UDC 621.3.072.8:629.33

Yu. V. Khatskevych, Cand. Sc. (Tech.), Assoc. Prof.,
I. M. Lutsenko, Cand. Sc. (Tech.), Assoc. Prof.,
A. V. Rukhlov, Cand. Sc. (Tech.), Assoc. Prof.

National Mining University, Dnipro, Ukraine, e-mail: 7169103@i.ua

PERSPECTIVES OF LOAD MANAGEMENT IN ENERGY SYSTEM WITH THE HELP OF ELECTRIC VEHICLES

Ю. В. Хацкевич, канд. техн. наук, доц.,
І. М. Луценко, канд. техн. наук, доц.,
А. В. Рухлов, канд. техн. наук, доц.

Державний вищий навчальний заклад „Національний гірничий університет“, м. Дніпро, Україна, e-mail: 7169103@i.ua

ПЕРСПЕКТИВИ РЕГУЛЮВАННЯ ГРАФІКА НАВАНТАЖЕНЬ ЕНЕРГОСИСТЕМИ ЗА ДОПОМОГОЮ ЕЛЕКТРОМОБІЛІВ

Purpose. Determination of expediency of the use of electric vehicles as load-regulators on the basis of analysis of load diagrams and existing energy tariffs for Ukraine and some European countries; definition of the main technical requirements for implementation of the regulation.

Methodology. Analysis of the actual load diagrams for national energy systems of Ukraine and European countries. Development of principal schemes and decisions for implementation of electric vehicles into the power supply system of Ukraine.

Findings. Expediency and prospects of the use of electric vehicles as load-regulators in the nets 0.4 kV of suburban areas in Ukraine are substantiated. Methodology for selecting appropriate capacity and location for charging/generating stations is proposed. It is shown that development and implementation of financial stimulation tools for owners of electric cars to rationalize connections of the vehicles to the greed will contribute to increasing quantity of electric cars, improving efficiency of national power supply system operation and enhancing of ecological state in the country.

Originality. New methodology approaches to modernization of power supply system of Ukraine in order to use electric vehicles as load-regulators are developed.

Practical value. Economical expediency of the use of electric cars as load-regulators is substantiated both for energy system and for car owners. Schemes of electric vehicles connection for generation of power to the greed are proposed and analyzed.

Keywords: *load management, energy system, electric vehicles, charging/generating station*

Introduction. One of the most important directions in development of transportation system is gradual replacement of vehicles with internal combustion engines to electric vehicles in order to reduce CO_2 emissions. Many European countries support development of electric vehicles at legislation level and determine requirements and conditions of realization of electromobility integration [1]. Increasing quantity of electric vehicles makes them an important component of the power supply system at the regional level and at the level of the whole country. Development of power systems and Smart Grid technologies for electric vehicles (EV) should take into account requirements and limitations of charging modes of EV batteries for effective integration to the hybrid power supply system [2, 3].

Integration of large quantities of electric vehicles into the grid brings new opportunities in providing flexibility in power management in distribution networks. In particular, beyond their typical roles as loads to a power system, electric vehicle battery systems can serve as distributed energy storage for grid power management. Charge of vehicles can be carried out mainly during the off-peak period of time and generation of energy from the battery to the grid – at peak periods of time. Such a load management allows utilities to reduce demand for electricity during peak usage times, which can, in turn, eliminate the need for peaking power plants and help reduce harmful emissions, since peaking plants or backup generators often produce more emission and have less efficiency than base load power plants. This task is relevant for many European countries and for Ukraine as well.

Sufficient quantity of electric vehicles working together for load management could cause the same advantages for a power grid as a pumped storage power station including reduction of CO_2 emissions [4]. Managed properly, electric vehicles can potentially improve the reliability and stability of utility grids, support integration of renewable energy generations, and improve overall system efficiency, leading to the concept of vehicle-to-grid.

Realization of this concept requires analyses of electric loads of a country to determine the expediency of load management, estimation of economic feasibility for the energy system, environment and owner of electric cars, development of technical solutions for vehicle-to-grid energy transmission and ICT system for charge-discharge processes, working out of charging station topology and evaluation of necessary changes of grid elements.

Analysis of the recent research and publications. In 2012 aspects of interrelations of Smart Grids in power supply systems and dissemination of electric transport were discussed at International Transport Forum in Leipzig [3]. Electric cars are considered as possible sources for load management. It is stressed that successful realization of this approach needs development of intellectual systems for power consumption control that enable effective modes of energy consumption and generation to grid.

There is a problem of development of global standards for smart grids with EVs as load-regulators and unification of technical decisions in this field that has to be solved in the near future.

In the research studies [5, 6] aspects of effective control for charging/generating processes with the use of Smart Grid + Intelligent energy management technologies in the places of EV connection to the grid are considered. Such technologies are used to balance consumption and generation of electric power in order to reduce peak loads in a power supply system and therefore to decrease global cost of electric energy (for electric vehicle owners and for other consumers). Attention is paid to development of intellectual energy management system, selection of parameters and thresholds depending on particular installation, technical parameters, legislation aspects, characteristics of EV, etc. These parameters should be taken into account while developing such systems for conditions of Ukraine as well.

Investigations of typical routes and daily use of electric vehicles are represented in [7]. On the basis of worked out EV use templates, smart algorithms of charging/generating processes control were developed. There is underlined necessity of adaptation of the algorithms according to particular conditions of the power system operation in the place of EV connection in order to improve working parameters of grids. For this purpose methods for linear programming, genetic algorithms could be used.

Using batteries of electric vehicles as electric energy sources for covering peak loads in the power supply system has economic feasibility for the owner of the vehicle that depends on tariffs, legislation and technical requirements of the country [8].

The effect of EV use on the existing power supply system including operation modes and deterioration level of transformers, which is necessary to take into consideration in the planning of topology and placement of charging/generating stations in the grid is investigated in [9]. It is necessary additionally to pay attention to carrying capacity of power lines, commutation equipment, metering and controlling devices in the grids with electric vehicles.

Thus, the **objective of the work** is determination of expediency of the use of electric vehicles as load-regulators on the basis of analysis of load diagrams and existing energy tariffs for Ukraine and some European countries; definition of the main technical requirements for implementation of the regulation.

Depending on structure of generating capacities in the country the need in load-regulators can vary significantly. In the work energy system of Ukraine and some European countries where electric transport is implemented will be analyzed.

Presentation of the main research. *Ukraine.* The total installed capacity of power plants in Ukraine at the end of 2014 was 55.1 GW, of which 62.2 % came from thermal power plants and combined heat and power station, 25.1 % – nuclear power plants, 10.6 % – hydro power plants and pumped storage power plant, 2.1 % – power stations that run on alternative energy sources (wind farms, solar, biomass).

The structure of the generating capacity of the united energy system (UES) of Ukraine to ensure effective regulation of frequency and power in the power system is not optimal, because of these factors:

- a significant share of nuclear power plants (electricity generation to 60 %), which, according to the technological regulations of their operation, are base load power plants;
- a decrease in maneuverability of thermal power units that run on solid fuels;
- accelerated development of generation facilities based on alternative sources that causes variability in power generation.

Covering of daily load curve of UES of Ukraine is determined by the following factors:

- significant variations in power demand over time;
- the structure of generation capacity;
- maneuvering capabilities of generating equipment;
- carrying capacity of power lines.

Daily consumption curve for the UES of Ukraine for different periods of the year is characterized by significant variations (mainly – due to the increase in domestic and municipal electricity), which has the annual trend towards an increase (Fig. 1). The most important share of maneuvering component is covered by thermal power plant units. The value of this component varies from 4–5 (in summer) to 6–8 GW of capacity (in winter). It is necessary to stress that these operation modes lead to increased deterioration of equipment, fuel usage and harmful emissions.

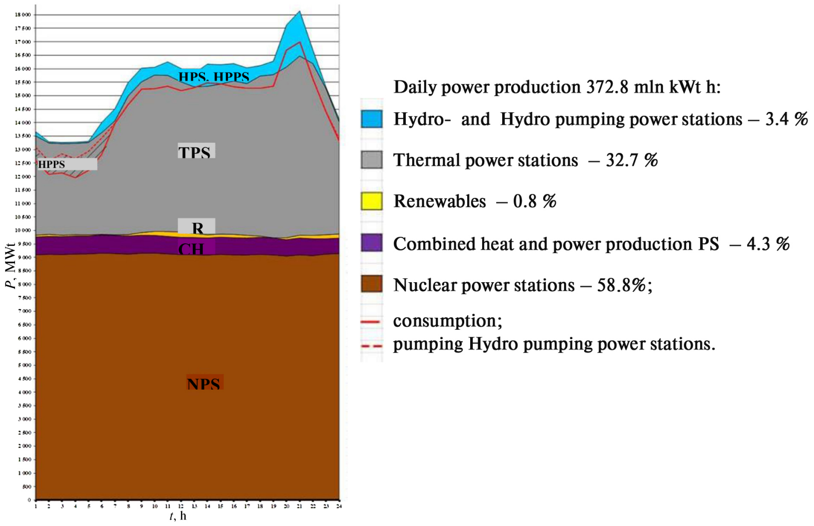

Fig. 1. Daily power demand in the UES of Ukraine on 09.09.2015

Therefore development of load management system on the basis of electric vehicles is important for Ukraine.

Germany. Analysis of load diagram of the country evidences irregularity of power demand during the day and significant differences between load on week days and weekends. The main energy sources to cover the irregular part of the load diagram are hard coal and gas heat power plants and pumped storages (Fig. 2).

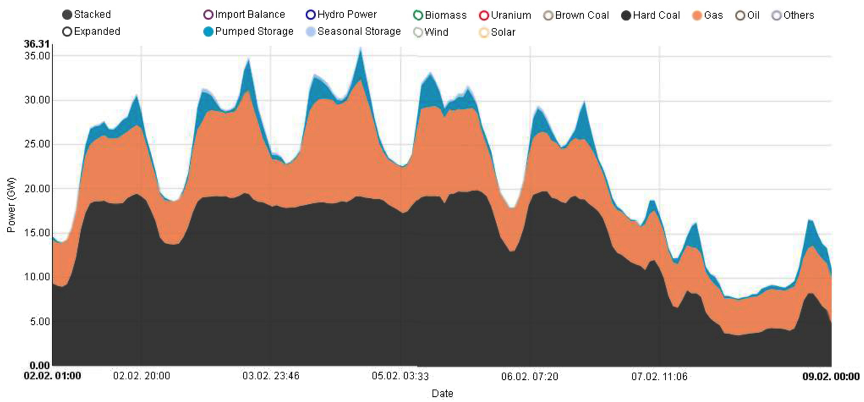

Fig. 2. Sources used to cover irregular part of power demand in German energy system, February 2^{nd} till 8^{th}, 2015

The configuration of the load diagram confirms the necessity to replace peak coal and gas power sources by cleaner and more effective technologies such as EVs.

France. Power demand changes significantly during the day and during working week (Fig. 3). Each day has morning and evening peaks of power consumption. The main energy sources of the country's energy system that are used for producing energy at peak periods are heat power plants of fossil gas, hydro and hydro pumping generation. Power plants on gas fuel ensure about 5–8 GW of electric power. The replacement of these sources by EVs will bring ecological and economic benefits.

Spain. Electrical load of the power system varies during the day (Fig. 4). The main power sources that provide power supply at peak periods are mostly the same as for Germany – coal heat power plants, power plants with combined production of heat and electricity and hydro power stations. In the winter time the level of the irregularity of power load in the country is higher and the rate of using heat power plants on fossil fuels increases.

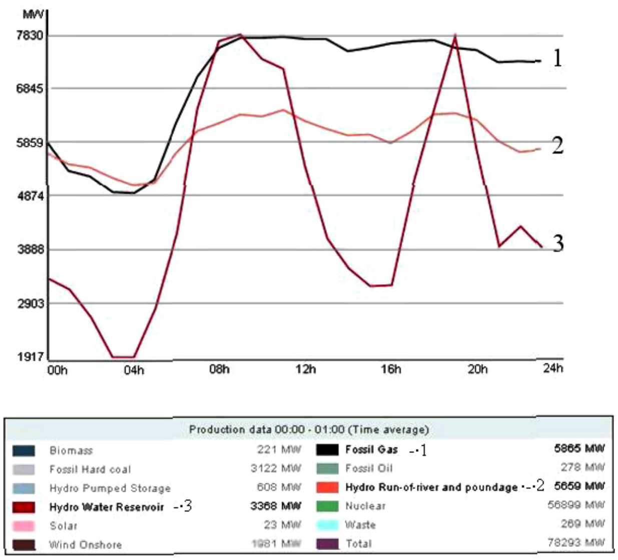

Fig. 3. The main sources to cover irregular power load in the energy system of France, February 4^{th}, 2015

As we can see use of the traditional fossil fuel could be reduced due to load management with the help of electric transport.

Thus, on the basis of analysis of load diagrams and power sources, conclusion is made that for each country the use of electric transport including electric cars for load management in the system will lead to decrease in the fossil fuels use and elimination of the dangerous emissions caused by it. The higher is the rate of load irregularity the higher is importance of the management.

In Ukraine, 6–8 GW capacity of coal heat power plants which are used now to cover peaks in power demand is to be replaced by environmentally friendly sources. Capacity of peak power plants in Germany that use fossil fuel (mainly hard coal and gas) reaches 30 GW, in France – 8 GW, in Spain – 10 GW. This power capacity could be partly replaced by electric vehicles working in mode of the power load management.

Economic feasibility for power system. Quantity of energy that could be generated to the grid by electric vehicles for load management depends on quantity and power capacity of their batteries.

Approximate quantity of electric cars that are necessary to cover 1 GW of power capacity in the grid during a peak period is equal to

$$N_{EV} = \frac{P_m}{KP_{EV}} = \frac{10^9}{0,6 \cdot 6700} \approx 250000, \qquad (1)$$

where $P_{EV} \approx 6700$ W is approximate power capacity of the electric car battery that takes part in generation of energy into grid (that is equal to generating of power to the grid from battery with 40 kWh during 6 hours); K is the coefficient that takes into account diversity of participation of electric vehicles into load management.

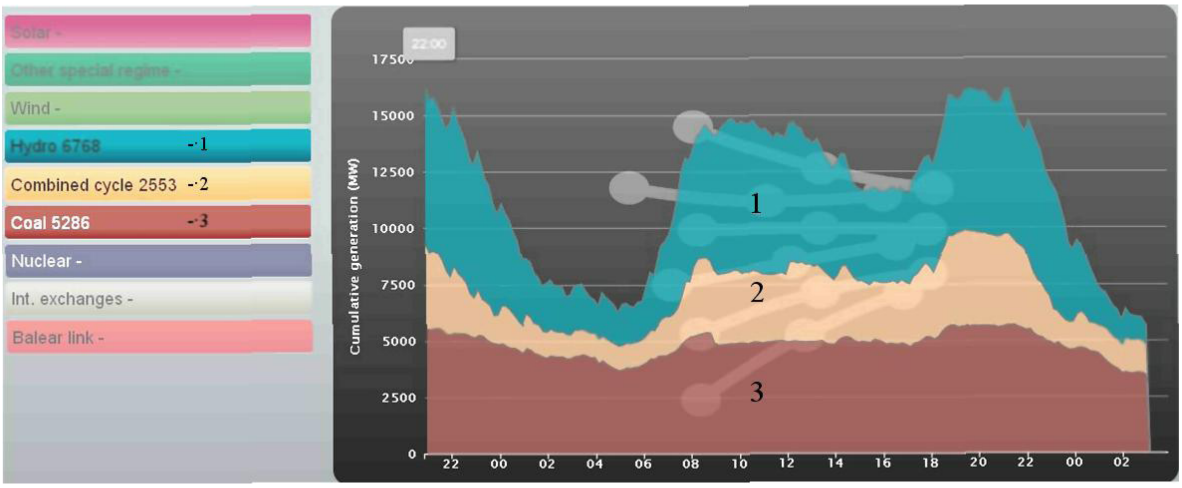

Fig. 4. The main sources to cover irregular power load in the energy system of Spain, February 4th, 2015

The target EV fleet in Europe by 2020 will make 4 million cars: 1.8 million all-electric vehicles and 2.2 million hybrid EV [10]. This quantity of EV used for load management will allow covering 8–10 GW of peak power capacity and therefore reducing required capacity of power plant on fossil fuels. Planned targeted quantity of electric cars in Ukraine by 2020 is to make 250 thousand that is enough to cover 1 GW of power.

Ecological benefit of this approach is the decrease in dangerous emissions due to elimination of fossil fuel burning at peak heat power plants. First of all, it is necessary to reduce the use of coal fuel, because it causes the highest level of harmful emissions.

Estimated amount of electric power generated by cars during peaks in the power supply system due to discharge of the batteries into the grid is, kWh per day

$$\Delta W_{EV} = KW_{EV}N_{EV} = 0.6 \cdot 40 \cdot 250000 = 600 \cdot 10^4, \quad (2)$$

where W_{EV} is average power capacity of an electric car battery, kWh.

Roughly the same amount of electric energy will be consumed during night hours from power system for charging batteries. However, the power stations working during nights in a regular mode provide significantly less specific consumption of fuel than working in peak mode.

For conditions of the power supply system of Ukraine growth of specific fuel consumption by heat power plants in peak modes per 1 kWh of produced energy (in comparison with operation in a regular mode) is $\Delta g_{sf} \approx 70$ g of standard fuel. Thus, daily reducing of standard fuel use in heat power plants due to load management will be, tons.

$$\Delta G_{sf} = \Delta W_{EV} \Delta g_{sf} = 600 \cdot 10^4 \cdot 70 = 420. \qquad (3)$$

Taking into account heat equivalent of hard coal with the combustion heat of 27 MJ/kg the yearly reduction of consumption will be equal to $\Delta G_c = 420 \cdot 365 \cdot 29.3/27 \approx 66.4 \cdot 10^3$ tons. With average coal price of 80 Euros per ton total cost of saved amount of coal will be about 5.3 million Euro per year.

As a result of the covering of heat power plants capacities working in the peak operation mode harmful emission will be reduced. Based on the specific amount of emissions (g) for generating of 1 kWh of power energy at heat power plant yearly emissions reduction will be, thousand tons:

- SO_2: $\Delta G = 1.5 \cdot 600 \cdot 10^4 \cdot 365 \approx 3.3$;
- NO_2: $\Delta G = 0.7 \cdot 600 \cdot 10^4 \cdot 365 \approx 1.5$;
- CO_2: $\Delta G = 900 \cdot 600 \cdot 10^4 \cdot 365 \approx 1900$.

For European countries' conditions expected elimination of harmful emissions will be less than for Ukraine because of the use of more environmentally friendly and up-to-date technologies for power generation.

Benefits for owners of electric cars. It is necessary to create economic benefits for owners of electric cars to stimulate them to take part into load management. Currently the easiest way to do it is to provide different tariffs for energy consumption and generation according during a day.

For example, in Ukraine for domestic consumers there is tariff with different levels of costs during the day: for peak-off period (23^{00}–7^{00}) average cost of electric energy is T_{min} = 0.022 €/1 kWh; for peak period (8^{00}–11^{00}; 20^{00}–22^{00}) – T_{max} = 0.083 €/1 kWh. So during peak-off periods battery of electric car consumes about W_{EV} = 40 kWh of energy from grid for charging and during peak period generates this amount of energy into the grid back.

Economic benefit for the owner of an electric car from participation in load management in power system is, € per day

$$\Delta C = W_{EV} T_{max} - W_{EV} T_{min} = 40 \cdot 8.3 - 40 \cdot 2.2 = 2.44. \quad (4)$$

The participation in load management with the described operational mode during 150 days per year will cause benefit of $\Delta C_{year} = 150 \Delta C = 150 \cdot 2.44 = 366$ € per year.

It is necessary to stress that power energy tariffs have stable tendency to growth, therefore economic benefits for owners will increase as well.

In the European countries there are also power tariffs with differentiation of the rate during the day. In Germany power tariffs depend on generation and transportation companies and vary within the country. For estimation of economic benefits approximate values of 0.199 €/1 kWh for night (peak-off period from 22^{00} till 6^{00}) and of 0.253 €/1 kWh for day (peak period from 6^{00} till 22^{00}) are assumed. Using formula (4) we obtain daily benefit amounts of 2.2 € and yearly – 330 €.

In France there are tariffs for peak and off-peak consumption that vary for different power supply companies. For calculations off-peak tariff of 0.104 €/1 kWh from 23^{00} till 6^{00} and tariff of 0.151 €/1 kWh for peak period from 6^{00} till 23^{00} were taken. Based on these data daily economic benefit of an electric car owner due to use of the car in load management could reach 1.9 € and yearly – 285 €.

In Spain differentiation of tariffs exists as well. For estimation of economic effect, off-peak tariff 0.096 €/1 kWh from 23^{00} till 13^{00} in summer and from 22^{00} till 12^{00} in winter and 0.181 €/1 kWh for peak period from 13^{00} till 23^{00} in summer and from 12^{00} till 22^{00} in winter were taken. This allows the owner of EV to receive 3.4 € per day and 510 € yearly for load management with electric car.

It is important to underline that to attract electric car owners to manage the load in power supply system other tools could be used as well: green tariffs for generation of energy into the grid during peak hours, bonuses for signing the contract for load management, decrease in cost of consumed energy, etc.

For implementation of the proposed approach to the load management a set of problems should be solved.

1. Allowing owners of electric vehicles to take part into load management process at the legislation level.
2. Developing business models and special tariffs for attracting owners of EV.
3. Developing and implementing smart metering devices.
4. Calculation of characteristics and selection of the distribution grid equipment taking into consideration effect of electric vehicles during charging and generation processes.
5. Selecting the optimal topology for charging/generating points for EV.
6. Developing energy management system for distribution network.
7. Power quality control for generation to the grid.
8. Selection of equipment for generating points.

Enhancing of energy characteristics of batteries, development of systems for intellectual control of charging/discharging processes taking into account planned mileage of a car will stimulate implementation of the described approach to load management.

Further some of the aforementioned technical aspects of load management with electric vehicles are considered.

Selection of the power capacity and location of charging/generating points depends on parameters and regime of the grid. The main technical characteristics that will affect the selection are:

- power carrying capacity of distribution network that receives energy generated by EVs;
- rated level of voltage deviation;
- load and overload capacity of transformers feeding distribution grid with EVs;
- level of higher harmonics generated into the grid by invertors of EVs during discharge into the grid.

Depending on location of cars during the peak period in power system 2 schemes of connection of electric cars to grid should be analyzed.

1. Electric cars (their quantity could be from some items to some hundreds) are located at public parking that could be used for receiving of energy from EVs and transmission into the greed and for charging of EVs as well. Simplified scheme of connection is represented in Fig. 5.

To provide reliability of power supply such a station should have 2 reserving transformers with separate feeding lines (line 1 and 2 in Fig. 5). Each of the lines should be able to carry maximal total capacity of the station and have separate connection to switchgear 0.4 kV of substation. This scheme of connection permits avoiding the changing of carrying capacity and configuration of other distribution lines connected to the substation. The use

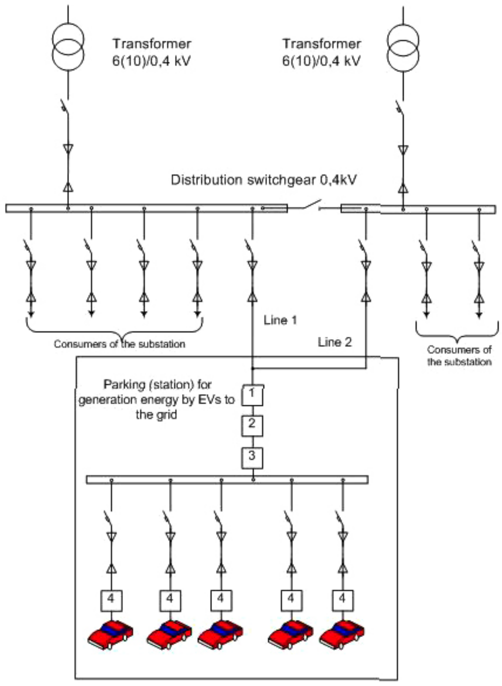

Fig. 5. Simplified scheme of EV connection to the grid at public parking:
1 – the main (bilateral) meter of electric energy; 2 – the main inverter; 3 – controlling device for charging/generating energy flows; 4 – individual bilateral meter of electric energy, controlling device for charging/discharging of EV

of dedicated lines for stations' connections will enable to optimize carrying capacity of them and to assure rated level of voltage deviation depending on power capacity of the station.

The main metering device for the whole station is needed to monitor electric energy capacity that is generated to the bass bars of the substation, individual meters – for paying to owners of electric vehicles for generation of energy into the grid.

Expedient value of power capacity to generate with this scheme of connection is limited by the value of irregular part of load diagram of the particular substation and power capacity of the transformers to which the public parking is connected. The irregular part of load diagram for any substation should be estimated in advance according to the monitoring data of a power supply company or results of energy audit before the public parking is designed. It is important to avoid the transmission of energy through transformers of the substation into higher voltage grid, because it will cause the increase in power losses and load of transmission lines. Therefore quantity of energy generated at the peak period by electric vehicles to the grid of each substation should not exceed the power consumption of the substation.

Advantages of load management using this scheme of electric vehicle connection are:

- it is quite easy to organize parking stations for electric transport using existing stations and re-equipping part of their territory for electric vehicles' needs taking into account significant rate of transport with internal combustion engines;
- use of devices for groups of EVs simplifies technical implementation of the parking stations;
- decrease in power losses in transformers and power transmission lines of middle and higher voltage;
- absence of countermoving energy flows in the lines of particular consumers;
- simple algorithms for control of energy supply and generation at the substation level.

Disadvantages of electric energy generation into the grid with the scheme (Fig. 5) are:

- absence of voltage regulations in the lines of consumers fed from the substation;
- no influence on power losses in the consumers' lines due to load management.

2. One or some electric vehicles are situated in the private garage (private parking) and generate energy for their own domestic consumption or consumption by the nearest consumers that are connected to the same lower voltage substation. Simplified scheme of connection is shown in Fig. 6.

Advantages of the scheme are:

- decrease in power and voltage losses in the lower voltage grid;
- reduction of voltage deviation and voltage imbalance rates.

Disadvantages of the scheme are as follows:

- if there is a need to generate energy not only for one's own consumption but also to the grid for other consumers the replacement of feeding lines according to changing of load level for transmission of generated energy is required;

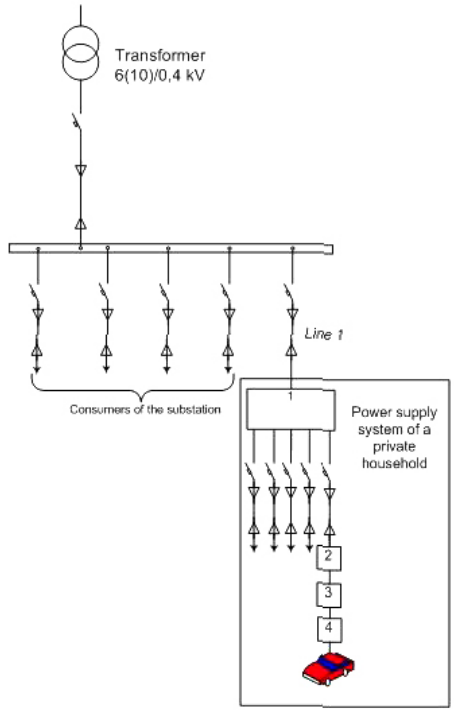

Fig. 6. Simplified scheme of electric vehicle connection to the grid in private household:
1 – distribution switchgear of the household; 2 – inverter; 3 – bilateral meter of electric energy; 4 – controlling device for charging/discharging of EV

- installation costs of the equipment should be paid by the owners of EVs, which makes this technical decision less attractive for them.

An important aspect of the approach is providing of participation in load management without changes in modes of use of electric transport as a vehicle.

Conclusions.

1. Development of legislation base and technical requirements for the using electric vehicles as load-regulators in the grid of 0.4 kV for suburban areas in Ukraine is a relevant task.

2. For effective use of EVs in power supply systems it is necessary to take into account existing characteristics of grids, level of intellectual control, topology and configuration of the grid and feeding transformers. According to these requirements two principal schemes of connection of EVs to the grid in Ukraine are proposed.

3. Development and implementation of economic stimulation of users to participate in load management will contribute to electric transport dissemination, enhancing effectiveness of the national energy system and improving ecological state in the country.

References.

1. *ISO Standards. ICS 43.120. "Electric road vehicles"* [online]. Available at: <http://www.iso.org/iso/iso_catalogue /catalogue_ics/catalogue_ics_browse.htm?ICS1 =43&ICS2=120> [Accessed 5 December 2016].

2. Hu, Z., Song, Y. and Xu, Z., 2014. Hierarchical Coordinated Control-Strategies for Plug-in Electric Vehicle Charging. In: Rajakaruna, S., Shahnia, F. and Ghosh, A., eds., 2014. *Plug In Electric Vehicles in Smart Grids*. Springer: Power Systems, Ch. 3, pp. 55–87.

3. Vardakas, J. S., Zorba, N. and Verikoukis, C. V., 2015. A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimization Algorithms. *IEEE Communication Surveys and Tutorials*, 17(1), pp. 152–178.

4. Robinson, A. P., Blythe, P. T., Bell, M. C., Hübner, Y. and Hill, G. A., 2013. Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips. *Energy Policy*, 61, pp. 337–348.

5. Project report, 2013. Demand management of electric vehicle charging using Victoria's Smart Grid [pdf]. Available at: <http://percepscion.com/wp-content /uploads/sites/3/2014/01/Demand-management-of-EV-charging-using-Victorias-Smart-Grid_May-2013.pdf > [Accessed 11 December 2016].

6. Mets, K., Verschueren, T., Turck, F. and Develder, C., 2011. Exploiting V2G to optimize residential energy consumption with electrical vehicle (dis)charging. In: *2011 IEEE First International Workshop on Smart Grid Modeling and Simulation (SGMS)*, 17 October 2011 [pdf]. Available at: <http://users.atlantis.ugent.be/cdvelder/papers/2011/mets2011sgms.pdf> [Accessed 7 December 2016].

7. Slipchenko, N. I, Pismenetskiy, V. A., Gurtovoy, M. Yu. and Makhlova, V. O., 2013. Determination of run optimum distance for electric vehicle taking into account its basic parameters, *Vostochno-Yevropeyskiy zschurnal peredovykh tekhnologiy*, 4, pp. 50–55.

8. Kara, E. C., Macdonald, J. S., Black, D., Bérges, M., Hug, G. and Kiliccote, S., 2015. Estimating the Benefits of Electric Vehicle Smart Charging at Non-Residential Locations: A Data-Driven Approach. *Applied Energy*, 155, pp. 515–525.

9. Godina, R., Rodrigues, E., Matias, J. and Catalão, J., 2015. Effect of Loads and Other Key Factors on Oil-Transformer Ageing: Sustainability Benefits and Challenges. *Energies*, 8, pp. 12147-12186 [pdf]. Available at: <http://www.mdpi.com/1996-1073/8/10/ 12147/pdf/> [Accessed 3 December 2016].

10. Global EV Outlook, 2016. Beyond one million electric cars [pdf]. Available at: <https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf> Available at: <http://www.mdpi.com/1996-1073/8/10/12147/pdf/> [Accessed 3 December 2016].

Мета. Визначення доцільності використання електромобілів як споживачів-регуляторів на основі дослідження графіків навантаження та існуючих тарифів на електроенергію на прикладі України й декількох європейських країн; формулювання основних технічних вимог для реалізації регулювання.

Методика. Аналіз фактичних графіків електричних навантажень національних енергосистем України й низки європейських країн. Розробка принципових схемних рішень для впровадження електромобілів у систему енергопостачання України.

Результати. Обґрунтована доцільність і перспективність використання електромобілів як споживачів-регуляторів електричного навантаження в мережах 0,4 кВ населених пунктів для умов України. Запропонована методологія вибору потужності й розміщення станцій заряду/розряду. Показано, що розробка та впровадження механізмів економічного стимулювання споживачів до раціонального графіка включення електромобілів у мережу сприятиме збільшенню темпів зростання кількості електротранспорту, а також підвищенню ефективності роботи національної енергосистеми, поліпшенню екологічної обстановки в країні.

Наукова новизна. Розроблені методологічні підходи до модернізації системи електропостачання України для застосування електротранспорту як споживача-регулятора.

Практична значимість. Доведена економічна доцільність використання електротранспорту для регулювання графіка навантаження як для енергосистеми, так і для власників електротранспорту. Запропоновані й проаналізовані схеми підключення електромобілів для генерації енергії в мережу.

Ключові слова: *регулювання навантаження, енергетична система, електромобілі, станції заряду/розряду*

Цель. Определение целесообразности использования электромобилей в качестве потребителей-регуляторов на основе исследования графиков нагрузки и существующих тарифов на электроэнергию на примере Украины и нескольких европейских стран; формулирование основных технических требований для реализации регулирования.

Методика. Анализ фактических графиков электрических нагрузок национальных энергосистем Украины и ряда европейских стран. Разработка принципиальных схемных решений для внедрения электромобилей в систему энергоснабжения Украины.

Результаты. Обоснована целесообразность и перспективность использования электромобилей в качестве потребителей-регуляторов электрической нагрузки в сетях 0,4 кВ населенных пунктов для условий Украины. Предложена методология выбора мощности и размещения станций заряда/разряда. Показано, что разработка и внедрение механизмов экономического стимулирования пользователей к рациональному графику включения электромобилей в сеть будет способствовать увеличению темпов роста количества электротранспорта, а также повышению эффективности работы национальной энергосистемы, улучшению экологической обстановки в стране.

Научная новизна. Разработаны методологические подходы к модернизации системы электроснабжения Украины для применения электротранспорта в качестве потребителя-регулятора.

Практическая значимость. Доказана экономическая целесообразность использования электротранспорта для регулирования графика нагрузки как для энергосистемы, так и для владельцев электротранспорта. Предложены и проанализированы схемы подключения электромобилей для генерации энергии в сеть.

Ключевые слова: *регулирование нагрузки, энергетическая система, электромобили, станции заряда/разряда*

Рекомендовано до публікації докт. техн. наук С. І. Випанасенком. Дата надходження рукопису 16.09.16.