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THE IMPACT OF THE IMPLEMENTATION OF ELECTRIC TRANSPORTATION ON THE UKRAINE'S INTEGRATED POWER SYSTEM FUNCTIONING

Abstract. *The rapid development of electric transportation in the world is due to significant economic and ecological advantages. The Ukrainian government also is planning to develop a national strategy and plans for the implementation of electric transportation. But the additional load poses challenges for Ukraine's Integrated Power System. The analysis of the influence of electric transportation introduction on Integrated Power System operation would facilitate its effective government implementation. The aim of this paper was to estimate the effect of implementation volumes of electric transportation on the Integrated Power System operation, fossil fuel consumption, greenhouse gases, and pollutant emissions. A set of calculations was carried out for electric transportation volumes from 30 to 420 thousand electric vehicles by step 30 thousand based on a program and information complex simulating the operation of Ukraine's Integrated Power System, which has been developed in the Institute of General Energy of the National Academy of Sciences of Ukraine for the past few years. The calculations show that the share of nuclear power plants in Ukraine's Integrated Power System increases according to the growth of the electric vehicles fleet. Therefore, it is expected to decrease fuel consumption as well as greenhouse gases and pollutants emissions. Fuel intensity is reduced by approximately 5% for electric transportation volume of 150 thousand and approximately 8% for 300 thousand. Specific emissions decrease faster due to the ratio of coal and gas power plants. Fuel intensity considerably varies from 0.07 (Summer) to 0.15 (Winter) tce/kWh. In general, the additional load from the implementation of electric transportation positively affects the energy system of Ukraine, increasing the efficiency of its operation by reducing specific fuel consumption. It should be noted that such trends are observed exclusively for Ukraine due to the specific structure of Ukraine's Integrated Power System with the large share of nuclear energy.*

Keywords: electric transportation, Ukraine's Integrated Power System, greenhouse gas emissions, pollutant emissions.

1. Introduction

Nowadays humanity is seriously concerned about the problem of global warming and local environmental pollution. Transportation is one of the economic sectors that is facing serious challenges due to environmental concerns. These concerns include the combustion of fossil fuels, global warming, and local pollution. Implementation of battery-powered electric vehicles (EVs) could be an effective solution to mitigate environmental issues and reduce fossil fuel consumption.

The fleet of electric transportation rapidly increases worldwide [1, 2]. The number of electric vehicles per 1,000 residents in the EU significantly varies. For example, in 2020 this indicator totals 6.5 in France, 8.5 in Germany, 20.6 in Sweden and 81 in Norway. Ukraine is significantly behind in the number of electric cars (approximately 0.75 numbers of electric vehicles per 1,000 residents). Now the Ukrainian government is planning to develop a national strategy and programs for electric transportation implementation.

The common practice is to compare emissions from EVs with petrol cars using average consumption of electricity/fuel per 1 km and specific emissions of greenhouse gases (GHG) and pollutants from electricity/fuel [3–6]. Similar approach is used for evaluating economic efficiency of electric vehicles exploitation. This approach is not comprehensive. We should take into account that EVs charging is an additional load on energy system operation. Therefore electric transportation causes changes in energy system functioning and consequently changes in the emission level.

Although EVs present several environmental advantages, a massive introduction of them could create several issues in the power grid, which has been studied by several researchers [7]. For example, in [8], the impact of different penetration levels of plug-in electric vehicles in a distribution system was considered, and it was demonstrated that a significant EVs load leads to voltage drop and voltage deviations. In [9], it was demonstrated that charging EVs considerably increases the distribution load and, so, the total power losses. Furthermore, EVs charging increases the daily peak load. The authors of [10] indicated that EVs generate substantial investment costs in distribution systems, and that power losses can reach up to 40% for EVs penetration of 62%. In [11], it was exposed that EVs fast charging leads to harmonic issues and failure to respect IEEE standard limits. In [12], it was proposed that the life durations of low-voltage transformers are reduced with a high penetration of EVs.

Although EVs presents several environmental advantages a massive introduction of them could create several issues in the power grid, which has been studied by several researchers [13] for the massive introduction of EVs into power systems. For example, smart charging of EVs is an important area of study, which allows EVs users and grid operators to properly manage EVs charging profiles in order to obtain technical and economic benefits, as well as considering the specific demand-side management of EVs [14].

Some other researchers have focused on the management of EVs charging stations. In particular, it is crucial to locate the optimal placement of EVs charging stations to meet technical grid constraints, considering customer wait times [15].

Therefore the fundamental study of the influence of electric transportation implementation on Ukraine's Integrated Power System (IPS) is needed for developing strategies of EVs fleet increase. The experience of other countries is not applicable for Ukrainian circumstances. Ukraine's IPS is a unique complex system with different energy sources, partly obsolete equipment etc.

The main factors to consider are the volume of EVs and EVs charging modes. The specific feature of electric transportation is the opportunity to vary the charging load during the day due to implementing different regulatory and/or incentive measures. The influence of EVs charging modes were analyzed in [16].

The aim of the paper is to estimate the effect of implementation volumes of electric transportation on the IPS operation, fossil fuel consumption, GHG and pollutant emissions.

The study was carried out for the pre-war state of the IPS. Now the IPS has suffered huge damage due to the war with the Russian Federation. Nevertheless, the IPS will definitely be restored and updated in the post-war period. It should be expected nuclear and hydropower will recover to the same extent. TPPs are likely to be equipped with new generating equipment and exhaust gas purification systems. At the same time, the IPS operation characteristics, specific fuel consumption and emission factors will change. In such cases it is necessary to re-calculate relevant values.

2. Methodology

The author uses a program and information complex simulating the operation of Ukraine's Integrated Power System developed in the General Energy Institute of National Academy of Sciences of Ukraine [17].

This complex is based on a non-linear mixed integer least-cost dispatch model. It contains information of all power units in the Ukraine’s IPS mentioned below.

Nuclear energy provides a reliable base load and covers more than half of the electricity production in Ukraine (55.5 in 2021). There are four nuclear power plants (NPPs) in Ukraine with a total installed capacity of 13835 megawatt (MW) (15 reactors in total, including 13 reactors with a capacity of 1000 MW and two reactors with a capacity of 415 MW and 420 MW, respectively) [18].

At the beginning of 2022, there were 12 thermal power plants (TPPs) in Ukraine with a total installed power capacity of 21.5 gigawatt. Most TPPs are using coal as a primary fuel. In 2021, the TPPs' share in electricity production was 23.8% [19].

At the beginning of 2022, the total installed power capacity of combined heat and power plants (CHPs) was 6.1 GW. Most CHPs are using natural gas as a primary fuel. In 2021 the share of CHPs and cogeneration units in electricity production was 5.5%.

At the beginning of 2022, there were ten large hydropower plants (HPPs) with a total installed power capacity of about 4.7 GW (101 units in total) and three pumped storage plants (PSPs) with an installed capacity of 1.5 GW (11 units ranging from 33 MW to 324 MW per unit). Hydropower plays a crucial role in the functioning of the Ukrainian power system, as HPPs and PSPs are the main providers of auxiliary services to meet the peak demand of the power system and balance Renewable Energy [20]. PSPs also contribute to flattening the night "gaps" of electricity consumption. In 2021, the share of HPPs and PSPs in electricity production was 5.8% and 0.8%, respectively.

The photovoltaic (PV) sector had the highest growth rate among other renewable energy sources (RES) in Ukraine during 2019–2021. At the beginning of 2022, the total installed PV capacity reached 7.6 GW or 80% of the total RES installed capacity in Ukraine (including 45,000 prosumer installations with a total capacity of 1.2 GW) [21].

At the beginning of 2022, Ukraine's total installed capacity of wind power plants (all onshore) was 1.6 GW. Almost all wind power plants in Ukraine were built in the southern regions near the Azov and Black seas coasts (Kherson and Zaporizhzhia regions), where natural conditions for wind power plants are the most favorable.

A set of calculations was carried out for electric transportation volumes from 30 to 420 thousands by step 30 thousands.

3. Results

Fig. 1 shows the Structure of Ukraine's IPS for the different volumes of electric transportation. The share of nuclear power plants increases according to the growth of EVs fleet. This dependence is not linear because NPP units can only operate at full capacity. The shares of coal and gas TPPs and CHPs are not monotonic, but fluctuate over the entire range. Therefore it is expected to decrease fuel consumption as well as GHG and pollutants emissions.

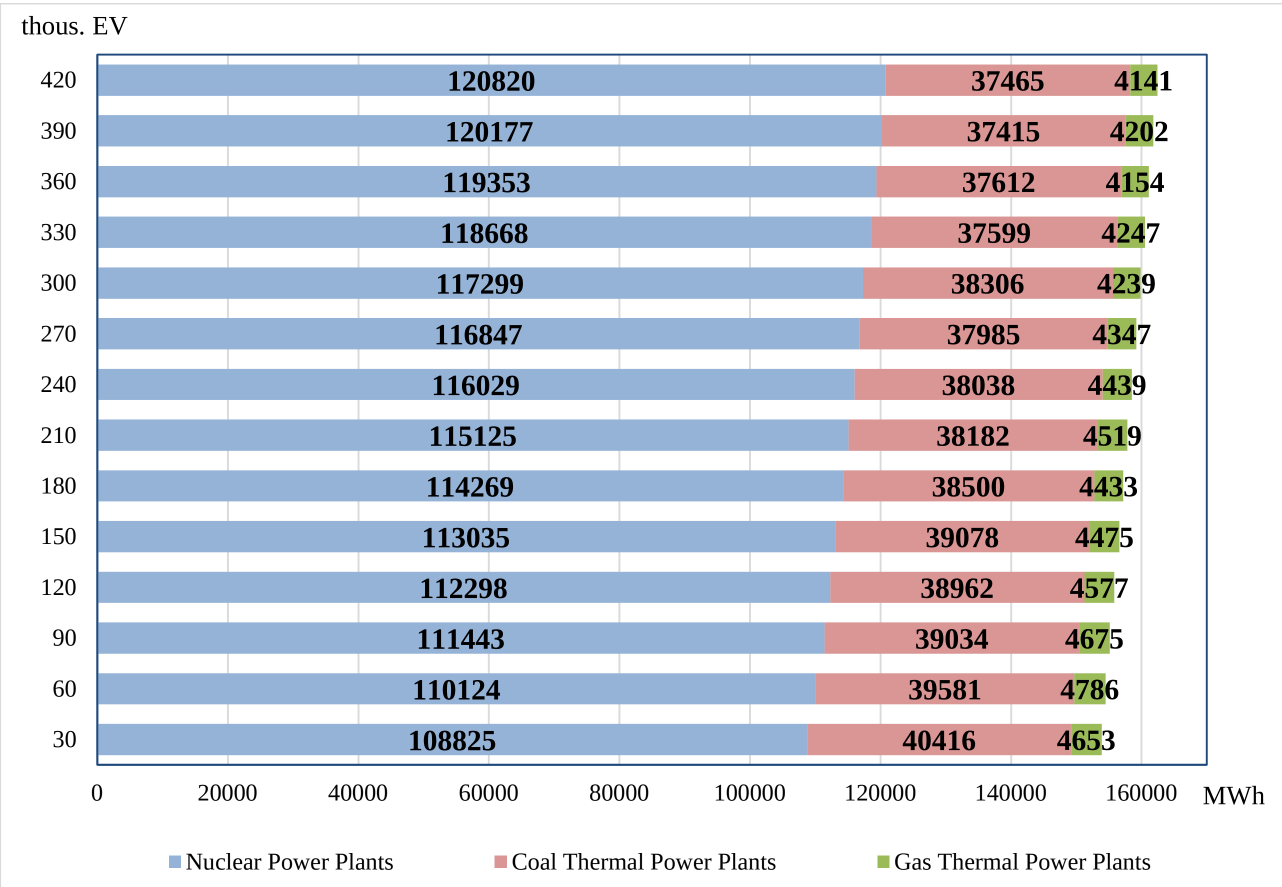

Fig. 1. Structure of Ukraine's IPS for the different volumes of electric transportation

Fig. 2 illustrates this fact. Fuel intensity is reduced by approximately 5% for EVs volume 150 thousands and approximately 8% for EVs volume 300 thousands. Specific emissions decrease faster due to the ratio of coal and gas power plants.

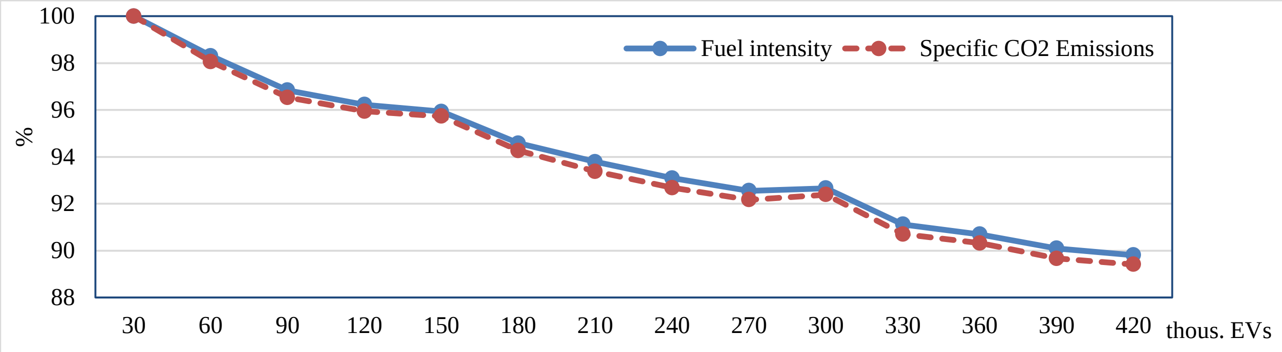

Fig. 2. Dependence of fuel intensity and specific CO_2 emissions on the volumes of electric transportation

Table 1 includes more detailed information about fuel consumption, GHG and pollutants emissions for the different volumes of electric transportation. Fig. 3 and Fig. 4 show the detailed structure of IPS (including renewable energy resources) for the EVs volumes 150 and 300 thousands correspondingly.

Table 1. Fuel combustion, fuel intensity, GHG and pollutants emissions for the different volumes of electric transportation

Volume of EVs, thous.	Electricity produced, MWh	Fuel combusted, thous. tce	Fuel intensity, tce/kWh	CO_2 Emissions, Gg	Specific CO_2 Emissions, Gg/kWh	SO_2 Emissions, Gg	NO_x Emissions, Gg	Dust, Gg
30	190881	22231.9	0.116	55437.3	0.290	148.60	33.73	7.80
60	191558	21932.3	0.114	54556.1	0.285	145.60	33.33	7.64
90	192234	21681.4	0.113	53893.8	0.280	143.67	32.96	7.54
120	192910	21619.6	0.112	53753.1	0.279	143.36	33.00	7.52
150	193587	21629.5	0.112	53822.9	0.278	143.77	33.04	7.54
180	194263	21399.3	0.110	53184.7	0.274	141.76	32.61	7.43
210	194940	21294.6	0.109	52866.5	0.271	140.64	32.42	7.37
240	195616	21209.6	0.108	52655.8	0.269	140.09	32.40	7.35
270	196292	21159.8	0.108	52546.3	0.268	139.87	32.42	7.33
300	196969	21257.1	0.108	52850.9	0.268	140.98	32.66	7.39
330	197645	20975.7	0.106	52066.4	0.263	138.50	32.17	7.26
360	198322	20949.2	0.106	52022.7	0.262	138.49	32.27	7.26
390	198998	20881.9	0.105	51820.9	0.260	137.79	32.17	7.22
420	199674	20886.1	0.105	51851.7	0.260	137.97	32.17	7.23

The Table 2 and Table 3 illustrate the behavior of fuel intensity and emissions throughout the year for the EVs volumes 150 and 300 thousands correspondingly. Fuel intensity considerably varies from 0.07 (Summer) to 0.15 (Winter) tce/kWh. The larger share of NPPs (Fig. 3 and Fig. 4) explains this trend. The minimal values are observed in Summer when the share of electric transportation additional load is bigger than in Winter.

In general, the additional load from the implementation of electric transportation positively affects the energy system of Ukraine, increasing the efficiency of its operation by reducing specific fuel consumption. It should be noted that such trends are observed exclusively for Ukraine due to the specific structure of Ukraine's IPS with the large share of nuclear energy.

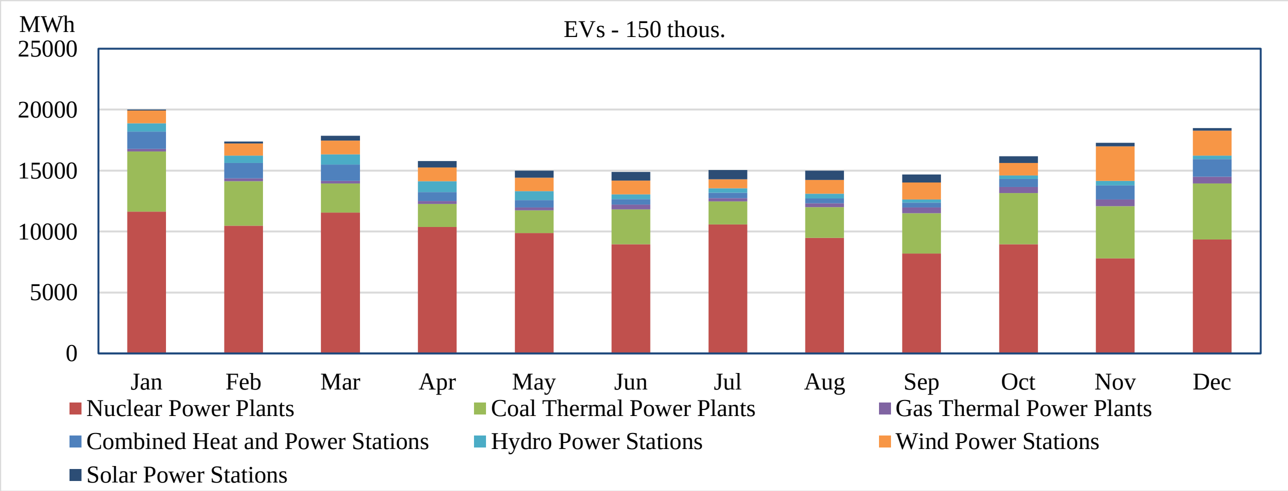

Fig. 3. Detailed structure of Ukraine's IPS for the electric transportation 150 thousand EVs

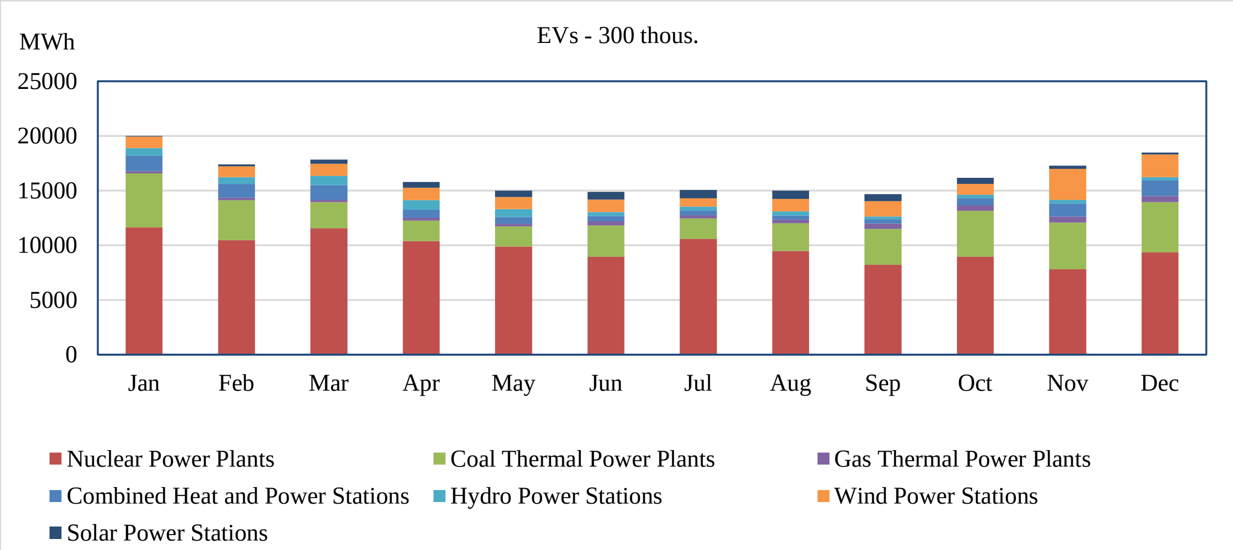

Fig. 4. Detailed structure of Ukraine's IPS for the electric transportation 300 thousand EVs

Table 2. The behavior of fuel intensity and carbon dioxide emissions throughout the year for the electric transportation 150 thousand EVs

Month	Electricity produced	Fuel combusted	Fuel intensity	CO_2 Emissions	Specific CO_2 Emissions	SO_2 Emissions	NO_x Emissions	Dust
Units	MWh	thous. tce	tce/kWh	Gg	t/kWh	Gg	Gg	Gg
Jan	19689	2559.3	0.13	6361	0.32	16.98	4.21	0.89
Feb	17089	2033.8	0.12	4966	0.29	12.85	3.23	0.67
Mar	17514	1569.7	0.09	3650.9	0.21	8.6	2.39	0.44
Apr	15475	1149.6	0.07	2764	0.18	6.94	1.7	0.36
May	14648	1097.2	0.07	2677.7	0.18	6.91	1.66	0.36
Jun	14632	1371.4	0.09	3464.9	0.24	9.48	2.08	0.5
Jul	14699	1087.1	0.07	2731.2	0.19	7.41	1.64	0.39
Aug	14636	1314.4	0.09	3362.2	0.23	9.39	1.98	0.5
Sep	14325	1862.1	0.13	4847.1	0.34	13.91	2.77	0.74

Continuation of Table 2.

Month	Electricity produced	Fuel combusted	Fuel intensity	CO_2 Emissions	Specific CO_2 Emissions	SO_2 Emissions	NO_x Emissions	Dust
Oct	15819	2323.8	0.15	5984.2	0.38	16.9	3.5	0.89
Nov	16927	2502.7	0.15	6215.7	0.37	16.54	3.77	0.87
Dec	18133	2758.3	0.15	6797.9	0.37	17.86	4.12	0.94

Table 3. The behavior of fuel intensity and carbon dioxide emissions throughout the year for the electric transportation 300 thous. EVs

Month	Electricity produced	Fuel combusted	Fuel intensity	CO_2 Emissions	Specific CO_2 Emissions	SO_2 Emissions	NO_x Emissions	Dust
Units	MWh	thous. tce	tce/kWh	Gg	t/kWh	Gg	Gg	Gg
Jan	19976.59	2666.99	0.13	6680.44	0.33	18.08	4.47	0.95
Feb	17347.97	2092.01	0.12	5144.45	0.30	13.48	3.41	0.70
Mar	17801.05	1631.29	0.09	3828.86	0.22	9.20	2.51	0.48
Apr	15753.15	1166.19	0.07	2807.86	0.18	7.07	1.75	0.37
May	14935.48	1083.40	0.07	2649.02	0.18	6.86	1.64	0.36
Jun	14909.92	1470.66	0.10	3743.35	0.25	10.37	2.24	0.55
Jul	14986.72	1029.92	0.07	2567.61	0.17	6.87	1.56	0.36
Aug	14923.47	1277.13	0.09	3267.70	0.22	9.13	1.91	0.48
Sep	14603.13	1645.90	0.11	4233.51	0.29	11.92	2.40	0.63
Oct	16106.37	2133.35	0.13	5454.39	0.34	15.22	3.17	0.80
Nov	17204.80	2407.21	0.14	5958.66	0.35	15.77	3.64	0.83
Dec	18420.15	2653.03	0.14	6515.03	0.35	17.01	3.96	0.89

4. Conclusions

The rapid development of electric transportation in the world is due to significant economic and ecological advantages. The Ukrainian government also is planning to develop a national strategy and plans for the implementation of electric transportation. But the additional load poses challenges for Ukraine’s Integrated Power System. The analysis of the influence of electric transportation introduction on IPS operation would facilitate its effective implementation in Ukraine.

This paper analyzed the influence of electric transportation volumes on fuel consumed by IPS, fuel intensity and emissions levels.

A set of calculations was carried out for electric transportation volumes from 30 to 420 thousands by step 30 thousands based on a program and information complex simulating the operation of Ukraine's Integrated Power System, which has been developing in the General Energy Institute of National Academy of Sciences of Ukraine.

The calculations show that the share of nuclear power plants in the Ukraine’s IPS increases according to the growth of EVs fleet. Therefore, it is expected to decrease fuel consumption as well as GHG and pollutants emissions. Fuel intensity is reduced by approximately 5% for EVs volume 150 thousands and approximately 8% for EVs volume 300 thousands. Specific emissions decrease faster due to the ratio of coal and gas power plants. Fuel intensity considerably varies from 0.07 (Summer) to 0.15 (Winter) tce/kWh.

In general, the additional load from the implementation of electric transportation positively affects the energy system of Ukraine, increasing the efficiency of its operation by reducing specific fuel consumption. It should be noted that such trends are observed exclusively for Ukraine due to the specific structure of Ukraine's IPS with the large share of nuclear energy.

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ВПЛИВ ОБСЯГІВ ВПРОВАДЖЕННЯ ЕЛЕКТРОТРАНСПОРТУ НА ФУНКЦІОНУВАННЯ ОБ'ЄДНАНОЇ ЕНЕРГЕТИЧНОЇ СИСТЕМИ УКРАЇНИ

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Анотація. *Стрімкий розвиток електротранспорту у світі зумовлений значними економічними та екологічними перевагами. Український уряд також планує розробити національну стратегію та плани впровадження електротранспорту, але додаткове навантаження створює виклики для Об'єднаної енергосистеми України. Аналіз впливу впровадження електротранспорту на функціонування ОЕС сприяв би ефективній реалізації намірів уряду. Метою даної роботи було оцінити вплив обсягів впровадження електротранспорту на роботу Об'єднаної енергосистеми, споживання викопного палива, парникові гази та викиди забруднюючих речовин. Проведено комплекс розрахунків для обсягів електротранспорту від 30 до 420 тис. електромобілів кроком 30 тис. на основі програмно-інформаційного комплексу моделювання роботи ОЕС України, який розробляється в Інституті загальної енергетики Національної академії наук України. Розрахунки свідчать, що частка атомних електростанцій в Об'єднаній енергосистемі України зростає відповідно до зростання парку електротранспорту, тому очікується зменшення споживання палива, а також викидів парникових газів і забруднюючих речовин. Паливоємність зменшується приблизно на 5% для електротранспорту обсягом 150 тис. і приблизно на 8% для 300 тис. Питомі викиди зменшуються швидше за рахунок співвідношення вугільних і газових електростанцій. Паливоємність значно коливається від 0,07 (літо) до 0,15 (зима) т.у.п./кВт·год. Загалом додаткове навантаження від впровадження електротранспорту позитивно впливає на енергетичну систему України, підвищуючи ефективність її роботи за рахунок зменшення питомих витрат палива. Слід зазначити, що такі тенденції спостерігаються виключно для України через специфіку структури її ОЕС з великою часткою атомної енергетики.*
Ключові слова: електричний транспорт, Об'єднана енергетична система України, викиди парникових газів, викиди забруднюючих речовин.

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