IOP Conference Series: Materials Science and Engineering

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Prospects of introducing alternative sources of energy on Ukrainian railways

To cite this article: V V Panchenko *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1021** 012008

Prospects of introducing alternative sources of energy on Ukrainian railways

V V Panchenko [1,2], A S Masliy [1] and R O Kharin[1]

[1] Department of Electric Power Engineering, Electrical Engineering and Electromechanics Ukrainian State University of Railway Transport, Feyerbakh Square 7, 61050, Kharkiv, Ukraine

[2] Email: vlad_panchenko@ukr.net

Abstract: The potential of solar and wind energy was investigated, the existing premises of using the electric power obtained from non-conventional power sources of non-traction consumers for power supply of an electric traction system were analyzed. The influence of solar generation sources connected with the traction substation tires on the stability of non-traction consumers was determined. Possible options of connecting renewable energy sources to the railway power systems were examined. Calculations for determining the number of solar panels for compensating the auxiliary power consumption of the traction substation were made. The modeling of the possibility of implementing alternative energy sources in a traction substation in the PVsyst program was carried out. In Ukraine, the change of conditions for the provision of electricity supply services was caused by the rapid growth and development of renewable energy sources, in connection with which the number of suppliers increased. The question about the possibility of using alternative electricity sources to compensate the auxiliary power consumption of traction substations arises. Therefore, it is relevant to solve the problem of joint work of auxiliary power consumers together with non-traditional energy sources. The auxiliary power consumption of the traction substation include: heating drives and tanks of transformers; cooling down trip coils, relays, control panels, alarm systems, alarm and centralization and blocking devices; heating substation premises, store rooms and shower room. In order to implement alternative energy on the railway, it is necessary to analyze the auxiliary power consumption of the traction substation; to analyze the possibility of placing alternative power sources on the traction substation premises; to investigate how the powering system of the auxiliary power consumption of the traction substation can operate (both directly and in parallel mode).

1. Introduction.

In Ukraine, the amount of electricity obtained from non-traditional sources is growing. At the same time, alternative sources of electricity are developing rapidly, the number of suppliers is increasing and the conditions for providing electricity supply services are changing [1]. This process is conditioned by the difficult environmental situation, environment protection procedures and the complexities of energy policy in the world. Over the past few years, Ukraine has made significant progress in the development of alternative energy sources, in particular solar and wind power plants. However, the introduction of innovative energy-saving technologies using alternative renewable energy sources is still at the initial stage in our country. Today, the Ukrainian railways almost exclusively use traditional power supplies in their power supply systems. Yet, the rapid development of alternative energy is pushing for the modernization of railway power supply systems through the introduction of non-conventional power sources [2]. We believe that the introduction of solar and wind energy sources is the most acceptable solution to the issue. The main directions for introducing alternative energy on the railway are as follows:

- power supply of traction power supply systems from the external power system, in which, alternative sources of energy operate along with traditional ones;
- power supply to compensate power auxiliary consumption of a traction substation, objects of infrastructure of non-traction consumers both separately, and in a parallel mode of work [3].

It is especially important in the regions where the external electricity supply of railways is unstable, so the use of independent sources of electricity is crucial to ensure the traction and meet the needs of non-traction railway consumers [4]. Nowadays two documents regulate the requirements for connecting solar and wind power plants to industrial power grids in Ukraine:

- requirements for wind and solar photovoltaic power plants for connection to external electrical networks;
- connection of wind energy facilities to electrical networks. Procedure and requirements. The document [5] defines the basic requirements for wind and solar photovoltaic power plants (i.e. for power plants that use static electronic energy converters) with a capacity of 150 kW for connection to public grid.

Connection to electrical networks of other types of renewable sources with synchronous generators that are directly connected to electrical networks is regulated by other normative documents in force in Ukraine.

2. Analysis of the recent researches and publications.

Researching the possibility of introducing alternative sources of energy to compensate power auxiliary consumption of traction substations is topical and promising. Over the past years a number of experimental researches have been conducted on introducing alternative energy sources on Ukrainian railways. The analysis of the recent researches and publications, which initiated the solution of this problem, showed that such scientists as M. Pastushenko, O. Polyakh, V. Sychenko, O. Bondar, Y. Honcharov, E. Kosarev, M. Prykhoda, T. Reshetnyak and others paid their attention to various aspects of renewable energy sources. The following tasks have been solved:

- analysis of the solar generation impact on the operation of traction substations on electrified railways;
- prospects for the introduction of renewable energy sources on the railway transport of Ukraine;
- the possibility of using alternative sources of energy to compensate power auxiliary consumption of traction substations, etc.

On the territory of Ukraine the conditions for the provision of electricity supply services have been changed, which caused a rapid increase and development of renewable energy sources. Therefore, it is necessary to solve the problem of joint work of auxiliary consumers with non-traditional energy sources.

3. Defining the aim and objectives of the study.

The aim is to study the possibility of introducing alternative energy sources into the power supply network of electrified railways by equipping a DC traction substation No. 18 in Zmiiv, Kharkiv region with a solar power plant to compensate its power auxiliary consumption.

To study the possibility of introducing alternative energy sources on the railway the following tasks should be solved:

- to analyze power auxiliary consumption of the traction substation;
- to analyze the possibility of locating alternative power sources on the premises of the traction substation;
- to investigate the operation modes of the power supply system to compensate power auxiliary consumption of the traction substation (both directly and in a parallel mode).

IOP Conf. Series: Materials Science and Engineering 1021 (2021) 012008 doi:10.1088/1757-899X/1021/1/012008

4. Presenting the main material.

The object of the study was a DC traction substation No. 18, Zmiiv, Kharkiv region, its auxiliary power consumption is 27,513 kWh in the period from March to May. For the spring period, the average auxiliary power consumption is 9171 kWh per month, i.e. 299.05 kWh (12.46 kWh) per day.

Let's calculate the number of solar panels to provide power for auxiliary power consumption. It is necessary to determine the type of solar panel to perform the calculation. Jinko Solar JKM305M-60 Eagle 305 W solar panels cost not much, but are of high efficiency.

The total power of the solar battery consists of the output power of individual photovoltaic modules. The output current of the solar photovoltaic modules is determined by the number of elements connected in parallel, and the output voltage – by the number of elements connected in series. Having the nominal power of the photovoltaic station and the power of one photo module, we determine the required number of photo modules:

$$N^{сб} = \frac{P_{nom}}{P_1^{pm}} \tag{1}$$

where P_{nom} is nominal power of the photovoltaic station [W]

P_1^{pm} is nominal power of a photo module [W]

$$N^{pm} = \frac{15000}{305} = 49 \text{ pcs.}$$

Let us recalculate the total number of photo modules, taking into account the way they are connected to the inverter. The number of modules connected in series:

$$N_{ser}^{pm} = \frac{U_{inv}}{U_{\max}^{pm}}, \tag{2}$$

where U_{inv} is the output voltage of the inverter [V]

$U_{\max}^{pm}$ is the voltage of a photovoltaic module [V]

$$N_{ser}^{pm} = \frac{230}{22,8} \approx 10 \text{ pcs.}$$

the power of the batteries connected in series:

$$P_{ser}^{pm} = N_{ser}^{pm} \cdot P_1^{pm}, \tag{3}$$

$$P_{ser}^{pm} = 10 \cdot 305 = 3050 \text{ W}$$

the number of photovoltaic modules connected in parallel:

$$N_{par}^{pm} = \frac{P_{\max}^{sys}}{P_{ser}^{pm}}, \tag{4}$$

where $P_{\max}^{sys}$ is the power of the settlement system;

$$N_{par}^{pm} = \frac{12,46}{3,13} = 4 \text{ pcs.}$$

the total number of photovoltaic modules in the system:

$$N^{pv} = N^{pm}_{par} \cdot N^{pm}_{ser}, \tag{5}$$

$$N^{c\delta} = 10 \cdot 4 = 40 \text{ pcs.}$$

the total number of photovoltaic modules:

$$S_{pvm} = S_1 \cdot N^{pm}, \tag{6}$$

$$S_{pvm} = 1,63 \cdot 40 = 65,2 \text{ m}^2$$

The total area of the roof of the traction substation No. 18, Zmiiv is 378 m^2, i.e. the area required for solar-battery cells will occupy 17.24% of the total roof area [6].

Let's determine the number of solar panels, their location and model a solar power plant to compensate the auxiliary power consumption of the traction substation using the software package PVsyst.

Let's have a look at the traction substation No. 18, Zmiiv of the Regional Branch «Pivdenna Zaliznytsia» of Ukrzaliznytsia JSC (Figure 1).

Figure 1. Traction substation No. 18, Zmiiv.

The initial data of the selected solar panels, inverters, traction substation were entered into the PVsyst program (Figure 2). We selected solar panels of Jinko Solar JKM305M-60 Eagle 305 [7] W brand. They are modern single-crystal solar batteries that:

- cost not much and are of high efficiency;
- withstands harsh operating conditions, high salt spray performance and ammonia resistance;
- uses the latest technology to increase the efficiency of the module, which makes it ideal for roof installation;
- minimizes the possibility of rupture of conductive track network.

Solar panels work only when there is some sunlight. Dynamic current significantly decreases in the cloudy weather or in the darkness. To compensate this effect, the battery must accumulate the electricity produced by these modules during the day [8]. There are different types of batteries. Therefore, rechargeable batteries for photovoltaic systems must meet certain requirements:

- low level of self-discharge;
- ability to work in modes;
- deep discharge;

- operate with small charge currents;
- operate at below-freezing temperature (for year-round systems);
- minimum service requirements [9].

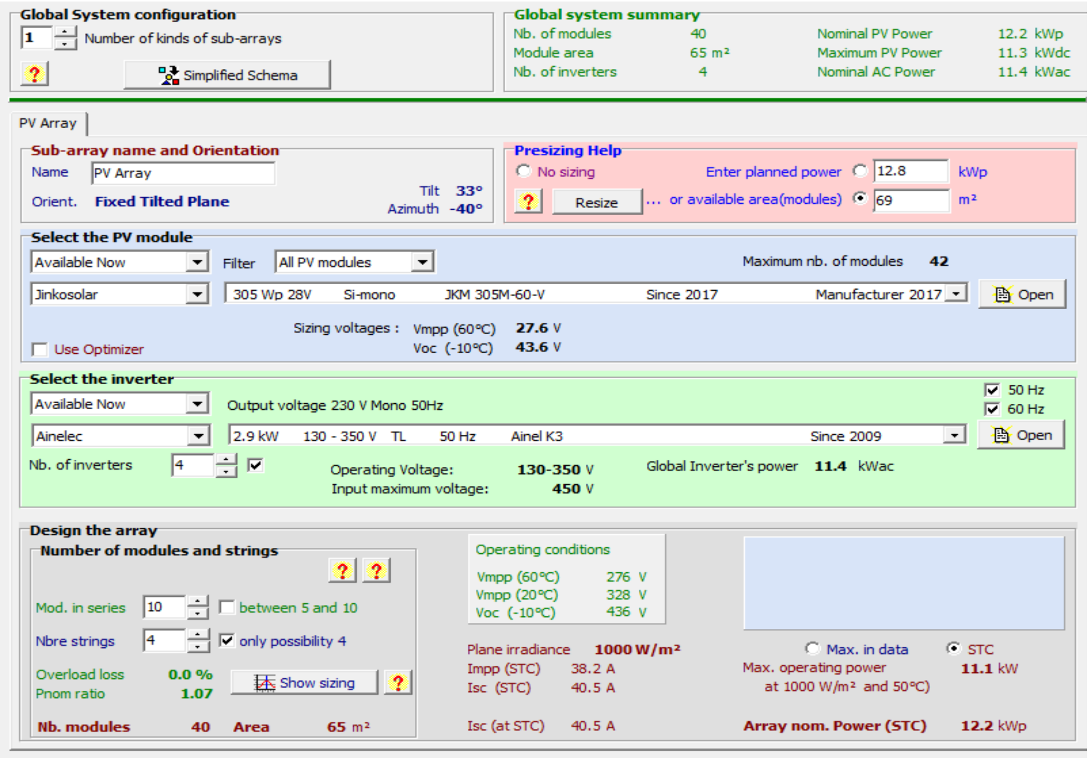

Figure 2. Initial data of a solar substation.

We calculated the number of solar panels and determined their location with the maximum efficiency in real operating conditions (Figure 3). Solar panels are located in 4 rows of 10 photo modules each with a total capacity of 12.20 kW and occupy a total area of 65 m^2.

We chose an Ainelec K3 130-350V/50Hz inverter with a maximum efficiency of 98%.

The solar battery tilt is 33° (the optimal tilt for the eastern region of Ukraine and the location of the substation) and the azimuth is 40°. Such parameters guarantee the highest "potential" indicator of energy production [10].

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Grid-Connected System: Simulation parameters

Project :	**Zmiyiv**			
Geographical Site		**Zmiyiv**	Country	**Ukraine**
Situation	Latitude	49.67° N	Longitude	36.35° E
Time defined as	Legal Time	Time zone UT+2	Altitude	85 m
	Albedo	0.20		
Meteo data:	**Zmiyiv**	NASA-SSE satellite data 1983-2005 - Synthetic		
Simulation variant :	**Traction substation №18 Zmiyiv**			
	Simulation date	20/02/20 14h56		
Simulation parameters	System type	**Building system**		
Collector Plane Orientation	Tilt	33°	Azimuth	-40°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			
PV Array Characteristics				
PV module Si-mono	Model	**JKM 305M-60-V**		
Original PVsyst database	Manufacturer	Jinkosolar		
Number of PV modules	In series	10 modules	In parallel	4 strings
Total number of PV modules	Nb. modules	40	Unit Nom. Power	305 Wp
Array global power	Nominal (STC)	**12.20 kWp**	At operating cond.	11.06 kWp (50°C)
Array operating characteristics (50°C)	U mpp	289 V	I mpp	38 A
Total area	Module area	**65.5 m²**	Cell area	57.0 m²
Inverter	Model	**Ainel K3**		
Original PVsyst database	Manufacturer	Ainelec		
Characteristics	Operating Voltage	130-350 V	Unit Nom. Power	2.85 kWac
Inverter pack	Nb. of inverters	4 units	Total Power	11.4 kWac
			Pnom ratio	1.07
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	127 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Figure 3. Characteristics of the substation modeling.

The calculations show that this solar substation completely covers the value of the auxiliary power consumption of the design traction substation. The auxiliary power consumption of the traction substation is 11.08 kW, the solar substation will generate 12.20 kW, which completely covers the electricity consumption.

The location of solar panels on the roof of the traction substation is illustrated by the 3D model in PVsyst program (Figure 4). The model of the traction substation is as close as possible to reality. The solar panels are located on the roof of the traction substation with a tilt of 33° and are directed to the east to maximize energy production.

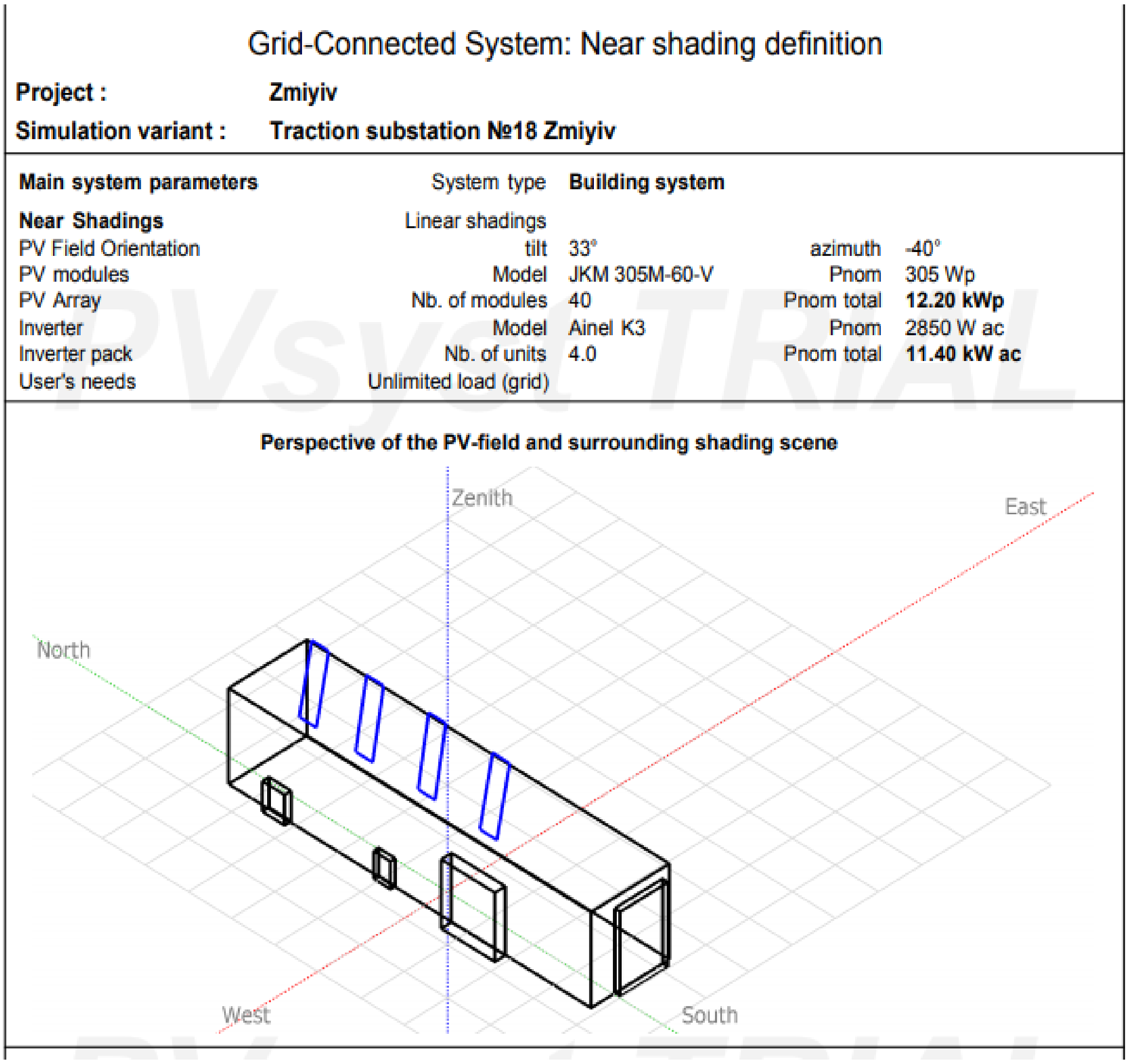

Figure 4. 3D model of the traction substation withy solar panels installed.

The efficiency of the solar substation for the calendar year is illustrated by figure 5, where the total energy obtained from alternative sources is 13.92 MW per year. The performance ratio of the solar substation is 84.57%. The average indicator of alternative energy obtained is 3.13 kW per day, the average loss of alternative energy is 0.57 kW per day.

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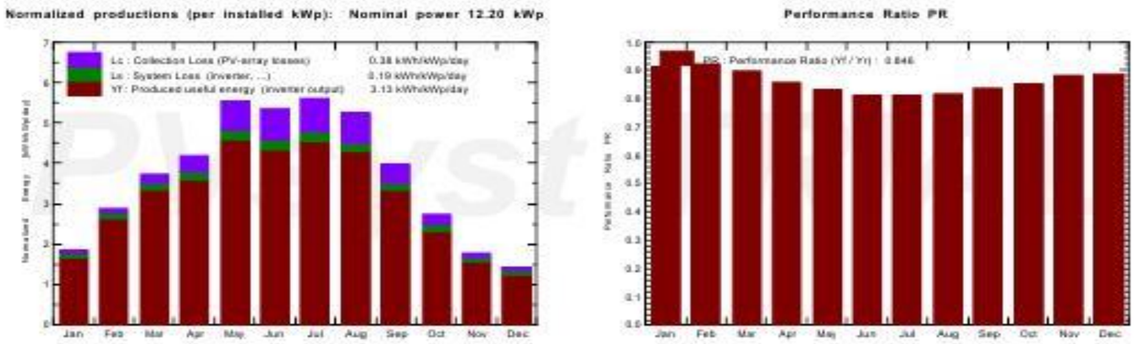
Grid-Connected System: Main results

Project : **Zmiyiv**

Simulation variant : **Traction substation №18 Zmiyiv**

Main system parameters	System type	**Building system**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	33°	azimuth	-40°
PV modules	Model	JKM 305M-60-V	Pnom	305 Wp
PV Array	Nb. of modules	40	Pnom total	**12.20 kWp**
Inverter	Model	Ainel K3	Pnom	2850 W ac
Inverter pack	Nb. of units	4.0	Pnom total	**11.40 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**13.92 MWh/year**	Specific prod.	1141 kWh/kWp/year
	Performance Ratio PR	84.57 %		



Traction substation №18 Zmiyiv

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	36.9	22.32	-5.24	57.5	54.3	0.680	0.640	0.912
February	56.8	30.52	-4.86	80.4	76.6	0.953	0.902	0.920
March	94.6	50.22	0.72	115.1	110.4	1.333	1.262	0.899
April	117.6	63.30	9.83	125.9	120.9	1.392	1.312	0.854
May	166.8	77.50	16.58	171.2	164.4	1.830	1.731	0.829
June	163.8	80.70	20.21	160.4	153.7	1.679	1.584	0.810
July	172.4	79.98	22.71	174.1	167.1	1.818	1.719	0.809
August	151.3	69.13	22.13	162.9	156.7	1.709	1.618	0.814
September	104.7	51.60	16.21	119.7	114.9	1.291	1.220	0.836
October	65.1	35.03	9.06	84.5	80.6	0.936	0.879	0.852
November	35.7	22.20	0.55	53.2	50.3	0.613	0.573	0.883
December	27.9	17.98	-4.57	43.9	41.1	0.510	0.475	0.886
Year	1193.5	600.47	8.69	1348.8	1290.9	14.745	13.916	0.846

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

PVsyst Evaluation mode

Figure 5. Simulation results for power generation by a solar power station.

The simulation results indicate that the most productive period for the production of alternative energy is from June to August.

The average energy obtained through this period is 4.20 kW per day, the average loss per day is 0.92 kW. In winter, efficiency decreases but does not disappear.

The least favorable period for alternative energy production is the period from November to January. The amount of energy received is 1.6 kW per day, the average loss per day is 0.15 kW. The traction substation was modeled taking into account all climatic conditions of Kharkiv region. The results of calculations of the shading factor at different times of the year are shown in Figure 6.

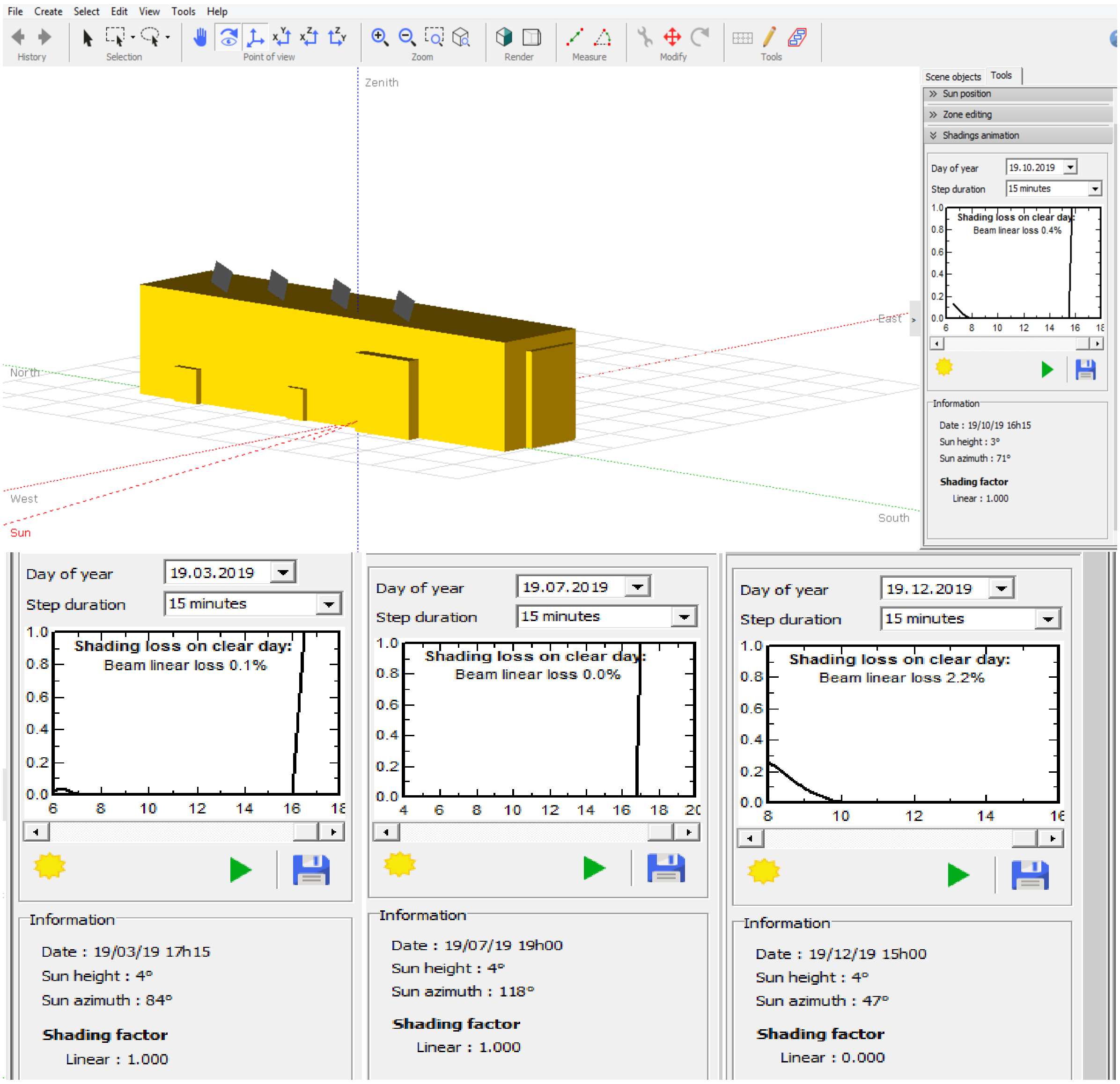


Figure 6. Seasonal shading factor

The greatest shading of solar panels occurs in the period from November to March, when it is about 40% of daylight, and the smallest shading of solar panels is observed from April to September – up to 15%.

5. Conclusions

The current preconditions for the use of electricity obtained from non-traditional sources for power supply to non-traction consumers have been analyzed.

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Having summed up studying the joint work of the auxiliary consumption of the traction substation with non-traditional energy sources, we have:

- calculated the number of solar panels and their ability to supply auxiliary power of the traction substation;
- modeled alternative energy production and defined shading factor for each season;
- determined that the total energy obtained from alternative sources is 13.92 MW per year, which is sufficient to compensate power consumption of the traction substation.

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