Zapronovano novu struktury zarjadnoi stanitsi dla elektromobiliv, chto rozroblena na bazi trofnego transformatora ta trirovennogo aktivnoho chotirikvadrantnogo vypriamlyachha z korrektsii koeffitsienta potustnosti. Oписano parametry zapronovanoi struktury zarjadnoi stanitsi, pervyy raspolozheno parametry semy zamicheniia akumulyatornogoovidiku elektromobiliva Tesla model S, kha pri-
vedeno do odnii ekvivalentnoi batrei. Oписano metod shifirohenka batrei postoiannyh stroomiv i postoiannyh
napryvok CC-CV, pri kha zabelenchetsya billa vity
kist cykli zarjad-roditad batrei. Navezheno matematicheskie formuly dla razrakhuhku sklyadnixh vtrat potust-
nosti in KKD zapronovanoi struktury zarjadnoi stanitsi na
intervalii poenog zarjad batrei.

Pristavshenii systemu avtomaticheskogo rezhevaniiia
stroomiv ta napryvka zarjad, kha zasnovana na shirotno-
imperialnoi modulii druguho rodii ta integralnymu rez-
latorii. Pristavshenii ihnaiu model zapronovano-
noi struktury zarjadnoi stanitsi v programmnomu seredovisii
Matlab/Simulink, ta takozj privedeno rezultaty modelle-
vaniia: osigilagrami vhodnih ta vyhodnih stroomiv i napryv,
navezheni diniakhis rouba regulatoria stroomu zarjad.
Shlyhom koloniialnoi approximacii energetichsikh char-
teristikiv IGBT-modulyi dla razrakhuku stanitsixa ta
diniakhixh vtrat v silnykh klyuchax aktívnoho vypriam-
lyachcha bylo stvoreno model razrakhuvachha vtrat.

Pokaza, kha pri zbiłenniih значених stroomu zarjad
v regiakh CC razrakhuytse integralne значений KKD pro-
cesu zarjadu zanhejat, prote u taj nech razblichetsya
ekoeffitsient potustnosti t zanhejat eimišii vishih gar-
moniiv. Vypsiano optimizaciu vatst potustnosti v zapro-
ponovannii sistem zarjadnoi stanitsi za parametrami min-
nimьm stroomu zarjad i chastoty modulacji v SIM.

Viksianii analiz sklyadnixh energiy vtrat v zapro-
ponovannii strukturi pînterdiiї ej energoeffektiinih
v porivnya z iñymi ishuchoh strukturyami. Pererahova
zapolnovanii struktury je te, kha ona zabelenchetsya pokra-
šeni pokazniki KKD, koeffitsienta potustnosti t zanhe-
ni eimišii vishih harmoniiv stroomu. Otrymani takii pokaz-
nikki sistemи: integralne значений KKD novogo pro-
cesu zarjadu elektromobiliv metodom CC-CV 95.6 %, koeffitsienta
potustnosti 0,99, koeffitsienta harmoniichh spotorev вхi-
nogo stroomu 2,5 %.

Klyuchovе slova: aktívny vypriamlyach, akumulyatorná
bateriya, zarjadna stanitsa elektromobiliva, koeffitsient
potustnosti, modellevania

1. Introduction

Every year, electric cars become more popular compared
to cars with internal combustion engines. The development
de electric vehicles (EV) and charging stations is given sig-
nificant attention to by researchers and manufacturers [1, 2].
At the same time, it is a relevant issue to improve the indi-
cators of energy efficiency of charging stations, namely, to
improve efficiency parameters, the indicators of sinusoidal
current consumption, and a power factor.

According to the international standard IEC-62196, there
are the following types of charging stations: Mode 1, Mode 2, Mode 3, Mode 4. The regulated pa-
rameters of charging stations in line with the standard are
given in Table 1.

Among these, the most powerful type of charging sta-
tion that makes it possible to implement the electric vehicle
fast-charging mode is Mode 4 [3]. Therefore, our research
is aimed at improving the performance indicators of the
Mode 4 charging stations.
In addition, at modernization, one of the requirements for charging stations is the possibility of ensuring a double-sided transfer of energy, which corresponds to the «vehicle-grid (V2G)» concept [4, 5].

2. Literature review and problem statement

Publications [6, 7] described the charging stations for electric vehicles containing two stages of electricity conversion, namely an input AC/DC rectifier and an output DC/DC converter of direct current (Fig. 1).

In a given topology, input rectifiers used to create a link of constant voltage. Next, the DC/DC converter enables the adjustment of voltage and current of each single electric vehicle charge over a predefined range. In some cases, the DC/DC converter is also used to ensure the galvanic isolation of an electric vehicle with the grid [8, 9]. A common disadvantage of the examined systems [10, 11] is the concept of a two-step energy conversion, which predetermines the power losses in two converters and, accordingly, a decrease in the efficiency of the charging station [12, 13]. Each of the reported technical solutions has its drawbacks and cannot be considered a complete solution to the existing technical issue.

Paper [14] proposed a transducer for the electric vehicle charging station, whose disadvantage is the efficiency value, which reaches 91 % at maximum. In addition, the reported transducer requires the electromechanic phase splitting, namely, the nine-phase power system, which makes the system more expensive and increases its dimensions.

Work [15] studied the efficiency of a charging station for electric vehicles based on an inductive power transfer converter (ITP). The topology of a given converter is shown in Fig. 2. According to the cited work, the converter efficiency depends on many factors and, at certain intervals of operation, decreases to 45–50 %, which is quite low. In addition, the cited work lacks data on the integrated efficiency value of a full battery charging process in an electric car.

Work [17] reports a study of the ITP-type converter, whose difference from the transducer reported in [15] is that instead of a diode bridge the fully manageable power transistors are used.

According to the study, the converter efficiency, when using power transistors based on silicon carbide (SiC) and gallium arsenide (GaN), is in the range from 83 to 98 %. It is worth noting that the SiC- and GaN-based transistors are considerably more expensive than classic MOSFET or IGBT transistors. In addition, the cited work lacks data on the integrated efficiency value of a full battery charging process.

| Type | Phase quantity | Charge voltage, V | Current type | Charge current, A | Charging station arrangement | Charging station location |
|------|----------------|-------------------|--------------|-------------------|-----------------------------|--------------------------|
| Mode 1 | 1 | To 250 | AC | To 16 | Onboard | Home |
|       | 3 | To 480 |       |       |                 | Home |
| Mode 2 | 1 | To 250 | AC | To 32 | Onboard | Private/Public |
|       | 3 | To 400 |       |       |                 | Private/Public |
| Mode 3 | 1 | To 250 | DC | To 70 |       | Home |
|       | 3 | To 480 |       | To 63 |                 | Home |
| Mode 4 | 3 | To 1,000 | DC | To 500 | External | Public |

Table 1. Parameters of charging stations
Paper [18] reports a study into the half-bridge ITP-type converter, shown in Fig. 4. According to the study, the converter efficiency was determined using an experimental sample with a power of 900 W and reached 92 % to 95.6 %, which is a high enough indicator. However, when charging an electric car with a power of 900 W, the charging process can last more than 90 hours; there are no data on the efficiency of a given converter when implementing a greater power.

Table 2 gives the characteristics of external charging stations [19].

### Table 2

| Manufacturer and model | ABB Terra 53 | Tritium Veefil-RT | Tesla Supercharger | EVTEC express&charge |
|------------------------|--------------|-------------------|-------------------|----------------------|
| Rated power, kW        | 50           | 50                | 135               | 150                  |
| Charge standard        | CCS Type 1   | CCS Types 1 and 2 | CHAde MO 1.0     | CHAde MO 1.0         |
| Power voltage          | 480 VAC      | 380...480 VAC     | 600...900 V DC    | 200...480 V AC       |
| Direct current output voltage, A | 200...500 50...500 | 200...500 50...500 | 50...410 170...500 |
| Efficiency, %          | 93           | >92               | 92                | 93                   |

Fig. 4. An electric vehicle charging station based on the half-bridge ITP-type converter

Fig. 5. A charging station system for electric vehicles with a single-stage energy conversion
The advantages of the proposed charging station with AR include:
- the high power ratio, close to unity;
- the low total harmonic distortion coefficient of current consumption (THD<5 %);
- the higher efficiency relative to the two-stage charging stations of the AC/DC – DC/DC type;
- a capacity to provide bilateral energy transfer.

4. 1. Parameters of the proposed charging station

A power grid's characteristics are determined by the parameters of a three-phase power substation transformer of the TMN4000/35/6 type, whose phase resistance is \( R_{ph}=1.4 \) Ohm [20, 21]. The line 1 parameters are determined by the distance between the traction substation and the converting transformer, which is accepted equal to 1 km. An aluminum three-wire cable, used in line 1, has a phase resistance magnitude of \( R_1=0.8 \) Ohm/km, and its cross-section is selected based on current and is 35 mm².

A converting transformer of the SPZ-1000/10UZ 6(10)/0.2 kV series has a nominal power of 0.878 MW and a short-circuit loss of 8 kW [22, 23]. The total equivalent resistance of its phase \( R_{ph}=1.73 \) mOhm. The line 2 parameters are determined by the distance between the traction substation and the converting transformer \( T1 \) and the active rectifier, which is taken equal to 50 m. In this case, the cross-section of a copper cable is 350 mm²; the phase resistance magnitude is \( R_{ph}=2.5 \) mOhm. The inductance value of the input values of the active rectifier is 0.2 mH.

We selected, for the active rectifiers, the switches of the CM6000DX-13T type made by Mitsubishi Electric with the parameters of a collector current \( I_e=600 \) A and the voltage of a collector-emitter \( U_{CE}=650 \) V, the capacity of each output capacitor equals 20 mF. The system of the automated control over the current and voltage of the battery is implemented on the basis of an integrated controller with the subsequent PWM formation of an input current shape [24, 25].

4. 2. The equivalent model of a battery pack

This paper examines the charge of the equivalent model of the battery compartment in the Tesla S electric vehicle, which contains 7,104 batteries by Panasonic NCR-18650b with a total capacity of 83 kWh [26, 27]. The battery connection circuit in the electric vehicle Tesla Model S is shown in Fig. 6.

In the battery compartment, individual batteries of the NCR-18650b type are connected in parallel into groups of 74 pcs. [28, 29]. With a parallel connection, the voltage of the group is equal to the sum of voltages of each element (4.2 V), the capacity of the group is equal to the sum of the capacities of the elements (250 A·h). Next, six groups are connected sequentially into a module.

In this case, the module voltage is summed up with the voltages of the groups and is equal to 25.2 V. The modules are then connected sequentially in a battery. In total, the battery contains 16 modules (96 groups in total). In this case, the voltage of all modules is summed up and is 400 V. We also calculated the equivalent resistance of the battery pack; based on that the average resistance of one rechargeable battery \( R_{NCR}=37 \) mOhm is equivalent to the battery resistance \( R_{bat}=27 \) mOhm.

4. 3. A battery charging algorithm

When implementing a fast battery charge, a significant role belongs to the method (algorithm), which would be used to charge the battery. The most popular method of battery charging is a Constant Current–Constant Voltage (CV-CV) method (Fig. 7) [30, 31].

The main idea of the method is that the battery is charged with the constant maximum current \( (i_{max}) \), which is determined by a battery manufacturer to a certain cutoff voltage \( (u_{max}) \), then it is charged at this voltage as long as the current consumption is reduced to about 0.1 or less, thereby ensuring a full charge. It should be noted that when switching from a CC mode to a CV mode (this occurs at about 80 % of the battery charge) the charging speed is significantly reduced [32, 33].

5. Calculation of the efficiency and losses of a charging station system

This paper estimated the efficiency of the proposed charging station, shown in Fig. 5. The efficiency was estimated based on the total energy of losses and usable power obtained by a battery over the full charging interval [34]. The efficiency is calculated from the following expression [35]:

\[
\eta = \frac{E_{load}}{E_{load} + \Delta E_L},
\]

where \( E_{load} \) is the usable energy transmitted to a battery over the charge duration; \( \Delta E_L \) is the total energy of losses in the considered micro-grid system.

\[
\Delta E_L = E_s + E_{L1} + E_{LIV} + E_{L2} + E_{LIII} + E_{L8} + E_{L8R} + E_{LCR} + E_{Lout},
\]

where \( E_s \) is the energy of losses in a source of 6(10) kV; \( E_{L1} \) is the energy of losses in line 1;
The usable energy transmitted to the load:

\[ E_{\text{load}} = \int_0^T (u_{\text{load}} - i_{\text{load}}) \, dt, \]  

where \( T \) is the full battery EV charge duration; \( u_{\text{load}} \) is the instantaneous value of the output voltage fed to the lithium-ion battery compartment (when charging, the range varies from 340 to 420 V); \( i_{\text{load}} \) is the instantaneous value of the load current (a battery charge), which, during charging, varies from 15 to 400 A.

The losses in a source of 6(10) kV, in line 1, in the transformer \( T_1 \), in line 2, and in a battery are calculated from the following formula [36]:

\[ E_i = \int_0^T (i^2 \cdot R) \, dt, \]

where \( i \) is the instantaneous current value in the section of the calculated circle; \( R \) is the instantaneous resistance value in the section of the calculated circle.

The selected switches for the active rectifier were an IGBT-module, the type of CM600DX-13T. The total losses in an IGBT-module consist of the dynamic and static losses in an IGBT-transistor and a reverse diode, calculated from the following expressions [37, 38]:

\[ E_{\text{VT,DC}} = E_{\text{VT,SW}} + E_{\text{VT,VD}}, \]

\[ E_{\text{VT,SW}} = E_{\text{VT,SW0}} + E_{\text{VT,SW1}}, \]

\[ E_{\text{VT,VD}} = E_{\text{VT,VD0}} + E_{\text{VT,VD1}}, \]

where \( E_{\text{VT,DC}} \) is the energy of static losses in IGBT-transistors; \( E_{\text{VT,SW}} \) is the energy of dynamic losses in IGBT-transistors; \( E_{\text{VT,VD}} \) is the energy of static losses in parallel diodes; \( E_{\text{VT,SW}} \) is the energy of dynamic losses in parallel diodes.

\[ E_{\text{VT,DC}} = \int_0^T (i_c u_{ce}) \, dt, \]

where \( i_c \) is the collector current; \( u_{ce} \) is the voltage between a collector and an emitter, which depends on the collector current magnitude. Dynamic losses in IGBT-transistors are determined from the following expression [39]:

\[ E_{\text{VT,SW}} = \int_0^T \left[ E_{\text{sw}}(I_c) + E_{\text{sp}}(I_c) \right] \, dt, \]

where \( E_{\text{sw}}(I_c) \) is the energy dissipated in a transistor when switching, which depends on the magnitude of a collector’s current; \( E_{\text{sp}}(I_c) \) is the energy that dissipates in a transistor at disabling, which depends on the collector’s current magnitude.

Static losses in reverse diodes are determined from the following expression [40]:

\[ E_{\text{VD,DC}} = \int_0^T (u_{\text{vd}} i_{\text{vd}}) \, dt, \]  

where \( u_{\text{vd}} \) is the drop in voltage on a reverse diode; \( i_{\text{vd}} \) is the reverse diode current.

Dynamic losses in reverse diodes are determined from the following expression [41]:

\[ E_{\text{VD,SW}} = \int_0^T E_{\text{sw}}(i_{vd}) \, dt, \]

where \( E_{\text{sw}} \) is the reverse diode recovery energy.

Data on \( E_{\text{sw}}(i_c), E_{\text{sp}}(i_c) \) and \( E_{\text{rec}}(i_c), u_{ce}(i_c), u_{\text{vd}}(i_{vd}) \) are borrowed from a datasheet to the CM600DX-13T module.

6. A simulation model of the proposed charging station

To experimentally test the theoretical assumptions, we built a model of the proposed charging station in the MATLAB programming environment (Fig. 8).
The method for solving differential equations ODE15S (Runge-Kutta method) was applied in simulation modeling, with the permissible relative modeling error of 0.01%.

The automated control system (ACS) for the active rectifier was built on the basis of an integrated regulator with the subsequent pulse-width modulation [42, 43]. The designed ACS ensures the predefined dynamics of change in the charging voltage and current under the CC-CV modes.

The advantage of a pulse-width modulation method over hysteresis is the possibility of reducing the switching frequency of AR switches; it predetermines the reduction of dynamic losses in the switches and an increase in efficiency [44, 45]. The proposed structural diagram of the AR control system with a pulse-width modulation is shown in Fig. 9, where $I_{as}$, $I_{out}$, $U_{as}$, $U_{out}$ are the currents and voltages of battery charging, received in the feedback and in a job signal unit, respectively.

In the system of automatic regulation of voltage and current of a charge of the battery in the CC-CV mode the integrated regulator is realized. A special feature of the developed controller is that various integrated coefficients are used for setting the current and voltage modes, which improves the dynamics of control in comparison to when the CC and CV modes apply the same coefficient (Fig. 10).

The basic MATLAB models of IGBT-transistors and power diodes do not take into consideration dynamic power losses [46]. In addition, the volt-ampere characteristics of transistors in MATLAB are represented by a linear function, which causes a rather large error in the simulation of static losses. More details about the simulation of static and dynamic losses in the power switches of converters when using the methods of approximation of energy characteristics of transistors are given in ref. [47]. To obtain higher accuracy, we built a model of the counter that takes into consideration all losses in the IGBT-transistors and reverse diodes in the CM600DX-13T module (Fig. 11).

It should be noted that the specified topology of a charging station converter could also be used with alternative power sources, such as solar panels with power storages [48].

The simulation of losses in the IGBT-modules involved the polynomial approximation of graphic dependences $E_{on}(i_c)$, $E_{off}(i_c)$ and $E_{rec}(i_d)$, $u_{ce}(i_c)$, $u_{fwd}(i_d)$, which are given in datasheet (the IGBT module CM600DX-13T). The approximation results are given in the following expressions:

$$E_{on}(i_c) = 6.230414 \cdot 10^{-6} \cdot i_c^2 + 7.992571096 \cdot 10^{-3} \cdot i_c + 1.495824769248; \quad (12)$$

$$E_{off}(i_c) = 39.857 \cdot 10^{-9} \cdot i_c^2 - 55.3643 \cdot 10^{-6} \cdot i_c + 71.5372 \cdot 10^{-3} \cdot i_c + 2.97379; \quad (13)$$

$$E_{rec}(i_d) = 39.776 \cdot 10^{-9} \cdot i_d^2 - 94.602431 \cdot 10^{-6} \cdot i_d + 81.874 \cdot 10^{-3} \cdot i_d + 1.2314; \quad (14)$$

$$u_{ce}(i_c) = 0.8639 \cdot i_c^2 - 2.1104 \cdot i_c^2 + 2.363 \cdot i_c + 0.5114; \quad (15)$$

$$u_{fwd}(i_d) = 1.2433 \cdot i_d^2 - 3.0339 \cdot i_d^2 + 2.9754 \cdot i_d + 0.5624. \quad (16)$$

We verified the results of calculating losses in IGBT-modules, obtained in MATLAB modeling, using the software MelcoSim 5.1 made by Mitsubishi Electric. Error in the calculation is 2...3%.

![Fig. 9. ACS of the voltage and current of battery charge in a three-phase AR with PWM](image)

![Fig. 10. A model of the ACS of voltage and current of battery charge in a three-phase AR with PWM](image)
7. Investigating energy indicators of the proposed charging station by simulation

The simulation results, namely the oscillographs of the input current and the input voltage of an active rectifier, are shown in Fig. 12.

The charging process, namely the dynamics of change in the output voltage and current of battery charge, as well as the SOC magnitude of the battery over the entire charging interval, is shown in Fig. 13.

Fig. 12. Oscillographs of the input current and voltage of an active rectifier

Fig. 13. Charging station operation oscillograms: a — output current and setting current (CC); b — output voltage and setting voltage (CV); c — battery charge level
The result of modeling is the derived values of the efficiency parameters and the components of the energy of losses within the system sections (Table 3).

| Components of energy of losses | Energy of losses, W·s | f\text{PWM}=10\text{kHz} | f\text{PWM}=20\text{kHz} |
|-------------------------------|-----------------------|---------------------------|---------------------------|
| In a source, \(E_S\)          | 1,768                 | 1,761                     |                           |
| In line 1, \(E_{L1}\)         | 1,013                 | 1,009                     |                           |
| In a transformer, \(E_{T1}\)   | 3,313                 | 3,299                     |                           |
| In line 2, \(E_{L2}\)         | 2,664                 | 2,653                     |                           |
| In AR input inductors, \(E_{IB}\) | 3,206       | 3,192                     |                           |
| In AR switches, \(E_{IS}\)     | 7,000                 | 7,193                     |                           |
| In output capacitors, \(E_{CR}\) | 468            | 464                      |                           |
| In a battery, \(E_{Bat}\)      | 6,753                 | 6,743                     |                           |
| Total losses, \(\Delta E\)     | 26,185                | 27,034                    |                           |

Table 4 gives the values of efficiency, the power factor, and the coefficient of harmonic distortions in a charging station system at different charge currents and the frequency of PWM.

| PWM frequency, kHz | Charge current under a CC mode, A | Efficiency, % | Charging time, s,10\(^4\) | Power factor | THD, % |
|--------------------|-----------------------------------|---------------|-----------------------------|--------------|--------|
| 5                  | 150 (0.6C)                        | 95.6          | 6.55                        | 0.985        | 11.8   |
|                    | 200 (0.8C)                        | 94.8          | 5.18                        | 0.987        | 9.8    |
|                    | 250 (1C)                          | 93.9          | 4.38                        | 0.989        | 7.2    |
|                    | 300 (1.2C)                        | 93.1          | 3.84                        | 0.991        | 6.0    |
|                    | 350 (1.4C)                        | 92.2          | 3.47                        | 0.992        | 5.1    |
|                    | 400 (1.6C)                        | 91.4          | 3.2                         | 0.992        | 4.5    |
| 10                 | 150 (0.6C)                        | 95.4          | 6.55                        | 0.987        | 6.1    |
|                    | 200 (0.8C)                        | 94.5          | 5.19                        | 0.99         | 4.6    |
|                    | 250 (1C)                          | 93.7          | 4.38                        | 0.991        | 3.7    |
|                    | 300 (1.2C)                        | 92.9          | 3.85                        | 0.992        | 3.1    |
|                    | 350 (1.4C)                        | 92.1          | 3.48                        | 0.992        | 2.7    |
|                    | 400 (1.6C)                        | 91.3          | 3.2                         | 0.993        | 2.5    |

Our research shows that the efficiency of the proposed structure of the charging station is quite high. There is a clearly noticeable dynamics indicating that the higher the charge current, the less the efficiency.

8. Discussion of results of studying the proposed charging station system

The structure of a charging station based on an active three-level rectifier has been suggested in this paper. The proposed technical solution makes it possible to control the charge current and voltage; relative to known technical solutions for charging stations, it provides for the improvements in the efficiency, the power factor, and total harmonic distortion coefficient of charging stations for electric vehicles (Table 4). The efficiency of the charging station, taking into consideration the losses of power in the battery of an electric vehicle at a charge current of 150 A, is 95.6 %, the power factor (PF) of the charging station is in the range of 98.5 % to 99.3 %; total harmonic distortion coefficient lies in the range from 2.5 % to 11.8 %. Results are explained by the fact that the proposed charging station executes the charging of electric vehicles by a single-stage conversion of electricity with an active three-phase three-level four-quadrant rectifier, which also enables the power factor correction mode.

We have given a procedure for determining the integrated efficiency value of a full charging process in the reported system of a charging station for electric vehicles, taking into consideration the parameters of a power grid, transformer, power switches of the converter, and the parameters of a battery compartment in an electric vehicle. A special feature of the study is a rather precise determination of static and dynamic losses in the power IGBT modules of an active rectifier in a charging station, which was performed using the polynomial approximation of energy characteristics \(E_{on}(i_s)\), \(E_{off}(i_s)\) and \(E_{rec}(i_s)\), \(u_s(i_s), i_fas(i_s)\) – equations (12) to (16). Thus, the calculation of loss takes into consideration the peculiarities of the applied modulation algorithm, as well as all transient processes at charging.

We have given the developed simulation model of the charging station and the results of modeling, which confirmed the high energy indexes of the proposed system.

The limitation of the current study is that the designed simulation model works adequately only under operating modes while under emergency regimes, when the voltage and current values exceed the rated values, the model could prove inadequate.

The disadvantages of the study are the lack of stability analysis of the automated control system.

In further studies, it would be advisable to conduct physical experiments.

9. Conclusions

1. We have proposed the structure of a charging station for electric vehicles consisting of an input transformer, a three-level active rectifier, and a load (the equivalent model of a lithium-ion battery pack in the electric vehicle Tesla Model S), which ensures, relative to known technical solutions for charging stations, the improvements in efficiency, power factor, and total harmonic distortion coefficient. The results obtained are explained by that the proposed charging station implements a one-stage conversion of electricity in an active rectifier with the power factor correction.

2. The procedure has been given and the efficiency of the charging process in the considered system has been calculated. At different parameters of the charge current and the switching frequency, the charging station efficiency, taking into consideration the losses of power in the electric vehicle battery, lies between 91.3 % and 95.6 %.

3. The MATLAB 2017b programming environment has been used to build a simulation model of the proposed charging station. Our study into the energy performance of the charging station based on a three-level active rectifier has shown that the power factor of the charging station lies in the range from 98.5 % to 99.3 %. Total harmonic distortion coefficient in the process of charging is between 2.5 % and 11.8 %.
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