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An experience of distant consumers power supply by means of the renewables given specific conditions

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Abstract. Local renewable energy resources (RES) are often considered as an alternative to the conventional power supply by means of power lines. This is an urgent approach for rural electrification if there are long distances from main substations, and distribution feeders' construction and service is not cost-effective for grid companies. Nevertheless, the real potential for RES implementation at some regions could be limited by economic, geographical and climatic factors especially.

The paper gives a review of the experience of power supply type selection for distant consumers given the specific northern continental conditions. The main goal of the paper is the methods estimating technical and economical efficiency of power supply system alternatives including centralized power supply and standalone microgrid implementation to select suitable power supply variant.

Key words

Rural electrification, power supply, renewable energy sources, microgrids, distribution systems.

1. Introduction

Nowadays there are many rural communities and small villages worldwide located far from districts' main cities [1, 2]. The level of infrastructure development in such areas leaves much to be desired. Existing old power supply systems of remote rural customers are characterized by the following issues:

1) *high investment* and maintenance costs associated with long-distant distribution feeders;
2) *sufficient voltage reduction* at the customers' side and excessive power distribution losses;
3) *the absence of backup source* in case of emergencies in the upstream electrical network for socially important objects.

A reconstruction of feeders and an interconnection of new rural customers located far from distribution substations, leads to significant investment costs, associated with long-distant distribution feeder construction. In should be noticed that such distribution feeders as a rule run across difficult access areas: dense forests, swampy grounds etc. Thereby, their operation and maintenance expenses increase greatly.

These problems can be eliminated by means of local microgrids construction [3] that can integrate different-type conventional and renewable energy sources, high-capacity electrical energy storage systems. The potential for renewable energy sources implementation in Russia is estimated to be promising in a half of regions; however, their application is limited by economic, geographical and, especially, climatic factors [4]. It should be noted that in the regions under consideration in the paper:

1) *average annual temperatures* are close to zero;
2) *average annual precipitation* is about 600 mm; average month snowfall at winter is about 50 cm;
3) *average annual number of sunshine hours* is less than 1800 hrs, also solar geometry is far from optimal;
4) *average annual wind speed* is less than 5 m/s.

In spite of the fact that these conditions are usually supposed not to be efficient for the renewables at least economically, technically this kind of power supply is feasible. If the power supply system is expected to be constructed anyway, the problem at hand is to select the suitable variant from conventional or RES.

The paper gives a review of experience of selection power supply for distant consumers by means at specific conditions. An attention is given to technological and economic boundaries of investment effectiveness applied to autonomous and/or backup power supply system (APSS) construction using renewable energy sources.

2. Geographical and technological zoning

The authors provide an approach based on geographic and technological zoning to identify the feasibility and effectiveness of different power supply systems application for remote rural customers with the focus on renewable energy sources. Provided approach is verified by the calculations, carried out for the Sverdlovsk, Chelyabinsk and Perm regions of Russian Federation with the total surface area of 450 000 km^2. Network interconnection and power transmission within the given territories is performed by JSC “Interregional Grid Company of Ural”.

A. Available wind resources

The feasibility study for wind generation application is based on the estimation of wind data, namely wind speed and direction. The variation of wind speed for a typical site is generally described by Weibull distribution and its’ probability density function:

$$p(v) = (k/c)(v/c)^{k-1}\exp\left[-(v/c)^k\right], \qquad (1)$$

where c – scale parameter, m/s; k – form parameter; v – wind speed, m/s; $p(v)$ – probability density.

Weibull distribution makes it possible to get the estimation of wind potential parameters, including average wind speed, the most probable wind speed etc. The most important Weibull distribution characteristic is form parameter k, which greatly depends on the type and vegetation of the terrain under consideration. The type of the surface can be subdivided into prevailing and islanded. In case of prevailing surface, the wind speed can be characterized as mostly uniform, in case of islanded surface – vice versa. The calculations, carried out for multiple sites, show, that form parameter of Weibull distribution for prevailing surfaces ranges from 2.0 to 2.5. For islanded-type terrains form parameter falls within the range of 1.5 and 2.0.

It cannot go unnoticed, that the type of the terrain and vegetation influences the distribution of the wind speed throughout the height. The lower the wind speed at a height of 10 m due to wind flow deceleration by irregular terrain surface, the higher the wind speed at a height above 100 m, and vice versa for flat surfaces. This fact makes it possible to introduce adjustment factors for wind speeds, measured at different ground heights. The calculated adjustment factors for wind speeds at a height of 10 m, depending on terrain and vegetation type, range from 0.5 to 0.79 with relation to wind speed at a height of 50 m. The same factors for the wind speeds at a height of 100 m range from 1.05 to 1.39.

Therefore, given the initial data about the type and vegetation of the territory and the average wind speed, one can develop a wind resource map. Figure 1 illustrates such a map for a service area of JSC “Interregional Grid Company of the Urals”. It should be noticed, that technological efficiency lower speed limit for wind generation standalone operation is about 5 m/s, while commercial efficiency limit for interconnected operation equals to 7 m/s. Moreover, wind generation application is not efficient in urban/suburban territories. For the given case study (Fig. 1) the most suitable region for wind generation development is located south of 54° north latitude and east of 59° eastern longitude.

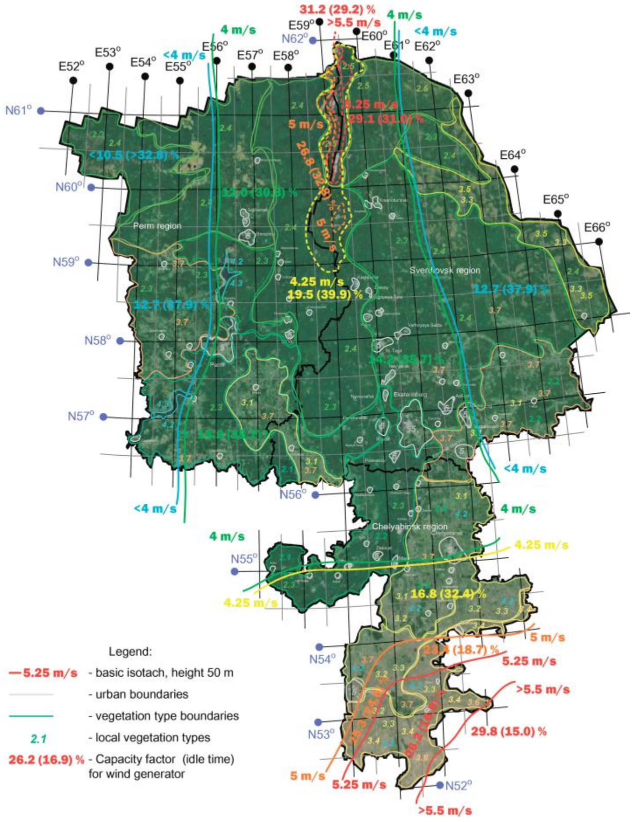

Fig. 1. Wind resource map

B. Available photovoltaic resources

Initial data regarding solar average insolation incident to a tilted surface, used in solar generation feasibility studies, were taken from international open database NASA Surface Meteorology and Solar Energy [5].

So far as photovoltaic (PV) power plant basic parameters are mostly defined by electric load characteristics, daily and seasonal energy consumption data is also required. All the calculations are carried out using standard efficiency factor of 15% for commercial PV panels, taking into account additional capacity reduction factor, accounting for external influence, such as solar panels shadowing and surface pollution, electric circuits efficiency etc. Taking all these point together, the resulting efficiency factor approximately equals to 9%. The effective PV array surface area and power plant installed capacity are calculated as follows:

$$S = W_{\mathrm{load}} / (w \cdot \eta \cdot k_{\mathrm{d}} \cdot k_{\mathrm{t}}) \qquad P_{\mathrm{inst}} = S \cdot p_o , \qquad (2)$$

where S – effective PV array surface area, m^2; W_{load} – monthly electric energy consumption, kWh; w – monthly averaged insolation on a tilted surface, kWh/m^2/day; η – PV panel efficiency factor, p.u.; k_d – additional capacity reduction factor, p.u.; k_t – air temperature correction factor, p.u.; P_{inst} – PV power plant installed capacity, kW; p_o – PV panel specific capacity, kW/m^2.

PV power plant capacity factor (CF) is calculated according to the following expression:

$$CF = w \cdot \eta \cdot k_{d} \cdot k_{t} \cdot S \; / \; P_{inst.} \cdot 24 \qquad (3)$$

The figure 2 illustrates PV power plant CF and installed capacity variation plotted against geographical latitude of the territory under consideration. The curves illustrate one of the first steps of feasibility studies regarding solar energy utilization for power supply of remote rural customers, located within the service area of JSC "Interregional Grid Company of Ural". Investigated load capacity ranges from 50 to 300 kW with a 50 kW step.

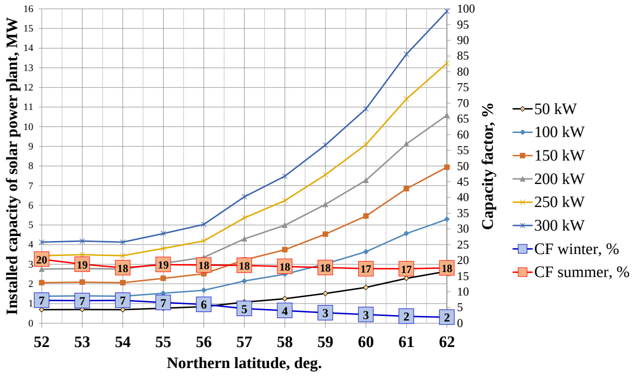

Fig. 2. Solar power plant installed capacity and capacity factor variation

As it can be seen from the figure, solar energy utilization for remote rural customers power supply in terms of standalone microgrids is mostly limited by short daylight time in winter – less than 6 hours. In that way, wintertime capacity factor ranges from 2% to 7% for a given case study, which is really far from technological effectiveness. In an effort to overcome this problem for northern regions, installed capacity of PV array and storage may be increased. However, that leads to additional investment and excess solar energy generation in summer. Also, an attempt to avoid mutual PV panels shading due to low northern sun leads to sufficient surface area growth of PV array. For example, for 100 kW PV installed power, it rises from 5 to 60 ha moving from 52° to 62° NL.

C. Long-distant transmission line construction

This section is devoted to investigation of maximum permissible electric energy transmission distances for overhead distribution lines 0.4 – 6(10) kV in terms of relation "transmission capacity – distance", suitable for power supply of remote rural customers. The key factors, influencing the relation "transmission capacity – distance" include active power flow, power factor, transmission line current carrying capacity, main substation voltage limits etc. The calculations are carried out taking into account power line construction specific and resulting impedance; current limits, voltage drop, remote end voltage; load losses (kW and p.u.), maximum permissible load (including losses). The calculation results of maximum permissible transmission distances for several basic cases are provided in Figure 3. Remote end transmission line voltage constraint is $0.95U_{rated}$.

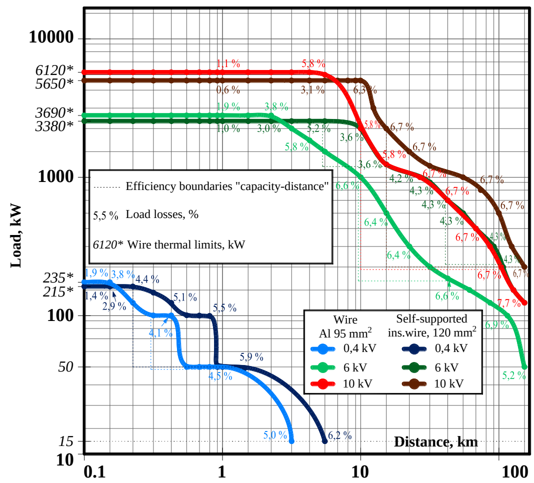

Fig. 3. Power line maximum transmission distances

Calculations show, that for a fixed distance the application of self-carrying insulated wire gives the possibility to increase the maximum permissible power flow almost twice due to significantly lower voltage drop. In case of fixed power flow, the distance can be increased by 2-3 times. In general, the application pf self-supported wire is more effective for electric loads with greater capacities, than for greater transmission distances. So, the technological efficiency limit for overhead power transmission line 0.4 kV is 1 km for electric loads up to 100 kW; 6 kV transmission line – 20-30 km for electric loads up to 500-400 kW; 10 kV transmission line – 35-70 km for electric loads up to 1000-500 kW.

3. Boundary conditions for standalone and centralized power supply systems

The basic technical and technological factors, influencing the APSS configuration, include the potential for renewable energy utilization, the possibility to organize centralized power supply and reliability class of electric load [6]. The efficiency of APSS is defined primarily by economic parameters. The basic criteria for APSS efficiency is assumed to be a specific cost of 1 kW of system's installed capacity, not exceeding specific cost of power network construction.

The model developed for microgrid implementation economic efficiency analysis. Discounted values of operating and fuel costs are calculated for each year. The function of cumulative costs for a case of overhead transmission line construction is given as follows:

$$C_{t\ Line} = K_L + c_L K_L \int_{t=0}^{t} \left[(1+\mu)^t dt \right] + W_{\Delta P} c_{EE} \int_{t=0}^{t} \left[\left[(1+\delta)(1+\mu) \right]^t dt \right] + \qquad (7)$$
$$+\left(W_{ENS} c_{1r} - W_{load} c_{2r.\Delta P} - \frac{W_{load} c_{2r.grid}}{744} \right) \times \int_{t=0}^{t} \left[\left[(1+\delta)(1+\beta) \right]^t dt \right],$$

where $C_{t\ Line}$ – cumulative costs for power transmission line construction, €; t – estimation period, year; K_L – investment costs for power transmission line construction, €; c_L – specific transmission line maintenance costs, %; c_{EE} – electric energy price, €/kWh; c_{1r} – power loss specific price according to straight-line tariff, €/kWh; $c_{2r.\Delta P}$ – power loss specific price according to double-rate tariff, €/kWh; $c_{2r.grid}$ – network operation costs indemnity according to double-rate tariff, %/year; μ – maintenance costs growth rate, %/year; β – power transmission tariff growth rate, %/year; $W_{\Delta P}$ – electric energy losses, kWh; W_{load} – electric energy consumption, kWh; W_{ENS} – energy-not-served for customers, kWh.

The function of cumulative costs for APSS is set:

$$C_{\mathrm{tSS}} = c_{\mathrm{DG}} K_{\mathrm{DG}} + c_{\mathrm{St}} K_{\mathrm{St}} + c_{\mathrm{RES}} K_{\mathrm{RES}} \cdot \int_{t=0}^{t} 1+\mu^{\ t} \mathrm{dt} + K_{\mathrm{DG}} + K_{\mathrm{St}} + \\ + K_{\mathrm{RES}} + \frac{C_{\mathrm{0fuel}} V_{\mathrm{fuel}}}{10^6} \int_{t=0}^{t} \left[1+\delta \quad 1+\alpha \right]^t \mathrm{dt} + \sum_t \left[N_{\mathrm{rep.t}} \cdot c_{\mathrm{rep}} \cdot 1+\psi^{\ t} \right] \tag{8}$$

where C_{tSS} – cumulative costs for alternative power supply system construction, €; K_{DG} – backup diesel generator investment costs, €; K_{St} – storage system investment costs, €; K_{RES} – renewable energy sources investment costs, €; c_{DG} – diesel generator specific maintenance costs, %; c_{rep} – capital repair price for a diesel generator, €; c_{St} – storage system maintenance costs, %; c_{RES} – renewable generation maintenance costs, %; α – fuel price growth rate, %/year; ψ – diesel generator capital repair price growth rate, %/year; C_{0fuel} – current diesel fuel price, €/l; V_{fuel} – annual requirement for diesel fuel, l; $N_{rep.t}$ – the amount of diesel generator capital repair, taken into account at the stage *t*.

Calculation results are presented in figure 4. The functions were estimated for supply distances ranging from 10 to 100 km and electric load of 100, 250 and 500 kW. The following assumptions were taken into account:

1) *For 500 kW electric load and supply distance starting from 70 km*, the second circuit is required (in Fig.4 this fact is depicted as a "step" in cumulative costs curve for 500 kW load).
2) *The price for power line construction does not depend greatly on particular electric load capacity*, because it mostly affects wire cross-section. Therefore, it is reasonable to consider APSS that have lower specific costs than a basic one: the most distant customer with the highest load capacity. For the given case study a basic alternative is assumed to be 500 kW with centralized power supply system.
3) *Cumulative costs for power supply system construction* of low-capacity customers are linearly dependent on distance of power supply.

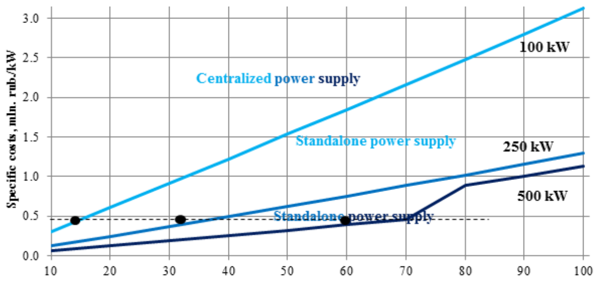

Fig. 4. Standalone microgrid system efficiency boundaries, km

The calculation results show, that in comparison with centralized power supply system construction, microgrid efficiency starts from 100 kW load capacity with total supply distance over 17 km, 250 kW load with distance over 40 km and 500 kW load with distance over 70 kW.

4. Conclusion

The work presented provides the following results.

1. The effects of low technical efficiency were described, including RES CF of 2-15 % compared to 30-50 % usually utilized in Europe. RES seem to be ineffective at least economically in specific northern continental weather conditions as considered in the paper. To ensure an appropriate level of reliable power supply, especially at winter, an excess of installed capacity is required, which is not demanded at summer.

2. Power line transmission limits typical for distant rural consumers were established. Given the lack of required voltage or capacity power source as well as power line construction limits, in some cases an alternative power supply is required.

3. The efficient boundaries between conventional power supply using power lines and alternative power supply systems using RES were determined.

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References

[1] A. Yadoo and H. Cruickshank, "Low-Carbon Off-Grid Electrification for Rural Areas: Lessons from the Developing World", Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2010, pp. 1-4.
[2] A. Zomers, "Remote Access: Context, Challenges, and Obstacles in Rural Electrification", IEEE Power and Enery Magazine, Vol. 12 , Issue 4, 2014, pp. 26-34.
[3] K. Ubilla et al., "Smart Microgrids as a Solution for Rural Electrification: Ensuring Long-Term Sustainability Through Cadastre and Business Models", IEEE Transactions on Sustainable Energy, Vol. 5, Issue 4, 2014, pp. 1310-1318.
[4] V.O. Samoylenko and S.A. Eroshenko, "The forecast of DG development features by methods of economic and geographical zoning", the materials of public periodic seminar «The issues of distributed generation interconnection and operation». Russian National Committee of CIGRE, 2014 [in Russian], URL: http://cigre.ru/activity/conference/seminar_c6/materials/
[5] NASA Atmospheric Science Data Center. Surface meteorology and Solar Energy. URL: https://eosweb.larc.nasa.gov/sse/
[6] S.A. Eroshenko et al., "Technical feasibility of distributed generation network connection", Advanced Materials Research, Vol. 860-863, 2014, pp. 2131-2136.