



INSTRUMENT-MAKING AND INFORMATION-MEASURING SYSTEMS

ПРИЛАДОБУДУВАННЯ ТА ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНІ СИСТЕМИ

UDC 621.31

USE OF SOLAR ENERGY FOR THE OUTDOOR LIGHTING OF TERNOPIL

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Summary. The analysis of the energy potential of solar radiation taking into account the climatic conditions of the city of Ternopil area during the last five years has been carried out. The average monthly and average daily values of solar radiation energy are determined. It is shown, that the most efficient for generation of electric energy is the period from April to September. The analysis of daily and monthly electricity consumption by the systems of outdoor lighting of the city of Ternopil for 2014 – 2016 is made. The methodology and the calculation of the autonomous system of power supply of outdoor lighting in the city of Ternopil using solar panels of KV 250M type, Li-ion batteries of LP48100ES type and the control system consisting of the MPPT controller watching charge – discharge of batteries and the inverter of Growatt 10000HY type, have been proposed. The technical and economic calculation of the cost of the autonomous power system have been carried out.

Key words: solar power station, solar battery, battery, outdoor lighting.

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Statement of the problem. The characteristic of modern power-engineering is the introduction of the recovering energy units and their efficient application. The most available energy units are the solar energy sources, which operate according to the principle of direct transformation of solar energy into electrical one and now they are widely applied. With this purpose the silicon-based solar batteries (SB) are used: monocrystalline (efficiency 16% – 19%), polycrystalline (efficiency 14% – 16%) and thinwalled (efficiency 6% – 9%) [1]. Introduction of the alternative and recovering energy units for the outdoor urban lighting is of special importance. It will make possible to reduce the expenditure costs and to improve the lighting systems operation stability and the urban lighting consumers comfort, which is very actual now.

Analysis of the latest investigations and publications. Application of the autonomous power supply for urban outdoor lighting in the Lviv region area has been analysed in the paper [2]. The photoelectric modules of the KV50/12-M type, accumulating batteries Santec 12-200 and lighting devices of the LED 2.80.4200 type of 80 W power have been used for this purpose. In the paper [3] the options of the lighting installations supply systems have been analysed: absolutely autonomous supply and the supply using the electrical network. In the paper [4] technical possibility to apply autonomous systems of urban lighting on the example of the Tomsk polytechnical university campus lighting, taking advantage of the 300W power solar batteries YL 300C-30b, 200 A·h capacity Li-ion accumulating batteries of the LT-LYP200 type,

the invertors MeanWell TS 3000 (1500) 48 V and the charge controller ECO Energy MPPT Pro 200/100. In most papers the results of investigations of the solar radiation energy power have not been available, but NASA site data has been used, which does not take into account the area climatic conditions [5].

In the paper [6] the analytical dependencies of the solar energy flow on the average cloudiness have been obtained basing on our own investigations of the energy power of the solar radiation and the forecast Bureau data, which make possible at the first approximation to use them for the other urban settlements.

The Objective of the work is to analyse the possibilities to use solar batteries for the outdoor lighting of Ternopil.

Statement of the task. To carry out comparison of the solar radiation energy potential with the consumed energy by the outdoor lighting of Ternopil. To build the model of the autonomous supply system and to develop the technical – economic calculation of the solar power plant for the systems of outdoor lighting of the city of Ternopil.

Presentation of the main ideas.

The value of the consumed electric energy per month E_{light} and per day of the month $E_{light,1}$ by the systems of outdoor lighting of the city of Ternopil during 2014 – 2016 according to the municipal enterprise (ME) „Ternopilmisksvitlo“ records are presented on Table 1.

In 2016 about $E_{light} = 3,025 \text{ mln. kW}\cdot\text{h}$ electric energy have been consumed for the outdoor lighting in Ternopil. This value was increased in $0,19 \text{ mln. kW}\cdot\text{h}$ (6%) in comparison with 2015 and in $0,26 \text{ mln. kW}\cdot\text{h}$ (8,5%) in comparison with 2014. Expenditures for the electric energy consumed for the outdoor lighting have increased in $1,926 \text{ mln. UAH}$ (52%) during 2016 and equal $3,65 \text{ mln. UAH}$. The graphs of these changes are presented in Fig. 1. Thanks to the introduction of the alternative energy units, solar batteries in particular, the decrease of the municipal expenditures for the urban lighting is possible.

Table 1

Electricity consumed by the outdoor lighting systems of the Ternopil city for 2014 – 2016

Month	2016 year		2015 year		2014 year	
	$E_{light}, \text{kW}\cdot\text{h}$	$E_{light,1}, \text{kW}\cdot\text{h}$	$E_{light}, \text{kW}\cdot\text{h}$	$E_{light,1}, \text{kW}\cdot\text{h}$	$E_{light}, \text{kW}\cdot\text{h}$	$E_{light,1}, \text{kW}\cdot\text{h}$
January	378479	12209	358080	11551	361028	11646
February	331628	11435	326007	11643	288645	10309
March	262031	8453	245677	7925	248674	8022
April	247283	8243	251398	8380	229125	7638
May	191166	6167	162687	5248	195455	6305
June	155271	5176	147566	4919	155642	5188
July	122452	3950	124275	4009	146096	4713
August	154740	4992	154256	4976	145116	4681
September	234089	7803	222651	7422	207923	6931
October	261248	8427	233795	7542	245428	7917
November	332402	11080	293809	9794	275132	9171
December	354216	11426	315762	10186	269110	8681
Total	3025005		2835963		2767374	

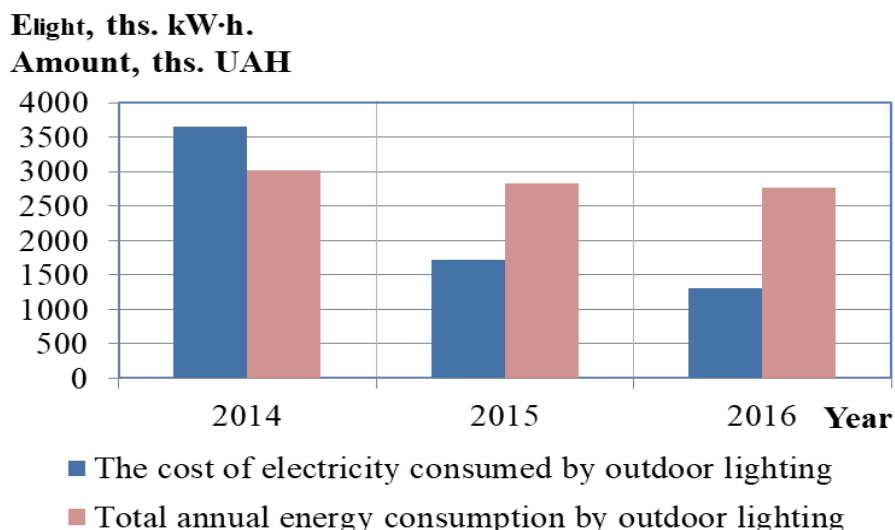


Figure 1. Chart of change in total annual energy consumed by the outdoor lighting E_{light} and its cost for the city of Ternopil

With this purpose the measuring of the solar energy flow during 2016 has been performed taking advantage of the installation described in [7]. The results of these investigations are presented on Table 2. The installation was mounted on the basis of the department of the applied information technologies and electrical-engineering of the Ternopil Ivan Pul'uj National Technical University in Mykulynetska Str., 46. The geographic coordinates of the measuring point are: latitude $49,53^{\circ}$ North and longitude $25,6^{\circ}$ East [6, 7]. Here the values of total energy of solar radiation E during the month and average values per day of every month $E_{average}$ are presented.

Table 2

Monthly and average daily energy of solar radiation

Month	$E, kW \cdot h/m^2$	$E_{average}, kW \cdot h/m^2$
January	45	1,4
February	65	2,2
March	82,4	2,6
April	105,2	3,5
May	134,7	4,3
June	136,7	4,5
July	144	4,6
August	141,3	4,5
September	100,7	3,3
October	48,7	1,6
November	38,3	1,3
December	34,2	1,14

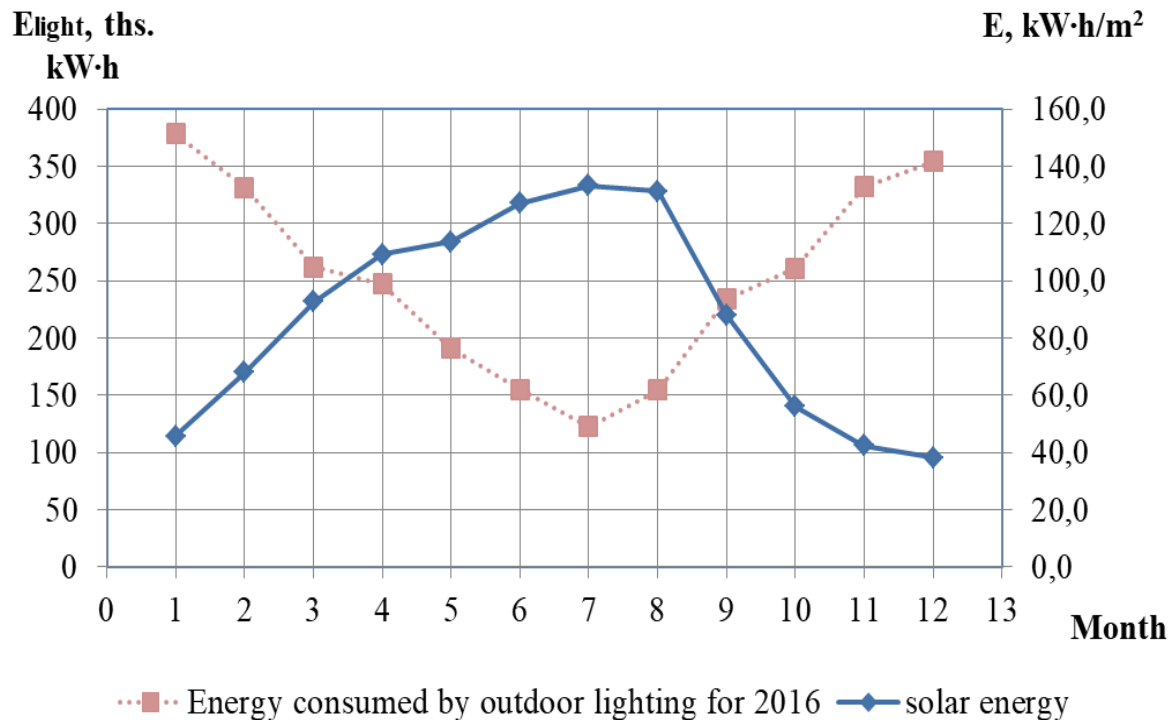


Figure. 2. Chart of change in average monthly solar energy E and the energy consumed by E_{light} outdoor lighting during 2016 for the city of Ternopil

Basing on the obtained results the comparison of the measured values of the solar energy flow with those recorded by the meteorological Bureau of Ukraine has been carried out, the level of cloudness in the area in question in particular, as the value of the solar radiation flow was not available [8]. In our previous paper [6] the relation between the average solar energy flow value during each month and average cloudness has been determined. It made possible to use the meteorological Bureau data during last 5 years for the estimation of the energy potential and to determine average monthly and annual energy of the solar radiation in Ternopil, which equals $1046 \text{ kW}\cdot\text{h}/\text{m}^2$. The chart of the average monthly change of the solar energy during the year are presented in Fig. 2. Here the chart of monthly consumption of the electrical energy E_{light} for the outdoor lighting in Ternopil during 2016 has been presented too.

Basing on the presented dependencies it can be concluded, that the most effective operation of the solar batteries is in the period from April till September. In other monthes, as the result of decrease of a sunny day, as well as the increase of the number of cloud days, the effectiveness of the solar systems decreases also.

Results of investigations.

Basing on the presented data the calculation of the solar energy installation for the outdoor lighting has been carried out. The batteries of the KV 250M type have been used, with nominal power 250 W and operating surface $1,6 \text{ m}^2$. To accumulate electrical energy the accumulation batteries of the LP48100ES type and the control system consisting of the controller 220 V watching the battery charge – discharge, and the inverter for the transformation of DC voltage into AC voltage with 50 Hz frequency.

The input performance factors of calculation are the average daily needs of the generated electrical energy for the outdoor lighting during every month of 2016, which are presented on Table 1.

The average daily electrical energy generated by one solar battery $E_{SB,1}$ was calculated according to the formula:

$$E_{SB,1} = \mu \cdot E_{average} \cdot S_0 \cdot \mu_b \cdot \mu_{in}, \quad (1)$$

where μ – solar battery efficiency;

$E_{average}$ – average daily value of the solar radiation energy;

S_0 – operating surface of one solar battery m^2 ;

μ_b – accumulation battery efficiency;

μ_{in} – inverter efficiency.

The number of solar batteries N was determined by the relation of the consumed energy for the lighting during one day $E_{light,1}$ to the generated energy by one solar battery:

$$N = E_{light,1} / E_{SB}. \quad (2)$$

On Table 3 the values of the generated electrical energy by one solar battery E_{SB} during every month, the number of solar batteries N needed for the autonomous supply of the outdoor lighting, as well as their total square S , have been presented.

Table 3

Performance factors of solar power plants at 100% autonomous power supply for outdoor lighting for each month in Ternopil

Month	$E_{SB}, kW \cdot h$	$N, \text{Number of units}$	S, m^2
January	9,9	38256	63505
February	14,7	22560	37450
March	18,2	14400	23904
April	23,4	10560	17530
May	29,8	6432	10677
June	30,2	5184	8605
July	31,8	3888	6454
August	31,2	4992	8287
September	22,3	10512	17450
October	10,8	24192	40159
November	8,5	39120	64939
December	7,5	47040	78086
Total:	238,3		

The series – multiple connection of solar batteries makes possible to regulate the input voltage and current, thus, it makes possible to choose the most efficient operating regime of the whole solar power plant. Having connected 24 solar batteries in series and having combined them into two parallelly, we will obtain: nominal voltage in the output – 737 V, light running voltage 895 V and current 16,4 A. For such connection of batteries it is worth using the control system based on the hybrid inverter of the Growatt 10000HY type with the nominal power 10

kW. This inventor makes possible to convert the direct voltage of the accumulating batteries into the alternative voltage 220 V. MPPT controller of the charge – discharge accumulating battery is built in it, which provides the most efficient operation of the solar power plant.

To calculate the accumulating system we expected the autonomous supply installation to work during 8 – 9 hours. Li-ion accumulators are proposed to be used for it, which have wide operating life temperature range and low self-discharge in comparison with other types of accumulators. Li-ion accumulating battery of the LP48100ES type, capacity $C = 100 \text{ A}\cdot\text{h}$, nominal voltage 48 V was chosen for the calculation.

The necessary capacity of the accumulating system C_b was calculated according to the formula:

$$C_b = E_{light.1}/(U_b \cdot k), \quad (3)$$

where $E_{light.1}$ – consumed energy for the outdoor lighting per day;

U_b – accumulating battery nominal voltage;

K – coefficient of the capacity consumption, taking into account the part of the accumulating battery energy, which can be used ($k = 0,8$).

The number of the accumulating batteries:

$$n = C_b/(C_{b.1} \cdot \mu_b), \quad (4)$$

where μ_b – accumulating battery efficiency coefficient ($\mu_b = 0,95$);

$C_{b.1}$ – capacity of one accumulating battery plant.

For the solar power-plant, which can provide the autonomous supply of the outdoor lighting the October 2016 data has been chosen. It will consist of 47040 solar batteries of total area 78086 m^2 . This area is big enough and practically is not available, that is why two options of application of the alternative units only during summer monthes have been analysed. With this purpose the data on May has been taken. The number of solar batteries for this month is 6432 items, general square being 10677 m^2 .

Technical – economic calculation for two types of solar power – plants has been carried out for the comparative analysis. The first type can totally provide the electrical energy for the outdoor lighting in Ternopil, using data on December. The excesses of the generated energy during summer period will be supplied into the network. For the second type of the autonomous energy system the data on May has been used. In this case, when in the winter period the energy is scarce, it can be taken from the network. The results of such calculation are presented on Table 4.

It is clear, that the first type power – plant needs 596,381 *mln. UAH.*, the second type – 91,375 *mln. UAH.* The expenditures for the mounting and further maintenance of every energy system have not been taken into account in these calculations.

Table 4

Technical-economic estimation of the solar power plant

The name of the equipment	Month	Price per Unit. th. UAH.	Number of units	Price th. UAH
Solar battery Kvazar KV 250M	December	7,9	47040	371616
	May		6432	50813
Inverter Growatt 10000HY	December	110	1040	114400
	May		134	14740
Li-ion batteries LP48100ES	December	9,5	4190	39805
	May		1695	16102
Mounting accessories for the installation of solar panels on the ground	December	180	392	70560
	May		54	9720
Total:	December			596381
	May			91375

Conclusions. Data on per month and annual consumption of the electrical energy for the outdoor lighting of Ternopil is presented in the paper. The method has been proposed and the calculation of the autonomous supply system for the outdoor lighting of Ternopil taking advantage of the *KV 250M* type solar batteries, nominal power being 250 W, Li-ion LP48100ES type accumulators and control system containing MPPT controller watching battery charge – discharge and the Growatt 10000HY type inventor, nominal power being 10 kW, has been carried out. Technical-economic calculation of two types of autonomous energy systems has been presented. The prospects for the application of the solar batteries for the outdoor urban lighting have been shown.

References

1. Kozhemiako V.P., Dombrovskiy V.H., Zherdetskiy V.F., Malinovskiy V.I., Prytuliak H.V. Analitichnyi ohliad suchasnykh tekhnolohii fotoelektrychnykh peretvoriuvachiv dlia soniachnoi enerhetyky, opyko-elektronni informatsiino-enerhetychni tekhnolohii, vol. 22, no. 2, pp. 141 – 157. [In Ukrainian].
2. Chumakevych V.O., Atamaniuk V.V., Puleko I.V., Dubovskiy A.M. Obgruntuvannia mozhlyvosti osvittleniia parkiv v mistsiakh postiinoi dyslokatsii za dopomohoiu soniachnykh batarei u Lvivskii oblasti, Natsionalna akademiia sukhoputnykh viisk imeni hetmana Petra Sahaidachnoho, vol. 13, no. 2, pp. 102 – 105. [In Ukrainian].
3. Pastushenko M.S. Perspektyvy vprovadzhennia vidnovliuvalnykh dzherel elektrychnoi enerhii na zaliznychnomu transporti Ukrainy, Enerhosberezhenye. Enerhetyka. Enerhoaudyt. 2013, no. 12, pp. 45 – 51. [In Ukrainian].
4. Surkov M.A., Sumarokova L.P. Otsenka vozmozhnosti primeneniia fotoelektricheskikh ustanovok dlia elektrosnabzheniia ulichnogo osveshcheniia v klimaticheskikh usloviyakh Sibiri, Internet-zhurnal „Naukovedeniye“ vol. 8, no. 6, 2016. [In Russian].
5. NASA Surface meteorology and Solar Energy. Available at: <https://eosweb.larc.nasa.gov/sse/>.
6. Andreychuk V., Filyuk Y. Analysis of the energy potential of solar light of the western region of Ukraine with the account of climatic conditions, eureka: physics and engineering, 2017, vol. 10, no. 4, pp. 25 – 32.
7. Andriichuk V.A., Filiuk Ya.O. Doslidzhennia enerhetychnoho potentsialu soniachnoho vyprominiuvannia v m. Ternopoli, Visnyk Ternopilskoho natsionalnoho tekhnichnoho universytetu, 2016, vol. 85, no. 1, pp. 95 – 100.
8. Meteopost (2017). Available at: <http://meteopost.com/weather/archive/>. [In Ukrainian].

Список використаної літератури

1. Аналітичний огляд сучасних технологій фотоелектричних перетворювачів для сонячної енергетики

- [Текст] / В.П. Кожем'яко, В.Г. Домбровський, В.Ф. Жердецький, В.І. Маліновський, Г.В. Притуляк // Оптико-електронні інформаційно-енергетичні технології. – Т. 22, № 2. – С. 141 – 157.
2. Обґрунтування можливості освітлення парків в місцях постійної дислокації за допомогою сонячних батарей у Львівській області [Текст] / В.О. Чумакевич, В.В. Атаманюк, І.В. Пулеко, А.М. Дубовський // Національна академія сухопутних військ імені гетьмана Петра Сагайдачного. – Т. 13, № 2. – С. 102 – 105.
 3. Пастушенко, М.С. Перспективи впровадження відновлювальних джерел електричної енергії на залізничному транспорті України [Текст] / М.С. Пастушенко // Энергосбережение. Энергетика. Энергоаудит. – 2013. – № 12. – С. 45 – 51.
 4. Сурков, М.А. Оценка возможности применения фотоэлектрических установок для электроснабжения уличного освещения в климатических условиях Сибири [Текст] / М.А. Сурков, Л.П. Сумарокова // Интернет-журнал «Науковедение». – Том 8, № 6 (2016).
 5. NASA Surface meteorology and Solar Energy. Available at: <https://eosweb.larc.nasa.gov/sse/>.
 6. Andriychuk V., Filyuk Y. Analysis of the energy potential of solar light of the western region of Ukraine with the account of climatic conditions, eureka: physics and engineering, 2017, vol. 10, no. 4, pp. 25 – 32.
 7. Андрійчук, В.А. Дослідження енергетичного потенціалу сонячного випромінювання в м. Тернополі [Текст] / В.А. Андрійчук, Я.О. Філюк // Вісник ТНТУ. – 2016. – Т. 85, № 1. – С. 95 – 100.
 8. Meteopost (2017). Available at: <http://meteopost.com/weather/archive/>. [In Ukrainian].

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ВИКОРИСТАННЯ СОНЯЧНОЇ ЕНЕРГІЇ ДЛЯ ЗОВНІШНЬОГО ОСВІТЛЕННЯ ТЕРНОПОЛЯ

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Резюме. Проведено аналіз енергетичного потенціалу сонячного випромінювання з урахуванням кліматичних умов території Тернополя протягом п'яти останніх років. Визначено середньомісячні та середньодобові значення енергії сонячного випромінювання. Показано, що найпродуктивнішим для генерації електричної енергії є період від квітня до вересня. Зроблено аналіз добового та місячного споживання електроенергії системами зовнішнього освітлення Тернополя за 2014 – 2016 роки. Запропоновано методику та проведено розрахунок автономної системи живлення зовнішнього освітлення Тернополя з використанням сонячних батарей типу KV 250M, Li-ion акумуляторів типу LP48100ES та системи керування, до складу якої входить MPPT контролер, що стежить за зарядом – розрядом батарей, а також інвертор типу Growatt 10000HY. Проведено техніко-економічний розрахунок вартості автономної енергетичної системи.

Ключові слова: сонячна електростанція, сонячна батарея, акумуляторна батарея, зовнішнє освітлення.

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