Sustainability in Local Power Supply Systems of Production Facilities Where There is the Compensatory Use of Renewable Energy Sources

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ABSTRACT

Renewable energy has become a promising way to meet growing energy needs in the society. However, operation of power supply systems based on renewable energy sources (RES) depends on a number of uncontrolled factors. This imposes certain restrictions on applications and causes application-related challenges. At this point, the search for the best combination of applied energy sources has been still a key issue. Methodological approaches to the solution to this problem are diverse. The idea of our research is the application of tools from economics and mathematics to measure the best mutual substitution of energy resources in the production facility local power supply system. Authors have considered the possible application of RES through the example of the Russian-based production facility typical in terms of average power consumption and size. Authors chose a solar power plant as a RES. From the simulation results, authors conclude that when using RES, in terms of gross figures, there is about 20-25% less consumption. This makes it possible to achieve the balanced energy consumption from traditional sources throughout a production cycle. Our calculations have showed that, depending on the seasonal prevalence, it is possible to reduce average daily costs for power (in case of compensation from RES) by about 15.75% in the first season, 37.04% in the second season, and 25.44% in the third season. As for time period, in the second season, in the half-peak period (43.68%), we achieve the highest saving, while the lowest saving in the half-peak period of the first season (1.22%). Thus, the application of the solar power plant as a part of the local power supply system of the production facility makes it possible on average to achieve the 13% less energy consumed from centralized sources. It is safe to say that the application of combined sources of power in local power supply systems of production facilities is economically feasible to compensate for peak and half-peak loads. Authors have concluded that the potential of RES at the enterprise might be only developed as that of an additional energy resource and full substitution is impossible.

Keywords: Renewable Energy Sources, Production Facilities, Centralized and Decentralized Power Supply Systems, Balance of Energy Resources, Resource Sustainability
JEL Classifications: Q43, L95, L97

1. INTRODUCTION

The ensured and uninterrupted power supply is a key economic challenge. The stimulation of the consumers' involvement (to achieve higher operating performance and reliability of the power supply system) has been a clear recent trend (Carley et al., 2017). At the same time, the observable higher resource intensity of production processes has greatly changed energy consumption in production facilities (Danilov, 2006). Now, renewable energy sources (RES) make a significant share in power balances. In terms of the never-ending deficit and growing costs for conventional power resources, the compensatory use of RES is a way to reduce the environmental load and achieve economic sustainability (Uno, 1995; Gulyani, 2001). Therefore, the transition to RES has become more and more relevant across the world.

The power supply to consumers based on RES-based power plants only is an application challenge difficult in its solution as their operation depends on uncontrolled factors. Hence, the use of these energy sources will impose certain restrictions related to uneven (volatile) generation from RES due to natural dependence on environmental conditions. As a result, their application becomes economically feasible when integrated with centralized power distribution systems (Sibikin and Sibikin, 2012).

As far as power supply networks were designed for the centralized power supply, the application of RES in them leads to new challenges. Among them, consider redundancy (need in the direct and reverse energy compensation), energy security and economic sustainability (Abrhám et al., 2018; Jefimovs, 2017; Lisin et al., 2018), insufficient funding for renewable energy projects, (Šimelytė et al., 2016), etc. However, we have observed a clear gradual transition from the strictly centralized model of power supply to consumers to the combined model, when renewable sources generate a part of energy. Operating directly in distribution power supply networks, RES might get main networks in peak periods unloaded, making them more reliable. Note that with the development of RES, there are changes to operating economic parameters of energy sector. In particular, in the world practice, there has been the gradual transition from the wholesale market to the balancing market of energy and power supply under bilateral contracts. These mechanisms are based on Demand Response (Sipina, 2014). However, in a number of countries, highly centralized power supply systems have been still in place (Kuzmin et al., 2019). This excludes possible implementing of bilateral contracts in the open market. One of the ways for their development is local optimization of energy consumption structure.

The introduction of RES in local power supply systems at production facilities obviously increases their operation sustainability and creates incentives for resource saving. The search for the best combination of energy sources has been still a key issue here to achieve the highest economic efficiency. Methodological approaches to this problem are diverse. This research idea lies on the application of tools from economics and mathematics to measure the best mutual substitution between energy resources in the production facility local power supply system. The model should be the base to calculate a ratio between energy source materials for the enterprise, taking into account external controlled parameters, including enterprise location, a type of RES, and other factors. There are no strict standards for choosing the resource structure in the local power supply system and this makes it possible to choose parameters under such projects in the variable-based manner.

2. LITERATURE REVIEW

In contemporary concepts of sustainable development, theoreticians pay special attention to renewable energy (Gracia and Quezada, 2016) with its essential role in the energy supply (Heshmati et al., 2015). Numerous researchers point out to fundamental importance of ongoing economic processes, for instance, Munasinghe (1994), Elliott (2007), Costantini and Crespi (2013), and Welfens et al.,

(2016) say that the transition to sustainable development in the energy sector is a global challenge. Such a transformation takes long time, but planning analysts have already developed plans for the transition to RES.

By impact of random natural processes and compared to primary energy sources, Lukutin (2008) and Gruzin (2014) divide dispersed RES sources into the renewable sources with conditionally controlled generation and renewable sources with controlled generation. The type of energy source predefines prospects for RES introduction under specific conditions.

Behera and Mishra (2019) and Saad and Taleb (2018) refer the expected technical and economic effect from RES introduction to optimization of generation, transportation and consumption of energy, accompanied by the economic growth. The ensured operational efficieny in power supply systems together with RES is one of the main objectives. At the same time, keep in mind that production enterprises face the need in the ensured uninterrupted power supply to their production processes (Todorov et al., 2019). Adaptive RES management meets such requirements the most with some functions decentralized.

Pagani and Aiello (2012) believe that, in terms of development of RES and limited centralized power supply, modernization of existing power supply systems has close links to SMART Grid technologies. Bharathi et al. (2017), Ahmad and Abrar (2017), Rogalev et al. (2018), Vlasov et al. (2019) consider the process-oriented side of the issue, where owing to local systems for self-regulation and self-diagnosis, power supply networks might control power supply depending on its consumption mode.

The mechanism for stimulating the involvement of both commercial consumers, and households in keeping the balance of energy resources is based on the demand response software (Ruiz et al., 2018). Such programs provide for payments to consumers for changes in their schedule of energy consumption under certain conditions. Treado and Carbonnier (2013) believe that the energy suppliers' ability to control the operation of consumers' electrical installations is an important stated feature of distributed RES, that is, the remote control over energy consumption, shifting it in time and adjusting it to the best schedule of cumulated generation. Looking forward, owing to flexible transient feedbacks with the application of communication networks, it will be possible to control operating modes of individual consumers' electrical installations in order to adjust consumption modes in terms of volatile energy generated by RES.

Nagurney and Matsypura (2007), Patil et al. (2018) consider the introduction of decentralized RES management in local enterprise power supply systems. They developed mathematical models for the best conditions and substantiated techniques for management of RES as compensatory sources. Vijay Venu and Verma (2010), Galaso and Kovářík (2018) believe that decentralization of some management functions lies on forms that the power supply system has to create conditions for sustainability and adaptability.

It is possible to refer to a number of other relevant aspects in development of the renewable energy sector. They have not been sufficiently studied so far or they have not had a conventional solution. We mean that the impact of RES on the structural, balance, and operational reliability of power supply systems (Rusan and Hassan, 2015; Rodionov, 2010), operational specifics of production facilities in terms of gradual decentralization of power supply, identification of challenges related to RES operation in electric networks (Nalbandyan and Zholnerchik, 2018; Rudchenko, 2017; Craig, 2019; McKenna et al., 2013), the best compensatory application of RES (Lushnikov et al., 1996; Bhandari et al., 2016; Bhandari et al., 2015), management of dispersed energy sources (Ramirez and Stoeglehner, 2018; Tarui, 2017; Brown and Sappington, 2017), etc.

The completed survey makes it possible for us to conclude that in recent decades, there has been an increasing interest in RES in the world. At different levels, people have clearly understood the need in the development of RES and their introduction in the existing power supply system. In general, sources of literature include the clearly stated objective, i.e. the search for the best combination of energy sources, where RES play a key role. Its solution is contingent on procedural closer definition of optimality parameters in compliance with the established conditions and restrictions. To achieve this, below, we make an attempt to measure the efficient operation of the local power supply system at a production facility with compensatory replacement of conventional energy sources with the renewable ones.

3. MATERIALS AND METHODS

Our research purpose is an analysis of prospective application of RES in local production power supply systems. The academic research focus on the evaluation of the best configuration of various sources of electric power, taking into account the available environmental capacity of the area where production facilities are located. In terms of a transition from the centralized distribution approach, it is important to maintain sustainabille operation of the enterprise. Researchers approach these tasks with the help of simulation techniques (Batkovskiy et al., 2015).

We expect that the RES (in the simulated case, this is an autonomous solar power plant) is able to compensate for peak and half-peak loads. We assume that solar panels will only be on top of production facilities and outside of other free areas. We expect that calculations will show, which share of the energy consumed by the enterprise might be compensated and whether it is efficient to use combined energy sources in terms of the conditionally uninterrupted demand.

For simulation purposes and the measurement of changes to the parameters in the power supply system, we build the research object taking into account average dimensions of production facilities and their average energy consumption in the Southern Federal District of Russia (IDGC of the South; and FGC UES).

For the calculation, we will use the following raw data:
Standar production facility: length c = 50 m, width d = 40 m,

Coordinates: 48°39'25''north latitude; 44°31'40'' east longitude, city of Volgograd, Russia (corresponds to the middle location of southern regions of Russia with the sufficient insolation),
Horizontal length of the array: B = 49,600 mm,
Panel tilt angle: α = 15,
Surface-to-array height: a = 0.5 mm.

We assume that there are solar panels across an entire available roof area of production facilities to cover the most of the plant's electrical load schedule. However, at the same time, daily load schedules of workshops come into account so that the solar panel generation capacity be not higher than the workshop load power to avoid the energy release back to the centralized power supply system.

The simulation lies on parmeters of the Trina Solar ALLMAX-PD05.08 panel with dimensions of 1,650 × 992 × 35 mm. ALLMAX Trina series panels are ideal for roof systems, they can generate relatively large energy even in terms of a small area. See details on panels of this type in Table 1.

Let us find the sun lean angle in summer:

$$\beta_{max} = 90 + \theta_L - N \qquad (1)$$

Let us find the sun lean angle in winter:

$$\beta_{min} = 90 + \theta_Z - N \qquad (2)$$

where θ_L, θ_Z is lean angle of the earth's axis in summer and winter respectively.

Let us find the array projection on the surface:

$$B` = \cos\frac{\alpha\pi}{180}B \qquad (3)$$

Table 1: Basic parameters of panels that belong to trina solar ALLMAX-PD05.08 type

Parameter	Meaning
Solar cells	Multicrystalline 156.75×156.75 mm (6″)
Cell orientation	60 cells (6×10)
Glass	3.2 mm (0.13″), High transmission, AR Coated tempered glass
Peak power watts-PMAX, Wp (P_m)	260-265
Power output tolerance-PMAX, W	0 ~ +5
Maximum power voltage-VMPP, V (U_{mp})	30.80
Maximum power current-IMPP, A (I_{mp})	8.61
Open circuit voltage-VOC, V	37.70
Short circuit current-ISC, A (I_k)	9.15
Module effciency m, %	15.9-16.20
Module dimensions	1650×992×35 mm (65.0×39.1×1.38″)
Weight	18.6 kg (41.0 lb)

Source: Trina Solar Limited (2018)

Let us find the array field length:

$$D = \sin\frac{\alpha\pi}{180}B \qquad (4)$$

Let us calculate the distance from the surface to the top point of the array:

$$A = D + a \qquad (5)$$

Going from available data, let us find the necessary distance between arrays of solar panels:

$$l = \frac{D}{\tan\dfrac{\beta_{min}\pi}{180}} \qquad (6)$$

Then, we calculate the general interval of placement according to the formula:

$$L = l + B' \qquad (7)$$

We measure a number of rows placed on a facility roof:

$$N_M = \frac{d}{L} \qquad (8)$$

We calculate the set production capacity as follows:

$$\sum P_{FAM} = N_{FAM}P_{NP} \qquad (9)$$

where N_{FAM} is total number of panels (550 psc); P_{NP} is noiminal capacity of a solar panel (260 W).

Going from the obtained value of the set power, let us choose the inverter taking into account normal losses. The solar inverter (that belongs to TriPower 15,000TL/20,000TL/25,000TL Series) is suitable for large-scale commercial and industrial power plants. Not only does it deliver extraordinary high yields with an efficiency of 98.4%, but it also offers enormous design flexibility and compatibility with many PV modules thanks to its multistring capabilities and wide input voltage range. See the parameters of the chosen inverter in Table 2.

When we make calculations for solar panel systems, actual insolation is important and we can only know it from observations. Actual insolation at a particular surface point depends on its location, orientation relative to the south, angle to the horizon, configuration of facilities around an object, natural barriers, temperature, and as a result, season of the year. The latitude is in charge of zoning and seasonality in distribution of solar radiation. For the selected location of the array, we took into account the following observed data for local insolation (Table 3).

The specifics of solar energy development and local insolation specifics show that the application of RES will be only in fragments as the compensation for peak and half-peak loads. Continuous

Table 2: Basic Parameters of invertor that belongs to Sunny Tripower 15,000TL type

Parameter	Meaning
Input (DC)	
Generator peak capacity	27,000 W peak
DC calculated capacity$\leq$	15,330 W
Max voltage input	1000 V
Max input current on entry A/B	33 A/33 A
Output (AC)	
Nominal capacity (at 230 V, 50 Hz)	15,000 W
Max apparent output AC	15,000 VA
AC voltage range	180 B...280 V
Nominal output current/calculated output current	29 A/21.7 A
THD	$\leq$3%
Max efficiency output/European efficiency output	98.4%/98.0%

Source: SMA Solar Technology AG

power supply is achievable owing to centralized sources that are main.

The given raw data are sufficient for the calculation of RES performance in the enterprise local power supply system. For this, it is important to find the energy before and upon the compensation.

We calculate the energy consumed before the compensation for a season according to the formula:

$$W_{bk} = P_{spoz}Tn \qquad (10)$$

where P_{spoz} is intake power, kWh/day; T is run-time of power consuming device, days, T = 30 days; n is number of months in a season, n = 4.

The energy, generated by the solar power plant (photovoltaic power system) per season:

$$W_{FAM} = P_{vir}Tn \qquad (11)$$

where $P_{vir.}$ is power output, kWh a day, T is operation period of enterprise, days, T = 30 days, n is number of months in a season, n = 4.

The energy consumed for the season, compensation included:

$$W_k = W_{bk} - W_{FAM} \qquad (12)$$

The actual power of solar panels is on average 75-85% of their nominal rated power. This primarily depends on climatic factors, as well as an inclination angle and orientation of the modules. Solar panels are the most effective when their surface is perpendicular to rays of the sun. Solar panels are fixed on roofs of production facilities, so they are not at the right angle to the sun rays throughout a day. In this case, workers choose such an inclination angle for the panels themselves which will ensure that they are at the right angle to the sun's rays for the longest time.

To calculate the annual energy generated by solar power plants, let us use Table 3. By multiplying data from Table 3 by a number of solar modules installed on a roof, we will obtain power and energy data for a particular facility. Next, let us measure the total energy generated by solar power plants in a year. See below the

Table 3: Local Monthly Average Insolation on Horizontal Surface in Indicated GMT-hours (kWh/sq.m.)

Month time	January	February	March	April	May	June	July	August	September	October	November	December
3 am	–	0.00	0.00	0.03	0.07	0.08	0.07	0.04	0.01	0.00	–	–
6 am	0.04	0.09	0.18	0.28	0.43	0.43	0.42	0.36	0.26	0.16	0.07	0.04
9 am	0.20	0.28	0.39	0.49	0.60	0.57	0.61	0.57	0.47	0.33	0.19	0.17
Noon	0.15	0.24	0.32	0.39	0.49	0.48	0.51	0.48	0.36	0.23	0.12	0.11
3 pm	0.00	0.02	0.06	0.12	0.20	0.22	0.23	0.18	0.07	0.02	0.00	0.00
6 pm	–	–	–	0.00	0.00	0.01	0.01	0.00	–	–	–	–

Source: Pionkevich (2016); Insolation tables; Quantity of solar Energy in Russain Regions

Table 4: Rate multipliers and period duration

Time	Night	Half-peak	Peak
Rate multipliers	0.25X	1.02X	1.8X
Period duration, h	7	11	6

Figure 1: Average monthly daily total solar energy, kW

simulated calculation of solar panels' power and energy depending on time of the say and season.

4. RESULTS AND DISCUSSION

Following average local insolation values and raw data used for simulation of the compensatory application of RES, let us calculate the capacity of solar energy generation by the production enterprise (average monthly). Let us measure the energy taking into account losses and the conversion factor in case of conversion of horizontal plane insolation values to the angulated plane ones (Figure 1).

As boundaries of periods, there are the following three seasons: the first one includes January, February, November, and December. The second one includes March, April, September, and October. The third one includes May, June, July, and August. Using insolation data, we created diagrams (Annex 1-3) for energy consumption by the enterprise in given seasons by the following parameters: energy consumption by the enterprise without compensation, power generated by the solar plant, energy consumption by the emterprise with the compensation from the solar power plant. The results show that using RES and judging from gross values, we see about 20-25% less consumption. This helps to achieve the even consumption of energy from conventional sources throughout a day.

Tariff rates are different by time period (night, half-peak, and peak) and season. In the case in question, the following rate multipliers and duration of periods are valid (Table 4).

The period when there is the compensation of consumption at the expense of RES coincides with the time of peak loads (daytime). Rate multipliers for the half-peak and night time offset benefits from RES. The cost of energy at this time is less. Therefore, it is comparable with the net cost of energy generated by RES.

Next, let us calculate power supply system parameters for various seasons (Table 5).

See details of the estimated energy consumed by the enterprise in Table 6 for the first season as an example.

It is clear from Table 6 that the average daily energy consumed by the enterprise local power supply system in the first season
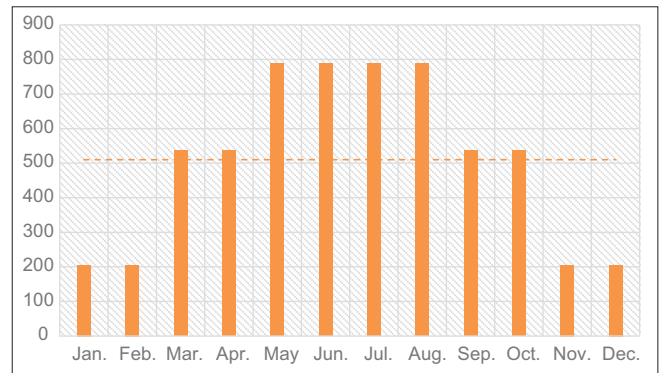
and compensation exluded is 1570 kW. The intraday dynamics of energy consumption is uneven and in 3 am to midnight it is 30-100 kW with the average value of 71.4 kW. Besides, during the day, there are intervals of high energy consumption, when values exceed the average one (over 71.4 kW). For instance, the total of 782 kW accounts for the interval of 8 am-4 pm, which is 50% of the daily energy consumption.

The solar power plant on average generates 206.4 kW per day. This is approximately 13% of the average daily consumption. The power of the solar power plant is also uneven during the day. It generates electricity from 6 am to 4 pm due to the regional intraday insolation time interval. The average power in the active operation interval of the plant is 20.6 kW, the highest is 30 kW, while the lowest is 7.5 kW.

Thus, inclusion of the solar power plant in the enterprise local power supply system makes it possible to achieve 13% less amount of the power consumed daily from centralized sources. The reduction is achievable owing to the compensation by the power plant and its use for supply of the required power in time of the high load of equipment.

Next, let us find the difference between the notional cost of the power consumed before and after the compensation (Table 7).

It is possible to find the cost for electricity for each period of time and season by multiplying a corresponding rate for consumers by a rate multiplier and an amount of electricity. The power consumption configuration over time is constant with the following distribution - 18%:52%:30%. Electricity generation by the solar power plant is subject to severe seasonal effects. As for the total volume of its distribution by time intervals, the configuration looks like 11%:63%:26%.

Table 5: Energy consumed by enterprise before and upon the compensation in various seasons

Season	Energy consumed before compensation, thousand kWh/season	Power of solar plant, thousand kWh/season	Energy consumed upon compensation, thousand kWh/season
Season 1	191.01	25.11	165.90
Season 2		68.70	122.31
Season 3		47.19	143.82

Table 6: Average daily parameters of enterprise local power supply system in the first season

Time	Consumption without compensation, kW	Solar power plant		Consumption with compensation, kW
		Power, kW	Insolation, kWh/sq.m.	
3 h am	32.0	0.0	0.0	32.0
4 am	30.0	0.0	0.0	30.0
5 am	48.0	0.0	0.0	48.0
6 am	70.0	8.6	0.06	61.4
7 am	70.0	14.3	0.10	55.7
8 am	80.0	22.9	0.16	57.1
9 am	90.0	30.0	0.21	60.0
10 am	100.0	30.1	0.21	69.9
11 am	100.0	28.6	0.20	71.4
Noon	85.0	28.6	0.20	56.4
1 pm	80.0	21.5	0.15	58.5
2 pm	90.0	14.3	0.10	75.7
3 pm	82.0	7.5	0.05	74.5
4 pm	75.0	0.0	0.0	75.0
5 pm	70.0	0.0	0.0	70.0
6 pm	80.0	0.0	0.0	80.0
7 pm	70.0	0.0	0.0	70.0
8 pm	72.0	0.0	0.0	72.0
9 pm	70.0	0.0	0.0	70.0
10 pm	78.0	0.0	0.0	78.0
11 pm	58.0	0.0	0.0	58.0
Midnight	40.0	0.0	0.0	40.0
Total	1570	2064	1.44	1363.6

Night time
Half-peak time
Peak time

Table 7: Calculated notional cost of the power consumed by enterprise before and upon the compensation (daily)

Season	Day period	Energy cost before compensation, kWh rate X	Cost of energy generated by solar power plant, kWh rate X	Cost of energy upon compensation, kWh rate X	Average saving for centralized energy consumption in case of compensation (%)
Season 1	Night	72.50	5.73	66.78	7.90
	Half-peak	883.44	10.76	61.74	1.22
	Peak	831.60	265.08	618.36	31.88
Season 2	Night	72.50	15.66	56.84	21.60
	Half-peak	883.44	385.90	497.54	43.68
	Peak	831.60	260.52	571.08	31.33
Season 3	Night	72.50	10.76	61.74	14.84
	Half-peak	883.44	265.08	618.36	30.00
	Peak	831.60	178.95	652.65	21.52

Our calculations have showed that, depending on seasonality, average daily costs for power in case of the compensation from RES might be about 15.75% less in the first season, 37.04% less in the second season, and 25.44% less in the third season. As for the day interval, the highest saving is achievable in the second season in the half-peak period (43.68%). The lowest saving accounts for the half-peak period of the first season (1.22%).

For simulation purposes, we assumed that we ignored the net cost of the power generated by RES for the enterprise local power supply system. The saving will be comparable when the standard rate parameter in the centralized distribution network and the net cost of the power generated by RES are included in the model. Nevertheless, it is safe to say that the application of combined power sources in local power supply systems of production facilities is economically feasible for the compensation for peak and half-peak loads.

The obtained simulation results showed that for the enterprise, the advantage of the combined power supply system is that

there is the distribution of power generating sources and thereby there are diversified supplies and lower dependence on external sources. Therefore, to solve tasks of operational management of standard modes of RES in the local system, one needs to use the adaptive approach to find the best ratio in the configuration of power sources. The efficiency of this approach gets higher if there are diverse RES control modes. The combined operation of centralized power sources and RES should be organized in such a way as to achieve the systematic technical and economic effect.

There are various techniques that we can use to find the best design and operational parameters of RES. The most suitable solution depends on the techniques that make it possible to obtain stable functional ties between controlled variables and control parameters. In time of the adaptive system making, one has to consider natural features, energy conversion processes, as well as its transmission and distribution in the local power supply system, where the energy demand is relatively stable. To do this, mathematical models need improvements. This will make it possible to measure the real impact of specific RES on stability parameters for the enterprise power supply regime. Solutions to the above mentioned problems will make it possible for us to develop a set of techniques and aids for the optimized combined application of diverse RES in electric networks, taking into account requirements and conditions of centralized power supply.

To achieve higher technical and economic performance in combined operation of RES and centralized distribution networks, it is necessary to continue research on features of their combined operation in the enterprise local power supply system. Optimization of schemes for RES connection to the electric network with a commensurate aggregate load power should be based on results of the analysed sensitivity of the RES influence on operation parameters of the enterprise local power supply system. Our calculations have showed that such solution might be applicable both to large and medium-sized production facilities, which are often main power consumers.

5. CONCLUSION

Tight conventional energy resources cause the need in wider use of RES. In general, there is a clearly set academic objective, i.e. to find the best configuration of the energy sources that are in use where RES play a key role. The research aims at getting closer to the answer to this question. In the simulated situation, we have tested the hypothesis that a RES (in the form of the autonomous solar power plant) is not only able to compensate for peak, but also half-peak loads at the standard production enterprise.

The obtained results show that the application of the solar power plant as a part of the enterprise local power supply system makes it possible to achieve a 13% reduce in the amount of the electric power consumed from the centralized sources. The reduction is achievable owing to the compensation from the generating power plant in time of the high load of the enterprise. Our calculations have showed that, depending on seasonality, it is possible to reduced average daily costs for electric power owing to the compensation from RES by about 15.75% in the first season,

37.04% in the second season, and 25.44% in the third season. As for day interval, the highest saving is achievable in the second season in the half-peak period (43.68%), the lowest saving is achievable in the half-peak period of the first season (1.22%). Thus, it is possible to state with confidence that the application of combined sources of electric power in local power supply systems at production enterprises for the compensation of peak and half-peak loads is economically feasible.

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ANNEX

Annex 1: Parameters of the enterprise local power supply system in the first rate season, kWh (average daily): power consumption by the enterprise, compensation excluded (blue line), power produced by the solar power plant (red line), power consumption by the enterprise with compensation from the solar power plant (green line)
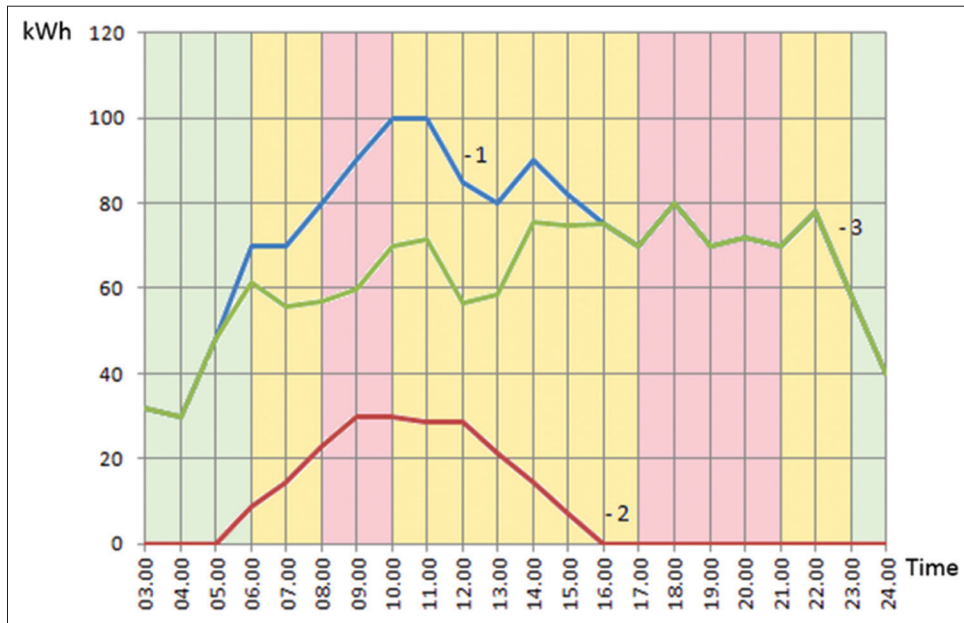
Annex 2: Parameters of the enterprise local power supply system in the second rate season, kWh (average daily): power consumption by the enterprise, compensation excluded (blue line), power produced by the solar power plant (red line), power consumption by the enterprise with compensation from the solar power plant (green line)
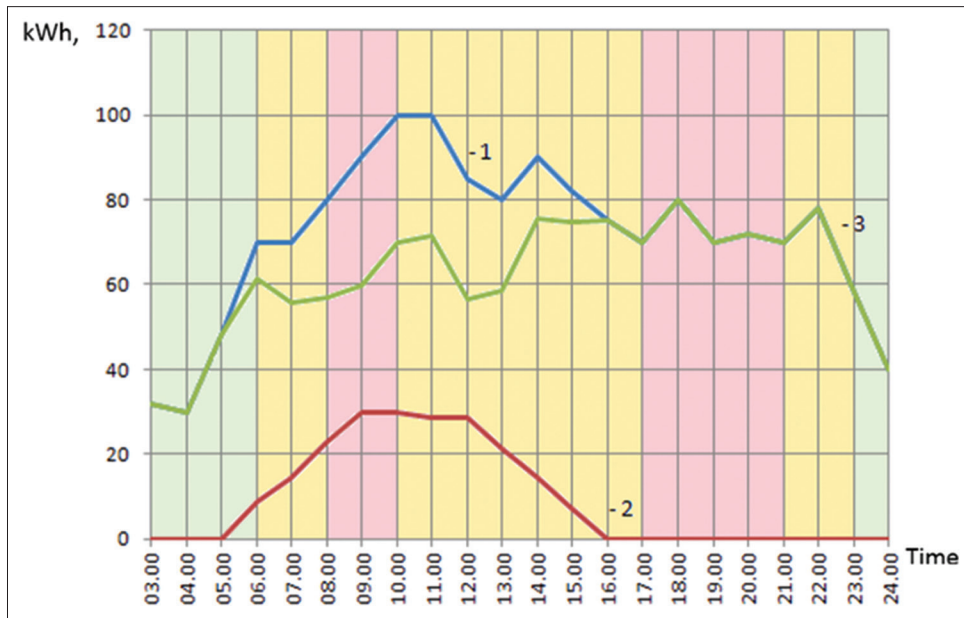
Annex 3: Parameters of enterprise local power-supply system in the third rate season, kWh (average daily): electric power consumption by the enterprise, compensation excluded (blue line), power produced by the solar power plant (red line), power consumption by the enterprise with compensation from the solar power plant (green line)