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ПРИЛАДОБУДУВАННЯ ТА ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНІ СИСТЕМИ

UDC 621.31

AUTONOMOUS POWER SUPPLY SYSTEM FOR OUTDOOR ILLUMINATION OF RESIDENTIAL AREAS IN THE TERRITORY OF UKRAINE

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Summary: *The methodology and the calculation of the autonomous power supply system for outdoor illumination using solar batteries of KV 250M type, Li-ion batteries of LP48100ES type and the control system consisting of the MPPT controller, controlling battery charge - discharge and inverter of Growatt 10000HY type are investigated. The technical and economic calculation of the autonomous energy system for the outdoor illumination of residential areas with the population of more than 1 million (Kyiv city) and with the population up to 10 thousand (Lanovtsi city) is carried out. The analytical dependences of energy consumed by outdoor illumination on the number of lighting points for different residential areas of Ternopil region are obtained.*
Key words: *solar power station; solar battery; accumulating battery; outdoor illumination.*

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Statement of the problem. The problem of effective use of natural resources, improvement of electric energy consumption systems, implementation of environmental technologies in everyday life and in production are of vital importance. One of the main aims and objectives in the field of energy efficiency improvement is the partial replacement of traditional resources by renewable energy sources which are lately paid much attention to [1-4]. The use of alternative sources of energy in outdoor illumination systems makes it possible to reduce the cost value, as well as to increase the operation stability and the comfort of the residential areas inhabitants, which are very important at present.

Analysis of the available investigations. For autonomous power supply of outdoor illumination of residential areas, photovoltaic modules of type KV50 / 12-M, accumulating batteries Santec 12-200 and lighting devices of LED 2.80.4200 type with power of 80 *W* are offered in paper [2]. In paper [3] analysis of the combined power supply system of lighting installations (LI) based on completely autonomous power supply and power supply using the electric network is carried out. In [4], the technical capability of the implementation of the autonomous system of street lighting on the example of the illumination of the territory of the Tomsk Polytechnic University, using solar batteries YL300C-30b with the capacity of 300 *W*, Li-ion accumulating batteries of LT-LYP200 type with the capacity of 200 $A \cdot h$, inverters MeanWell TS -3000 (1500) 48*V* and controllers of the charge of ECO Energy MPPT Pro

200/100 is shown. In most of the above mentioned papers solar batteries are used, but the results of the investigations of the energy potential of solar radiation in these regions are not presented. The data are mostly used from NASA site, and do not take into account the climatic conditions of the territories [5].

The objective of the paper is to analyze the capabilities of solar batteries use for outdoor illumination of the residential areas and camping sites distant from electric networks in the territory of Ukraine.

Statement of the task. To calculate the solar electricity generating units for power supply of the outdoor illumination systems on the basis of analysis of the solar radiation energy potential in certain regions of Ukraine and the amount of electricity consumed for the needs of outdoor illumination of the residential areas.

Analysis of the systems for outdoor illumination of residential areas in Ukraine.

The following parameters are used to characterize the systems for outdoor illumination of the residential areas in Ukraine: the total amount of electricity consumed by E_{light}, the number of lighting points with different types of light sources, the amount of electricity consumed by the lighting point (Table 1) [8]. At present, in the statistical reports of the city light organizations, the residential areas of Ukraine, the data on autonomous power supply systems for outdoor illumination are not presented, so they are not shown in (Table 1).

The total length of the electrical system of the outdoor illumination as at 01.01.2017 amounted to 98,8 *ths. km.* and for 2016 it increased by8,8 *ths. km.* (9%) compared to 2015. In 2016, 517,2 *mln. kW·h* of electricity for outdoor illumination were consumed. This index increased by 37,2 *mln. kW·h* (8%) compared to 2015. Electricity costs for outdoor illumination increased by 238 *mln. UAH.* during the year. (80%) amounts to 533 *mln. UAH*. The average annual energy consumption of one lighting point is 255,2 *UAH*., that is by 109,7 *UAH*. (75%) more than in 2015.

The total number of lighting points for outdoor illumination as at 01.01.2017 is 2,09 *mln. units*, that is by 59 *ths.* (3%) more than in 2015. In the field of outdoor illumination, 260,715 *ths.* incandescent lamps, 415,32 *ths.* fluorescent lamps, 279,80 *ths*. mercury-filled, 833,97 *ths.* sodium, 46,894 *ths.* metal-halide lamps and 252,04 *ths.* energy-saving light sources are used, that is by 141,4 *ths.* (8%) more compared to 2015.

Table 1

Indicators of outdoor illumination of residential areas of Ukraine

Administrative-territorial division	Number of consumed electricity - total, ths. E_{light}, $kW·h$	The amount of electricity consumed by the light points $E_{light.1}$, $kW·h$	Number of light points by types of light sources, ths. units					
	For 2016	For 2016	Incandescent lamps	Luminescent	Mercury lamps	Sodium lamps	Metal halide	LED light sources
1	2	3	4	5	6	7	8	9
Vinnitsa	15620,89	197	6,19	19,18	6,82	36,62	0,65	9,57
Volyn region	7618,2	165,8	8,47	13,89	4,29	17,9	0,06	0,28
Dnipropetrovsk	37921,42	166,96	28,71	107,04	15,13	43,13	0,49	32,63
Donetsk	27892,63	318,9	11,28	7,7	10,79	49,93	0,47	7,3
Zhytomyr	7151	160,47	6,54	3,9	3,07	18,64	1,63	10,77
Transcarpathian	13316,24	232,2	7,08	19,74	12,17	13,4	1,21	3,75
Zaporozhye	21352,7	171	10,91	17,75	31,31	42,42	6,47	16,01
Ivano-Frankivsk	9921,73	236,7	5,88	5,65	4,69	20,43	0,82	4,45
Kievskaya	40303	352,1	12,94	22,95	35,83	33,1	3,97	6,25

1	2	3	4	5	6	7	8	9
Kirovograd	10164,03	182,7	13,67	12,54	4,25	18,09	0,05	7,11
Lugansk	4082,8	232,8	1,3	5,76	0,99	6,85	0,01	2,65
Lviv	40837,02	385	15,85	13,08	9,6	46,52	9,03	12,09
Nikolaev	18189	237,74	8,72	1,5	10,29	25,63	4,98	25,38
Odessa	45672,8	6597,99	40,69	21,37	9,54	64,99	4,95	12,39
Poltava	12600	120	11	14	17	56	2	5
Rivne	14525,07	333,83	3,31	13,85	9,12	13,48	0,28	3,48
Sumy	17123,9	238,1	20,42	13,32	6,22	25,59	0,1	6,28
Ternopil	6759,35	204,85	6,63	5,31	5,36	10,19	0,02	5,48
Kharkiv	48052	339,9	11,62	27,92	11,36	77,61	2,58	18,84
Kherson	8540	315	3,8	4,4	6,2	11,7	0,1	0,9
Khmelnitsky	16418,27	221,82	8,06	12,56	15,52	25,76	0,93	11,2
Cherkassy	17683,37	210,5	5,06	35,61	19,15	16,9	2,47	4,83
Chernivtsi	7988,2	250,5	2,77	5,1	3,35	21,49	0,63	1,47
Chernihiv	6383,4	119,88	9,32	9,43	9,16	21,7	0,7	2,93
c. Kyiv	61047	339	0,5	1,8	18,6	115,9	2,3	41
Total for Ukraine	517164	12330,74	260,72	415,32	279,81	833,98	46,89	252,04

Analysis of the energy potential of solar radiation in Ukraine regions.

To estimate the capabilities of solar energy use for outdoor illumination, analysis of the energy potential of solar radiation in the regions of Ukraine was carried (Table 2).

Table 2 shows the average daily energy of solar radiation E_S, falling on the horizontal plane in spring-summer (April-September) and autumn-winter (October-March) periods [5]. It also shows the amount of electricity generated by one solar battery per year in spring-summer $E_{S\text{-}S}$, and autumn-winter $E_{A\text{-}W}$ periods.

Table 2

The energy potential of solar radiation in the regions of Ukraine
and the amount of electricity generated by one solar batttery per year

Administrative-territorial division	E_S, $kW{\cdot}h/m^2$		$E_{S\text{-}S}$, $kW{\cdot}h$	$E_{A\text{-}W}$, $kW{\cdot}h$
	Spring-summer period	Autumn-winter period		
1	2	3	4	5
Vinnitsa	4,58	1,65	342,8	123,2
Volyn region	4,42	1,55	331,3	116,0
Dnipropetrovsk	4,94	1,77	369,6	132,4
Donetsk	4,92	1,76	368,1	131,9
Zhytomyr	4,50	1,57	336,9	117,8
Transcarpathian	4,63	1,69	346,4	126,6
Zaporozhye	5,08	1,79	380,4	134,3
Ivano-Frankivsk	4,20	1,68	314,4	126,1
Kievskaya	4,58	1,62	342,9	121,2
Kirovograd	4,85	1,74	363,1	130,4
Lugansk	4,89	1,79	366,3	134,3
Lviv	4,26	1,58	319,1	118,2
Nikolaev	5,20	1,89	389,2	141,6
Odessa	5,20	1,89	389,2	141,8

1	2	3	4	5
Poltava	4,77	1,73	357,5	129,3
Rivne	4,45	1,56	333,3	117,0
Sumy	4,64	1,68	347,2	125,5
Ternopil	4,37	1,61	327,2	120,5
Kharkiv	4,78	1,74	358,1	130,4
Kherson	5,18	1,91	388,1	143,3
Khmelnitsky	4,48	1,63	335,8	122,0
Cherkassy	4,78	1,69	358,3	126,5
Chernivtsi	4,50	1,55	336,8	116,1
Chernihiv	4,20	1,68	314,4	126,1
c. Kyiv	4,58	1,62	342,8	123,2

To calculate the solar power installation for outdoor illumination of residential areas, solar batteries of KV 250M type with the nominal capacity of 250 *W* and a working surface of 1,6 m^2 were used. For the accumulation of electricity accumulators of LP48100ES type and a control system consisting of controller monitoring the battery charge – discharge and inverter for converting the direct voltage to the alternating 220 *V* with the frequency 50 *Hz*.
The average daily electricity generated by one solar battery E_{SB} is calculated by the formula:

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

where μ – is the efficiency of the solar battery;
$E_{average}$ – is the average daily value of the solar radiation energy;
S_0 – is the working surface area of one solar battery m^2;
μ_b – is the accumulator battery efficiency;
μ_{in} – is the inverter efficiency.

The number of solar batteries *N* and their area *S* is determined by the ratio of energy consumed for illumination E_{light} to the energy generated by one solar battery, E_{SB}:

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

$$S = N \cdot 1{,}6, \text{ m}^2. \quad (3)$$

Applying series-parallel connection of solar batteries, we can adjust the output voltage and current, which allows us to choose the most optimal mode of operation of the entire solar power plant. Connecting 7 solar batteries in series and then combining them into two parallel connected areas, we obtain: the nominal voltage 215 V, the idle voltage 262 V and the current 16,4 A. For such connection of solar batteries, it is efficient to use the control system based on a hybrid Inverter Growatt 10000HY type. This inverter makes it possible to convert the direct voltage from the batteries to the alternating voltage 220 V. It has built-in MPPT controller of the accumulating battery charge-discharge providing the most efficient operation of the solar power plant.

To calculate the accumulation system it is assumed that the installation of autonomous power of LI for outdoor illumination operates for 8-9 hours. For its implementation it is efficient to use Li-ion batteries with the wide temperature range of operation and low self-discharge in comparison with other types. For calculation Li-ion rechargeable battery of LP48100ES type with capacity C = 100 *A·h*, nominal voltage 48 V is used.

The required capacity of the battery C_b is calculated by the formular:

$$C_b = E_{light}/(U_b \cdot k), \quad (4)$$

where E_{light} – is the energy consumed for outdoor illumination;
U_b – is the nominal voltage of the accumulator battery;
k – is the coefficient of capacity use taking into account which part of the accumulator battery energy can be used ($k = 0,8$).

The number of accumulator batteries:

$$n = C_b/(C \cdot \mu_b), \quad (5)$$

where μ_b – is accumulator battery efficiency ($\mu_b = 0,95$);
C – is the capacity of one accumulator battery.

For comparative analysis of solar power stations, technical-economic calculation for two types of autonomous power supply of outdoor lighting in Kyiv was carried out (Table 3). The first type provides electricity for outdoor illumination of Kyiv city in the autumn-winter period. The surplus of electricity during the spring-summer months will be sent to the network. The second type provides autonomous power supply for outdoor illumination during the spring-summer months, and with lack of energy in the winter it will be taken from the network.

Table 3 shows that the I-type requires 503132 solar batteries, 35938 inverters, 16735 batteries and 4193 mounting components. To implement the given system of electric supply for outdoor illumination 8841,7 *mln. UAH* are needed. The II-type requires 177968 solar cells, 12711 inverters, 16735 batteries, 1484 mounting components and total cost is 3230,3 *mln. UAH*.

Table 3

Technical and economic calculation of solar powerstation for outdoor illumination of Kyiv city

The name of the equipment	type of power plant	Price per Unit. th. UAH.	Number of units	Price ths. UAH
Solar battery Kvazar KV 250M	I – type	7,9	503132	3974743
	II – type		177968	1405948
Inverter Growatt 10000HY	I – type	110	35938	3953180
	II – type		12711	1398210
Li-ion batteries LP48100ES	I – type	9,5	16735	158983
	II – type		16735	158983
Mounting accessories for the installation of solar panels on the ground	I – type	180	4193	754740
	II – type		1484	267120
Total:	I – type			**8841646**
	II – type			**3230261**

It is easily seen that the solar power installations, calculated on the basis of energy needs, for certain areas as well as for large cities, such as Kiev, require high costs and can be implemented in the distant future. Therefore, for calculations the average statistics data of the consumed electric power for outdoor illumination of the residential areas with the population of 5000 – 20,000 persons were taken. For example, the district centers of the Ternopil region were chosen. Data are shown in Tables 4 and 5.

The calculation of the number of lighting points was based on data of consumed electricity and the average value of consumption with one lighting point in the Ternopil region

(Table 1). Table 4 also provides data on the amount of electricity consumed by outdoor lighting *E*, monthly and during 2016 in the district centers of the Ternopil region.

Table 4

Indices of the outdoor illumination of district centers in Ternopil region in 2016

Month	Lanovci *E, kW·h*	Monas-tyrysk *E, kW·h*	Terebovlya *E,kW·h*	Shumsk *E, kW·h*	Buchach *E, kW·h*	Podvolochisk *E, kW·h*	Kremenets *E, kW·h*	Kozova *E, kW·h*	Berezhany *E, kW·h*
January	6900	7622	6879	12488	27250	20227	4265	14400	19100
February	6500	7600	9389	10856	26170	19041	10239	12180	18200
March	5900	6227	7675	8559	19406	14011	8388	10720	16400
April	5600	5724	7885	11880	17772	11248	10987	7810	10234
May	5400	4057	7639	7237	14536	10959	11668	6800	10230
June	5200	3230	4809	5493	13208	9229	8059	6700	10100
July	5000	2927	6339	5263	12651	8723	6692	6500	10030
August	5000	3287	5505	5440	13267	9406	6641	6500	11100
September	5000	4441	5813	8855	13859	8575	10202	6800	12500
October	5900	5247	10608	8385	21283	12199	13665	7200	18200
November	6500	6774	10701	8939	23690	11527	4670	8400	19200
December	7100	7590	11004	9500	26560	13000	3816	12200	19300
Total for the year	70000	64726	94246	102895	229652	148145	99292	106210	174594
Number of people (persons)	*8700*	*5887*	*13595*	*5453*	*12550*	*7985*	*21388*	*9194*	*18168*
Number of light points	*342*	*316*	*460*	*502*	*1121*	*883*	*485*	*522*	*1514*

In order to find the relation between the electricity consumed by the outdoor illumination and the number of lighting points, the graphical dependence for the selected regional residential areas was constructed (Fig. 1).

The graph was constructed using data averaging by means of the least squares method. As a result, we obtained the analytic dependences described by the equations:

$$N = 53842e^{0,146\ E};\ R^2 = 0,9399, \qquad (6)$$

$$N = 2666,\ E^2 - 8531,\ E + 79293;\ R^2 = 0,9569, \qquad (7)$$

where E − is the energy consumed by outdoor illumination during the year (*kW·h)*;
N – is the number of lighting points;
R^2 – is the correlation coefficient.

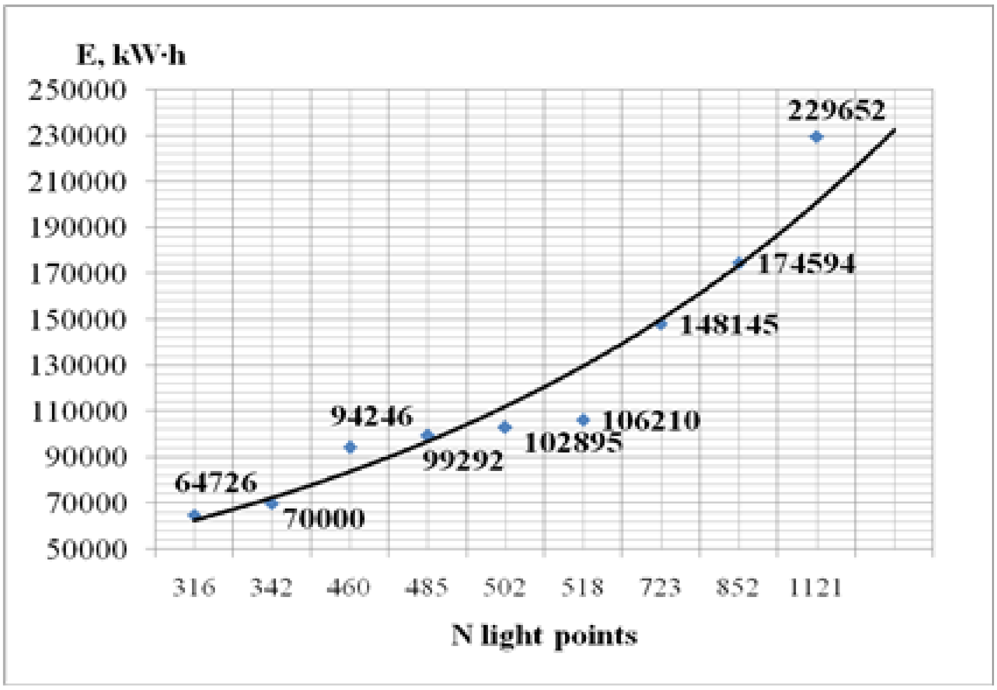

Figure 1. Dependence of energy consumed by outdoor illumination on the number of lighting points for various district centers of Ternopil region

On the example of Lanivtsi district center, two types of solar power stations were calculated on the basis of: I – on solar radiation during the autumn-winter period; II – during the spring-summer period.

It is shown in Table 5 that for I-type, providing electricity for outdoor illumination in the autumn-winter period, 588 solar batteries, 42 inverters, 1950 batteries and 5 mounting components are needed. For the implementation of the given system of electricity supply for outdoor illumination 28,7 *mln. UAH* are required. For II-type, providing autonomous power supply for outdoor illumination during the spring-summer months, 224 solar batteries, 16 inverters, 1950 batteries, 2 mounting components are required and the total cost is 22,4 *mln. UAH.*

Table 5

Technical and economic calculation of solar power station for outdoor illumination in Lanivci town

The name of the equipment	type of power plant	Price per Unit. th. UAH.	Number of units	Price ths. UAH
Solar battery Kvazar KV 250M	I – type	7,9	588	4645
	II – type		224	1770
Inverter Growatt 10000HY	I – type	110	42	4620
	II – type		16	1760
Li-ion batteries LP48100ES	I – type	9,5	1950	18525
	II – type		1950	18525
Mounting accessories for the installation of solar panels on the ground	I – type	180	5	900
	II – type		2	360
Total:	I – type			**28690**
	II – type			**22415**

Conclusions. The analysis of the outdoor illumination systems of the residential areas in the regions of Ukraine and analysis of the energy potential of solar radiation in their territories is carried out. The method of calculation of solar power installations for the outdoor illumination of the residential areas is provided. Two types of centralized solar power stations are offered. The first type completely provides electricity foroutdoor illumination during the autumn-winter period. The second type provides autonomous power supply for outdoor illumination during spring and summer months. The results of the technical and economic calculation of the solar power installation for the outdoor illumination of the residential areas with population over 1 million (Kyiv city) and with population up to 10 ths. (Lanivtsi town) are presented. The analytical dependences of energy consumed by outdoor illumination on the number of lighting points for different residential areas of Ternopil region are obtained.

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СИСТЕМИ АВТОНОМНОГО ЖИВЛЕННЯ ЗОВНІШНЬОГО ОСВІТЛЕННЯ НАСЕЛЕНИХ ПУНКТІВ НА ТЕРИТОРІЇ УКРАЇНИ

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Резюме. *Запропоновано методику й проведено розрахунок автономної системи живлення зовнішнього освітлення з використанням сонячних батарей типу KV 250M, Li-ion акумуляторів типу LP48100ES та системи керування, до складу якої входить MPPT контролер, що стежать за зарядом – розрядом батарей та інвертор типу Growatt 10000HY. Проведено техніко-економічний розрахунок автономної енергетичної системи зовнішнього освітлення населених пунктів з населенням понад 1 млн. (м. Київ) та з населенням до 10 тис. (м. Ланівці). Отримано аналітичні залежності енергії, спожитої зовнішнім освітленням від кількості світлоточок для різних населених пунктів Тернопільської області.*

Ключові слова: *сонячна електростанція; сонячна батарея; акумуляторна батарея; зовнішнє освітлення.*

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