, a Site Acceptance Test must be passed. Depending on the location and parking conditions at the charging station site, collision protection needs to be installed.
- Environment and location – The charging station must be placed where it will not obstruct other traffic. If the charging station is located more than 25 meters from the main cable, the grid operator may charge a fee. Due to excavation for the construction of the charging station foundations, it should not be near trees. Also, the charging station must not be located where special traffic regulation systems are in place.
- Management and monitoring – Under this guideline, monthly management reports, basic maintenance of the charging station, and availability of technical support 24/7 to address potential issues are implied. In case the charging cable cannot be disconnected from the station, it should be removed within 24 hours and returned to the owner within 72 hours. Spare parts essential for the functioning of the charging station must be available for at least 3 years after the contract expires.
- Functionality – This guideline explains how the charging station should function for the user. Power availability is one of those functions, meaning that smart charging should offer less available power in case of high network loads. Additionally, the charging station must be equipped with the option to delay charging from the moment the electric vehicle is connected to the station. In the event of a power supply interruption during charging or after power loss and restoration, charging resumes only after a new transaction is initiated or resumed.

- Design – The use of the charging station must be tailored to the user. Each charging station must be equipped with a Type 2 plug. Status indication, such as LED lights if included in the charging station, must comply with the client's policy.
- Engineering and safety – Each charging station includes short-circuit (SC) protection and overcurrent protection. The charging station and all other associated components must be grounded, and it is also possible to apply a common neutral line. Regarding the communication part, the charging station must locally store the data collected during charging in case it cannot be sent to the back-office system; otherwise, it sends it to the back-office system. Safety guidelines require earth leakage protection and measurement of the current flowing to the vehicle for each phase. If the power exceeds 10% of the specified value detected by the pulse with modulated (PWM) converter signal, charging will be interrupted, or the power consumed will be adjusted by PWM modulation.
- Smart charging and V2X – To enable smart charging, at least the following protocols must be satisfied: OCPI, OCPP v1.6, and OSCP. The OSCP (Open Smart Charging Protocol) is an open-source protocol that manages and communicates with the Distribution System Operator (DSO) through charging points. For example, when a driver plugs their electric vehicle into the charging station and requires faster charging, an additional request is sent via OSCP to the DSO, who can approve the request. Additionally, charging stations must include upgrades for future scenarios, such as V2X (Vehicle-to-Everything) capabilities.

From the provided data, it can be concluded that the Netherlands is the leading country in Europe in integrating electric vehicles to the distribution network. What can also be inferred from their guidelines is that they strive to adapt as much as possible to the demands of EU's action plans and EV policy. Due to the transition from fossil to alternative fuels, there is an increasing demand for electric power in Netherlands, however on a positive note this coincides with a rapid growth of renewable energy sources such as wind farms and solar panels. An example of the demand for increased power is in the province of Friesland in the village of Hallum. With existing underground 10 kV cables not providing sufficient capacity, the grid operator was forced to lay over 200 kilometers of new 20 kV cables, while the 10 kV cables still remain in use to meet the demand [33]. Similar circumstances await all other European countries, including Croatia, for better, safer, and more sustainable electric mobility.

Germany, as the second country in Europe by the number of charging stations, has integrated 130,828 public charging stations into its distribution network [34]. According to the German Association of the Automotive Industry (VDA), 48 % of communities in the country do not have a single public charging station [35]. Germany's current infrastructure of distribution network does not meet the requirements of the energy transition, and grid operators are forced to upgrade their LV network with cables of higher cross-sections. Like in other countries, Germany promotes charging stations with bidirectional charging capabilities. Since January 1, 2024, controllable consumer devices using electricity, such as heat pumps and electric vehicle chargers, should temporarily reduce their power consumption down to 4.2 kW in case of an imminent grid overload [36]. In return, the consumer will receive bills with reduced grid fees. As said, most low-voltage networks in Germany are not designed for rapid EV expansion, which is another reason for implementing this measure. Germany, like Croatia, has implemented the 2014/94/EU Alternative Fuels Infrastructure Directive (AFID) into its policy. The country currently has no regulations on smart charging, but it is already estimated that it could reduce investment in the distribution network by up to 33% from 2019 to 2050, so regulations on smart charging similar to those in the UK are necessary [37]. Daily peak load in Germany is considered to be between 6:00 pm and 8:00 pm, peaking around 7:00 pm. The use of smart charging can reduce the load by 7 to 8 % [38].

Due to the increase of wind power stations in the north and solar panels in the south of Germany, a capital investment is underway for transferring electric power from the north to the south and viceversa. TenneT and TransnetBW, two of Germany's four transmission system operators, have planned a solution named SuedLink for the interconnection between the north and south of the country via a 540-km cable system that will transmit 2 GW of high-voltage direct current (HVDC) on ±525 kV voltage [39]. Planned completion of the project is in 2029. SuedLink is one of the most important power grid and energy transition projects in Germany and will play a critical role in Germany's energy transition, enabling a reduction in the use of fossil fuels and helping the country achieve carbon neutrality by 2045. The link will efficiently transmit electricity, sending wind power from the north to the industrial south, or alternatively solar power from the south to the north when needed. This in turn will provide a greater amount of clean energy derived from renewable sources for charging stations, which will be of even greater importance when the V2G concept becomes a viable and commercial option [40]. Regarding the Grid Code, the rules for connecting charging stations to the grid in Germany are similar to the ones used in Croatia. The central part is the load flow analysis, which must be performed a priori in order to determine whether the existing grid is sufficiently dimensioned for the required additional power or whether reinforcements are necessary. Each installation location for charging stations is considered individually. Finally, the position of parking spaces and existing spatial conditions have a significant impact on the installation [41].

VI. CONCLUSION

An accelerated phase of modernizing the distribution power grid is ahead of many European countries, including the Republic of Croatia. Faced with such increasing demands posed by new mobility trends, DSO's currently do not fully meet these conditions. Distributed generation used in tandem with electric vehicles could significantly alleviate some of the congestion problems both from G2V and V2G points of view. This not only improves the decentralization of the power system but also maximizes the utilization of intermittent renewable energy sources. V2G technology offers many advantages for the distribution grid, but a significant downside for BEV owners is battery wear. Current battery technology is not ready for V2G technology because with each cycle battery health decreases, causing its degradation. Since V2G technology can accelerate battery degradation, which affects the BEV owner's income, more frequent changing of battery packs is not yet an affordable option, unless the incentive for V2G can compensate for the aforementioned degradation.

Specifically, since Croatia is a tourist destination, priority should be given to building a strong charging infrastructure for easier acceptance of a larger number of BEVs. Additionally, due to its strategic geographical position, it is crucial to maximize all renewable energy sources for sustainable mobility. Moreover, since in the last 5-10 years Croatia's peak load has shifted from December to July, regulations on smart charging need to be introduced as soon as possible because with smart charging, additional investments in the distribution power grid can be reduced, ensuring grid stability during these peak periods that coincide with the tourist season. The current government policy has not yet recognized BEVs as a priority and DSO should urge the introduction of demand response ancillary service for EVs. The Netherlands has made significant progress in this regard and is the leader in the European Union in terms of the number of charging stations. Germany has one of the most reliable grids in Europe, which is probably why they still lag behind Netherlands.

Currently, more or less all countries (except for UK, which is a pioneer in flexibility market) are incorporating EVs into their grids via conventional planning with minimal network upgrades in order to avoid large investments. DGs have already shifted this paradigm significantly, but due to the speed and the huge amount of EV connection requests, DSO's may not be able to keep track via conventional means. In addition, since constant upgrade is a costlier solution in the long run and the number of future EVs is disproportionatelly greater than that of conventional loads, the planning principles will have to be revised and allow the usage of smart technologies that optimise the operation of the existing grid. Something similar is already occurring at the transmission network, but for other reasons (rapid integration of wind farms with high installed power). It is important to recognize the integration of BEVs into the distribution grid as a priority as the number of BEVs on the roads increases every day, and meeting the technical challenges should be done in a timely manner, before the inrush of EVs outweighs the supporting infrastructure.

ACKNOWLEDGMENT

This work was supported in part by EU under grant agreement no. 101129321 project ERASMUS+ NEST4WB: New energy competence system and technology for WB energy stability system curriculum reform. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

This publication is based upon work from COST Action Randomised Optimisation Algorithms Research Network (ROAR-NET), CA22137, supported by COST (European Cooperation in Science and Technology).

This study was sponsored by the University of Rijeka under project uniri-zip-2103–8-22.

VII. REFERENCES

[1] R. Raff, V. Golub, D. Pelin and D. Topić, "Overview of charging modes and connectors for the electric vehicles," in *2019 7th International Youth Conference on Energy (IYCE)*, Bled, Slovenia, 2019.

[2] "Smanjenje emisija u prometu: objašnjenje novih ciljeva za smanjenje emisija CO2 iz automobila i kombija," pp. 1-3, 2023.

[3] Topic, D., Chamorro, H. R., Knezevic, G., Rye, R., Gonzalez-Longatt, F., Sood, V. K., & Perko, J., "Analysis of pv systems and charging stations integration into the public lighting infrastructure," in *IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, Bucharest, Romania, 2019.

[4] D. Topić, G. Knežević, D. Šljivac, M. Žnidarec and J. Perko, "Integration of the EV charging stations into the public lighting infrastructure," in *IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, Bucharest, Romania, 2019.

[5] S.-L. Andersson, A.K. Elofsson, M.D. Galus, L. Göransson, S. Karlsson, F. Johnsson, G. Andersson,, " Plug-in hybrid electric vehicles as regulating power providers: Case studies of Sweden and Germany," in *Energy policy*, 2010, pp. 2751-2762.

[6] Karmaker, A. K., Roy, S., & Ahmed, M. R., "Analysis of the Impact of Electric Vehicle," in *International Conference on Electrical, Computer and Communication Engineering (ECCE)*, Cox'sBazar, Bangladesh, 2019.

[7] George G. Karady, Shahin H. Berisha, and Tracy Blake(Arizona State Univ) , Ray Hobbs (Arizona Public Service Co.), "Power Quality Problems at Electric Vehicle's Charging station," in *International Congress and Exposition*, Detroit, Michigan, 1994.

[8] "NARODNE NOVINE," HEP – OPERATOR DISTRIBUCIJSKOG SUSTAVA D.O.O., [Online]. Available: https://narodne-novine.nn.hr/clanci/sluzbeni/2018_08_74_1539.html. [Accessed 13 May 2024].

[9] Currie, R. A. F., Ault, G. W., Foote, C. E. T., Burt, G. M., & McDonald, J. R., "Fundamental research challenges for active managment of distribution networks with high levels of renewable generation," in *39th International Universities Power Engineering Conference, 2004. UPEC 2004.*, Glasgow, 2004.

[10] Hidalgo, R., Abbey, C., & Joós, G., "A review of active distribution networks enabling technologies," in *IEEE PES General Meeting*, Minneapolis, MN, USA, 2010.

[11] "BC Hydro Power smart," [Online]. Available: https://electricvehicles.bchydro.com/charge/choosing-a-home-EV-charger. [Accessed 13 May 2024].

[12] Masoum, A. S., Deilami, S., Moses, P. S., Masoum, M. A., & Abu-Siada, A. , "Smart load management of plug-in electric vehicles in distribution and resindential networks with

charging stations for peak shaving and loss minimisation considering voltage regulation," *IET generation, transmission & distribution,* vol. 5, no. 8, pp. 877-888, 2011.

[13] Ravi, S. S., & Aziz, M., "Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives," *Energies,* vol. 15, no. 589, pp. 1-27, 2022.

[14] D. Goreta, "Francuska će zahtijevati da sva velika parkirališta budu pokrivena solarnim pločama," greenhr, 14 11 2022. [Online]. Available: https://green.hr/francuska-ce-zahtijevati-da-sva-velika-parkiralista-budu-pokrivena-solarnim-plocama/. [Accessed 3 May 2024].

[15] "Volkswagen Hrvatska," [Online]. Available: https://www.volkswagen.hr/id-tehnologija/garancija-i-njega-baterije. [Accessed 15 April 2024].

[16] K. B. Yuttana Kongjeen, "Impact of Plug-in Electric Vehicles Integrated into Power Distribution System Based on Voltage-Dependent Power Flow Analysis," *Energies,* 2018.

[17] D. Kolarić, "Auto start," 28 March 2024. [Online]. Available: https://autostart.24sata.hr/novosti/volvo-je-prestao-proizvoditi-aute-s-dizelskim-motorima-8809. [Accessed 20 April 2024].

[18] "Lex Europa," 22 October 2014. [Online]. Available: https://eur-lex.europa.eu/legal-content/HR/TXT/HTML/?uri=CELEX:32014L0094. [Accessed 1 May 2024].

[19] "Lex Europa," 13 Septmeber 2023. [Online]. Available: https://eur-lex.europa.eu/legal-content/HR/TXT/HTML/?uri=CELEX:32023R1804. [Accessed 14 May 2024].

[20] "Nacionalni Okvir Politika za provedbu Direktive 2014/94/EU," 4 October 2015. [Online]. Available: https://mmpi.gov.hr/UserDocsImages/arhiva/Prilog%202%20NOP%20ver30-05-2015%2014-7_15.pdf. [Accessed 1 May 2024].

[21] "ELEN," [Online]. Available: https://elen.hep.hr/. [Accessed 18 April 2024].

[22] "Zakon.hr," 12 December 2019. [Online]. Available: https://www.zakon.hr/z/690/Zakon-o-gradnji. [Accessed 28 April 2024].

[23] "zakon.hr," 4 August 2018. [Online]. Available: https://www.zakon.hr/z/368/Zakon-o-energiji. [Accessed 28 April 2024].

[24] "Narodne novine," 17 November 2017. [Online]. Available: https://narodne-novine.nn.hr/clanci/sluzbeni/2017_11_112_2625.html. [Accessed 28 April 2024].

[25] "Narodne novine," 13 March 2006. [Online]. Available: https://narodne-novine.nn.hr/clanci/sluzbeni/2006_03_28_664.html. [Accessed 28 April 2024].

[26] "Narodne novine," 10 May 2006. [Online]. Available: https://narodne-novine.nn.hr/clanci/sluzbeni/2006_05_52_1249.html. [Accessed 28 April 2024].

[27] V.Radošević, D.Puzak, M.Cvitanović, "TEHNIČKI I REGULATORNI UVJETI PRIKLJUČENJA PUNIONICA ELEKTRIČNIH VOZILA NA ELEKTROENERGETSKU MREŽU," in *HRVATSKI OGRANAK MEĐUNARODNE ELEKTRODISTRIBUCIJSKE KONFERENCIJE - HO CIRED*, Opatija, 2018.

[28] "PLAN RAZVOJA INFRASTRUKTURE ELEKTROMOBILNOSTI U CESTOVNOM PROMETU REPUBLIKE HRVATSKE," Obnovljivi izvori energije Hrvatske, Zagreb, 2022.

[29] "legislation.gov.uk," 2021. [Online]. Available: https://www.legislation.gov.uk/uksi/2021/1467/contents/made. [Accessed 2 May 2024].

[30] "EV BOX blog," 26 April 2023. [Online]. Available: https://blog.evbox.com/smart-charging-regulations#UK. [Accessed 14 May 2024].

[31] "European Alternative Fuels Observatory," [Online]. Available: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/netherlands/infrastructure. [Accessed 15 May 2024].

[32] "NKL Nederland," [Online]. Available: https://nklnederland.nl/wp-content/uploads/2021/12/NKL-Engels-2018-def-charging-stations.pdf. [Accessed 5 May 2024].

[33] "Thicker cables for sustainable energy," 22 June 2022. [Online]. Available: https://www.heijmans.nl/en/stories/thicker-cables-for-sustainable-energy/. [Accessed 5 May 2024].

[34] "European Alternative Fuels Observatory," [Online]. Available: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/germany/infrastructure. [Accessed 13 May 2024].

[35] I. Platini, "Mobilty portal Europe," 26 December 2023. [Online]. Available: https://mobilityportal.eu/current-state-charging-infrastructure-germany/. [Accessed 14 May 2024].

[36] "bundesnetzagentur," 27 November 2023. [Online]. Available: https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2023/20231127_14a.html?nn=659670%20njemacka%20regulacija%20dizalice%20topline%20i%20punja%C4%8Di. [Accessed 14 May 2024].

[37] Dr.U.Maier, F.Peter, A.Jahn, Dr.J.Hildermeier, "agora-energiewende," 24 October 2019. [Online]. Available: https://www.agora-energiewende.org/fileadmin/Projekte/2018/Netzausbau_Elektromobilitaet/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf. [Accessed 14 May 2024].

[38] C.Bermejo, T.Geissmann, F.Nägele, T.Möller, R.Winter, "McKinsey&Company," 4 June 2021. [Online]. Available: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-impact-of-electromobility-on-the-german-electric-grid. [Accessed 7 May 2024].

[39] "SuedLink," [Online]. Available: https://suedlink.com/. [Accessed 20 May 2024].

[40] F. Quecke, "Clean Energy Wire," 15 January 2024. [Online]. Available: https://www.cleanenergywire.org/news/germany-plans-use-railway-power-lines-relieve-strained-electricity-grid. [Accessed 10 May 2024].

[41] U.Ruths, A.Grüber, "GDW.DE," February 2022. [Online]. Available: https://www.gdw.de/media/2022/03/leitfaden_ladeinfrastruktur_umfeldmassnahmen.pdf. [Accessed 14 May 2024].