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Evaluation of technical and economic effect from setup of distributed photovoltaic generation on the Right-of-Way land of the North Caucasus Railway

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Abstract. In this work, we consider the concept of using a distributed solar power plant, setup on the right-of-way of the railroad. The proposed solution allows to shave peaks of electricity consumption without additional land alienation, using the existing power grids. The concept includes the setup of solar panels on the alienated land of the railroad. PV can be placed directly on the cross ties using damping elements, on the embankment slopes and on the right-of-way land. This solution allows minimizing the cost of solar panels installation along the railway tracks. The North Caucasus railway was considered to assess the gross, technical and economic potential of the proposed solution. The operational length of the railroad there is 6,472 km. The railway consists of large non-electrified sections, segments powered with 25 kV AC and 3 kV DC. The railroad is used not only for cargo transport, but also for long-distance and suburban passenger traffic. We have considered different scenarios for right-of-way land use rate and have shown that possible project costs could be reduced by ca. 25% by double land use only. This does not include shared electric grid infrastructure use that also should benefit considerably, but is hard to be estimated. While the potential nameplate capacity of such power plants within one region is 10s-100s of MW.

1 Introduction

Non-uniform spatial distribution of fuel and energy resources, and existing socio-economic, geographic, and climate factors in Russia lead to substantial costs for their regular supply to regions.

Insufficient modernization of the electric grids required for sustainable economy growth at regional and higher scale, leads to emergence of negative factors affecting all spheres of regions and municipalities development. The restrictive policy for electricity consumption hinders the expansion of industry, affects residential and commercial development, and, as a result, has a negative impact on the economy growth.

According to data provided by Joint-stock Company System Operator of the United Power System and the Russian Ministry of Energy, electricity consumption in Russia in February 2018 increased by 1.7%, as compared to 2017. At the same time, a record low output to consumed energy ratio is stressed in the South (SFD) and North-Caucasus Federal Districts (NCFD) 1, where the growing energy deficit makes it necessary to buy electricity from neighbor regions. The main areas of electricity consumption are transport, industry, and household. Nowadays, railroads represent the only significantly electrified transport mode, so it is reasonable to consider its energy system transformation 1.

In this work, we consider the concept of using a distributed solar power plant (SPP) deployed on the right-of-way (ROW) of the the North Caucasus railway (NCR). The solution allows reduction acute peak electricity shortage. It can be made without additional land alienation and new power distribution infrastructure. All this things are possible because the railways are well connected to the power grids. PV power plants can be placed directly on the cross ties using damping elements, on the embankment slopes, and

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the rest of ROW land. This solution allows minimizing the cost of solar panels installation along the railway tracks.

2 The considered area

The history of global power electricity shows the need of steepwise and planned branch develepment. The implementation of centralised power generation is related to the need for carefully planned investment cycles and to impossibility of sharp technology changes. That means need in electricity infrastructure preparation for new capacities connection 2. Also the equipment obsolescence should be considered. For example, it is known that in Russia about 60% of thermal power plants (TPP) equipment were put into service more than 30 years ago; 80% of nuclear power plants (NPP) – more than 20 years ago, and 21% of hydropower plants – more than 50 years ago 2.

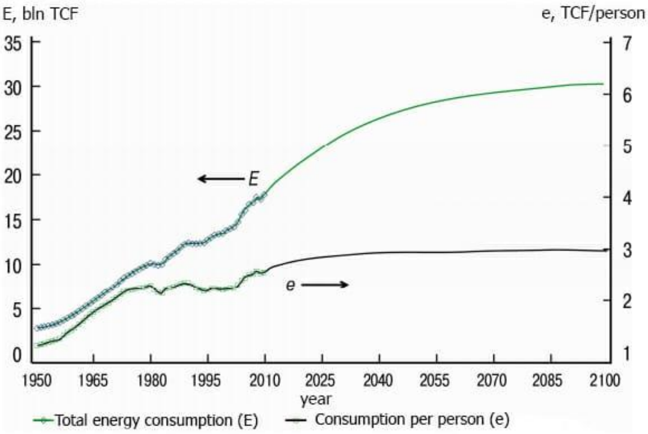

Fig.1. World energy consumption dynamics 4.

The distributed SPP on the base of NCR can help to unload the energy systems and make it decentralized. Also it is the possibility to enter the reneable sourses into system. The reason why this area can be chosen is its location close to the rapidly developing cities that have sharp energy shortage (Krasnodar, Sochi). Availability of suitable climatic parameters and local PV manufacturing in the Spavropol region also affected on the choice.The operational length of the railroad there is 6,472 km, while the total length of the main railway lines is ca. 6,311 km. The railway consists of large non-electrified sections, quite large segments powered with 25 kV AC and short-length parts with 3 kV DC. The road is used not only for cargo transport, but also for long-distance and suburban passenger traffic. We suggest the full cycle energy storage and transportation from SPP to consumer. In addition the secondary use of right-of-way lands is really important for regions with intensive agriculture and resorts, because the cadastral value of land and taxes are high. The railway and adjacent settlements will consume the main part of energy prodused but this way and the surpluses can be send to the wholesale market. Moreover the major surpluses are expected at times with peak electrical load when the electricity cost is maximum. Providing that PV is located in the interrail space, on the slopes and on the right-of-way land in the zones with different insolation, temprature of air and soil, we could calculate the possibility of smoothing the peak load patterns and the increase of total share purchased electricity by the region.

3 Potential output calculations

The concept includes the distributed PV generation connected to the traction and public electrical grid. The system feature is easy installation with no need for substructure change (slopes, berms, other structures in the ROW). In calculating the gross, technical and economical potentials, the total area of the railroad ROW land strip was taken. The results were obtained for three scenarios. The optimistic one includes use of whole available area. The realistic one considers partial land-use. And the minimum one suggests use of only one element, in this case, the rail-sleeper grid. Thus, to analyse the generating power orders, it is necessary to calculate the gross potential. The gross potential is the maximum potential that is suitable for solar energy conversion in the area. In other words, the total solar irradiation of the horizontal surface during the year.

$$W_G = E \cdot S, \qquad (1)$$

where E – the average value of incident solar radiation, S – considered surface area.

Table 1 shows the average values of the incident solar radiation in regions. To calculate the gross potential, the railway length is also needed (Table 2).

However, the gross potential considers the total energy that is available for conversion and does not consider the efficienty factor. The technical potential can give more reliable result.

Table 1. The average values of the arrival solar radiation on the light-incident surface, kWh/m^{2}month [5, 6].

Subject/month	1	2	3	4	5	6	7	8	9	10	11	12
Adygea	46,2	63,6	100,1	123,3	159,0	166,8	180,4	157,2	117,6	83,7	48,9	36,9
Kalmykia	41,9	58,2	97,7	129,6	177,0	174,3	186,9	163,1	119,4	79,4	39,3	31,6
Krasnodar Krai	36,0	54,0	89,0	120,9	167,7	174,0	189,7	164,6	120,6	80,6	42,9	29,8
Astrakhan Oblast	40,9	60,8	104,5	132,0	177,0	180,9	189,1	164,3	122,7	80,0	40,8	31,6
Volgograd Oblast	29,1	38,4	97,3	123,6	182,0	177,0	188,8	164,3	107,7	68,2	33,6	19,2
Rostov Oblast	37,8	55,4	88,4	116,7	167,1	172,2	183,5	160,6	112,8	73,2	37,5	28,8
Dagestan	45,9	60,8	98,3	135,6	177,3	186,6	190,7	164,6	120,0	82,2	46,8	36,9
Ingushetia	47,7	62,4	98,6	132,3	170,5	178,8	183,2	157,5	116,7	82,8	48,9	39,4
Kabardino-Balkaria	50,2	66,4	102,0	120,9	151,0	150,0	158,7	142,0	111,9	87,7	54,3	44,0
Karachay-Cherkessia	47,1	62,2	98,9	130,2	166,8	170,1	183,2	161,2	120,6	84,0	48,9	37,2
North Ossetia – Alania	50,8	66,9	103,5	129,6	164,0	167,4	173,0	149,7	113,4	84,9	54,0	43,1
Chechnya	49,3	65,8	102,9	133,8	171,7	177,9	183,8	156,6	117,3	84,6	51,6	42,2
Stavropol Krai	41,5	59,4	95,2	124,2	169,0	173,4	188,2	164,6	120,0	82,2	44,4	32,6

Table 2. The total PV square placed on the railways according to the scenarios, m^2 [7].

Subject/operation square	Minimal	Realistic	Optimistic
Adygea	160 100	320 200	480 300
Kalmykia	164 800	329 600	494 400
Krasnodar Krai	2 139 900	4 279 800	6 419 700
Astrakhan Oblast	629 600	1 259 200	1 888 800
Volgograd Oblast	1 617 200	3 234 400	4 851 600
Rostov Oblast	1 912 700	3 825 400	5 738 100
Dagestan	508 700	1 017 400	1 526 100
Ingushetia	38 800	77 600	116 400
Kabardino-Balkaria	133 300	266 600	399 900
Karachay-Cherkessia	50 600	101 200	151 800
North Ossetia – Alania	143 800	287 600	431 400
Chechnya	304 100	608 200	912 300
Stavropol Krai	921 800	1 843 600	2 765 400

The technical potential is the total energy that is converted and used at present technology development stage. To get the technical potential, data of PV manufacturers were used. According to those, the efficiency of commercially available silicon panels is about 21-23 % 8. Also the total system includes inverters with efficiency about 98% 9. Since energy is trasfered to traction substations without intermediate accumulation, energy storage was not considered:

$$W_T = E \cdot S \cdot \eta \cdot (1 - \chi(T_i - T)), \qquad (2)$$

where T$_i$ – the average monthly PV temperature, K; E – solar irradiation, kW/m^2/month; S – considered area, m^2; T – monthly average ambient temperature, K; η – PV conversion efficiency; χ – the temperature coefficient.

The gross and technical potentials for SFD and NCFD subjects are listed in table 3.

Table 3. Gross and technical potentials of solar energy generation, MWh/year

Subject	Gross potential			Technical potential		
	Scenarios					
	Minimal	Real	Optimal	Minimal	Real	Optimal
Adygea	205 520	411 040	616 561	40 939	81 879	122 818
Kalmykia	213 976	427 952	641 928	42 624	85 248	127 872
Krasnodar Krai	2 717 245	5 434 490	8 151 735	541 275	1 082 550	1 623 825
Astrakhan Oblast	833 968	1 667 936	2 501 904	166 126	332 252	498 379
Volgograd Oblast	1 987 862	3 975 724	5 963 586	395 982	791 964	1 187 946
Rostov Oblast	2 360 271	4 720 543	7 080 815	470 166	940 332	1 410 498
Dagestan	684 557	1 369 115	2 053 672	136 363	272 727	409 091
Ingushetia	51 169	102 338	153 508	10 192	20 385	30 578
Kabardino-Balkaria	165 172	330 344	495 516	32 902	65 804	98 706
Karachay-Cherkessia	66 306	132 612	198 918	13 208	26 416	39 624
North Ossetia – Alania	186 983	373 966	560 949	37 247	74 494	111 741
Chechnya	406 733	813 467	1 220 201	81 021	162 042	243 064
Stavropol Krai	1 193 454	2 386 908	3 580 363	237 736	475 472	713 208

For the further effectiveness comparison during the power plant life cycle, efficiency assessment is required for suggested and usual solutions. Electrity production cost during the life cycle, from the stage of design to the object liquidation. This parameter is known as levelized cost of electricity production. It includes all investment costs and incomes that are possible. Usually the results are obtained in \$/kWh for 20–40 years long life cycle 10. The levelized cost of electricity (LCOE) is calculated using formula:

$$LCOE = \frac{\frac{I+M+F}{(1+r)^t}}{\frac{E}{(1+r)^t}}, \qquad (3)$$

where I – annual investment expenses, \$; M – annual operation and maintenance expenses, \$; F – fuel expenses, \$; E – total electricity output per year, kWh; r – refinancing rate; t – system life cycle, years.

Table 4 shows the share of land value in investment expenses. The results can be very significant and take more than a half of the whole cost. We have estimated possible benefits at land double-use for the suggested solution – see table 5.

Table 4. Capital costs, RUR/kWh [11-13]

SPP name	Total investment, RUR	Annual electricity output, MWh	ROW, hectare	Nominal land cost, RUR	Capital cost, RUR/kWh	
					life cycle 30 years	excluding land
Kosh-Agach SPP	570M	5 800	40	6.452M	3,2	3,2
Abakan SPP	600M	6 500	69	344.903M	3,07	1,3
Orsk SPP named after A.A. Vlaznev	3 000M	32 000	105	407.620M	3,125	2,7

Table 5. Estimated investment cost benefits at ROW land double use.

Subject	Installed power in terms of range, kW	Investments with the value of ROW, million rubles	Proposed solution investments million rubles	Expected benefits, million rubles
Adygea	32 020	199,8	153,7	46,1
Kalmykia	32 960	205,7	158,2	47,5
Krasnodar Krai	427 980	2 670,6	2 054,3	616,3
Astrakhan Oblast	125 920	785,7	604,4	181,3
Volgograd Oblast	323 440	2 018,3	1 552,5	465,8
Rostov Oblast	382 540	2 387,1	1 836,2	550,9
Dagestan	101 740	634,9	488,4	146,5
Ingushetia	7 760	48,4	37,3	11,2
Kabardino-Balkaria	26 660	166,4	128	38,4
Karachay-Cherkessia	10 120	63,1	48,6	14,6
North Ossetia – Alania	28 760	179,5	138,1	41,4
Chechnya	60 820	379,5	291,9	87,6
Stavropol Krai	184 360	1 150,4	884,9	265,5

4 Conclutions

Consumed to produced electricity ratio analysis has revealed territories with acute energy shortage. All these regions have to buy electricity from the neighbors. In Russia, many of such regions are situated within Southern and North Caucauss federal districts. Quite long section of DC and AC electrified railroads can be found there. We suggest the solution based on the distributed solar power plant that could help to use modern power sources at reduced investment load. Because of comparatively high average solar irradiation, the LCOE shows that investment burden can be reduced by 15-30%. Such reduction means that extra generated powers can be started to remove energy shortage in the regions.

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