Application of a smart active adaptive system on the basis of renewable energy sources for electricity supply to an agricultural facility in highland regions of the Caucasus

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Abstract. This paper presents the collated results of the research conducted by the authors and made in the electric system of an agricultural holding. The article is devoted to the development of a smart electric grid which provides energy efficient electricity supply to responsible consumers of an agricultural facility. The research shows the main components of the smart electric system, their operation mode, their role in enhancing energy conservation and efficiency. The authors prove the efficiency of smart energy systems and renewable energy sources in electricity supply to an agricultural facility in the Chechen Republic.

1. Introduction

The technologies and principles for the distribution of generation have been getting more and more important for the last 20 years due to the increasing demand for electricity conservation and efficiency along with reduction of electricity component in the cost of industrial production. Nowadays the systems of distributed generation are the most efficient addition the centralized electric grid in case it is not reliable enough to supply power to the most responsible consumers. Taking into account abundant sources of wind energy in highland regions of the Chechen Republic, which lack centralized power networks and have no reliable electricity supply, using local sources of energy is highly recommended.

All over the world the distribution of electric generation aims at the decentralization of electric power systems along with using local energy sources and enhancing efficiency of electric supply to industrial, agricultural and housing facilities by approaching of the source to the consumer in case of lack or remote location of the centralized energy grid [1].

Taking into account the fact that the power system of the Chechen republic is undergoing reconstruction there are a number of problems which must be solved. They are the scarce of generation facilities, problems with reliability requirements fulfilment due to the deterioration of the significant part of the equipment and lack of processes automation. About one third of substations 35, 110KW, have been put into operation on the basis of a single-phase voltage transformer with no possibility of power supply redundancy. This condition of the electric power system along with the rise of energy consumption cannot provide reliability and quality of power supplies for the consumers.

According to the authors the problems mentioned above, in particular, the scarce of generation facilities and unreliability of electricity supply can be solved by creation of an autonomous micro-energy system which operates a smart electricity system with an active adaptive network on the basis of renewable sources of energy such as the wind and the sun for electricity supplies to an agricultural
holding.

2. Smart electric power system with an active adaptive network
Nowadays in all the developed countries of the world much attention is paid to electric power systems which use the newest equipment and technologies providing reliability and cost-effectiveness of electric systems.

Undoubtedly it is an acute task for the Russian electric power industry. The electric grid as a structure connecting the generation and the consumers, plays the key role in the renovation of electric power system on the basis of new principles. Due to the new technologies used in electric grids based on equipment features adjustment to the operating mode, active interaction between the generation and the consumers we can create an efficiently operating system. The integral part of this system are modern information diagnostic systems, control automation systems with all their components participating in production, transmission, distribution and consumption of electric power.

What is meant here is the creation of a smart electric power system with an active adaptive network (SEPS AAN) which is the most advanced system based on multiagent control of its operation and development. The purpose of this system is the provision of the efficient consumption of all types of resources (natural, human, social, productive) through the flexible interaction of its components (all generation types, electric grids and consumers) on the basis of modern technologies and a single smart control system [2].

The differences of this system from the traditional one are the following [3]:
- a number of active components which allow altering technological network settings;
- a big number of detectors measuring the current operating settings necessary to evaluate the network condition in normal, pre-fault, emergency and post-fault operating mode;
- the system of data collection, transmission and processing and the programs of adaptive control which can immediately influence the active network components and the electric devises of the consumers real-time;
- the presence of the necessary control elements and devices which can real-time immediately alter the topological network settings and also influence the related power assets (generation and consumption);
- a controlling system providing interaction between the network and the power generating facilities and allowing to react instantly to any changes in the operating mode of the electric power system;
- the ability of immediate evaluation of the current situation and forecast of the future situations in the whole power system and its parts and also influence to the power assets and equipment to prevent or contain electricity supply in case of emergency and post-fault recovering;
- a high operation speed of the controlling system and data exchange, assuring cycle control of the system’s condition, its parts and components with different timing cycles at different control levels.

The priority of the system’s factors and conditions as well as the system’s reliability and cost-effectiveness as a whole are the basis of an active adaptive network development and power system control.

Before developing a power layout with an active adaptive system on the basis of renewable sources of energy for an agricultural facility, we will prove the advantages of using renewable energy sources in the Chechen Republic

3. Climatic and energy characteristics of the sun in the Chechen republic
The location of the Chechen Republic between 42 and 46 degrees north latitude provides intensive inflow of solar radiation. Solar energy resources, expressed in terms of radiation balance, in plain and foothill areas consist 50 to 55 kcal/cm² per year. The duration of insolation is about 330 days per year. Days without sun are rare – 34 to 40 days in plain and foothill areas and 10–12 days in mountainous areas. The largest number of dull days is 61 in the plain areas. As a whole during a year the cloud cover
reduces the inflow of direct radiation for 20 to 25% of the potential.

The total radiation is the sum of direct and scattered radiation on a horizontal surface. The total radiation in the Chechen Republic peaks from May to July. The total radiation intensity varies between 280 and 300 MJ/m$^2$ in the foothill areas. In the mountainous areas it ranges from 360 to 400 MJ/m$^2$ [4].

The NASA database provides the average monthly size of the total solar radiation falling on a horizontal surface on the ground surface for each month for a period of 25 years from July 1993 to June 2018, Table 1. Each month the average value is the arithmetic mean of 3 hour values for that month. The values are given for the village of Shelkovskaya in the Chechen Republic with an area of 167.21 km$^2$.

### Table 1. Long-term (25 years) monthly average values of insolation falling on a horizontal surface (kWh/m$^2$ per day)

| Month | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year |
|-------|---|----|-----|----|---|----|-----|------|----|---|----|-----|------|
| $E_g^y$ | 1.61 | 2.36 | 3.30 | 4.51 | 5.67 | 6.07 | 5.92 | 5.05 | 3.94 | 2.69 | 1.67 | 1.30 | 3.67 |

The advisability of combined power supplies can be shown using the example of the power supplies to a cattle-breeding complex for 800 head with the total peak load of 257.6 kWh and an annual power consumption of 875.84 MWh.

The average value of solar energy gross potential per year is calculated on the following formula:

$$E_g^y = \frac{\sum_{k=1}^{d} E_g^y_k}{d} \quad (1)$$

$d$ – number of estimated months, $E_g^y$ – inflow of solar radiation on a horizontal ground for $k$ – a month.

The solar energy gross potential in the Chechen Republic is estimated at 3.67 kWh/m$^2$ per day:

$$E_g^y = (1.61 + 2.36 + 3.3 + 4.51 + 5.67 + 6.07 + 5.92 + 5.05 + 3.94 + 2.69 + 1.67 + 1.3) / 12 = 3.67 \text{ kW h/m}^2 \cdot \text{d} \quad (2)$$

Then the value of an annual solar energy gross potential is:

$$E_g^y = 3.67 \cdot 365 = 1340 \text{ kW h/yr} \quad (3)$$

The solar energy gross potential in the village of Shelkovskaya taking into account its land area is:

$$E_g^y = E_g^y \cdot S \Rightarrow E_g^y = 1340 \cdot 167.21 \cdot 10^6 = 224.061 \cdot 10^6 \text{ kW h/yr} \quad (4)$$

These calculations show that the village of Shelkovskaya has a significant solar energy potential which can be used as a source of electricity for a cattle-breeding complex power supplies.

### 4. Climatic and energy characteristics of the wind in the Chechen republic

According to the wind stream gross potential the Chechen Republic has a medium level of wind energy.

For efficient utilization of wind energy it is necessary to have full information about the wind as a natural phenomenon and a source of energy. The environmental characteristics needed to estimate wind energy gross potential are [5]: wind speed temporal variations; an average wind speed $V$; wind speed recurrence $t (V)$, %; wind speed duration $P(V)$, %; correction factors which take into account changes in the wind on the territory due to heterogeneity of the underlying surface; average vertical wind speed profile; top wind speed $F_{max}$; specific power $N_s$ and specific energy $E_s$ of the wind, wind energy resources of the region.

According to the NASA database the multi-year average wind speed in the village of Shelkovskaya is 4.67 m/s at the altitude of 10 m and 5.91 m/s at the altitude of 50 m, table 2.

### Table 2. Long-term (10 years) monthly and multi-year average wind speed at the altitude of 10
and 50 meters over a landscape like an airport

According to the multi-year average wind speed values at the altitude of the weathervane at the wind speed \( V > 5 \text{ m/s} \) there are good conditions for wind energy utilization, \( V < 4 \text{ m/s} \) utilization of wind energy isn’t recommended, \( 4 < V < 5 \text{ m/s} \) a business case for wind energy utilization is needed [6].

Along with the multi-year average wind speed the specific power of the wind flow is also an original characteristic of the wind intensity total level in the estimated region. It allows indicating the prospects of wind resources utilization: with specific power less than 100 (\( N_s < 100 \text{ W/m}^2 \)) it is not recommended, more than 400 (\( N_s > 400 \text{ W/m}^2 \)) there are good conditions, 100 < \( N_s < 400 \text{ W/m}^2 \) – a business case is needed.

Let us calculate the specific power and the specific energy of the wind flow at the altitude of 50 m to estimate the prospects of wind energy utilization.

In the calculation of the specific power by different means will take into account that the air density does not change and equates \( \rho_0 = 1.226 \text{ kg/m}^3 \).

1) \( N_s \) is growing according to the multi-year wind speed value \( V_0 \):

\[
N_s = \frac{1}{2} \rho V_0^3 = 126.54 \text{ W/m}^2
\]  

(5)

2) Calculation of \( N_s \) according to a range of speed observations \( V_i \) (a range of 3 hour observation):

\[
E_s = \sum_{i=1}^{2920} N_s i = \frac{1}{2} \rho \sum_{i=1}^{2920} V_i^3 \Rightarrow N_s = E_s / (8760 / 3) = \sum_{i=1}^{2920} N_s i / 2920 =
\]

(6)

\[= \frac{1}{2} \rho \sum_{i=1}^{2920} V_i^3 / 2920 = 126.92 \text{ W/m}^2
\]

3) Calculation of \( N_s \) according to multi-year recurrence \( t(V) \):

\[
E_s = \frac{1}{2} \rho T \cdot V_{gr j}^3 \cdot t(\Delta V_{jr}) ; \quad N_s = \frac{1}{2} \rho V^3.
\]

(7)

The results of the calculation are shown in Table 3.

Summing the specific energy values \( E_{sj} \) in the full range of the observed speeds we calculate the multi-year annual specific energy \( E_s \) and the specific power value \( N_s \) of the wind flow:

\[
E_{sj} = \sum E_{sj} ; \quad N_s = \frac{E_{sj}}{T} = 230 \text{ W/m}^2
\]  

(8)

\[
\begin{array}{|c|c|c|c|c|c|c|c|c|c|c|}
\hline
V^0 & 1 & 4.5 & 8.5 & 12.5 & 16.5 & 22 \\
\hline
t(\Delta V)^0 j & 10 & 52 & 8.5 & 12.5 & 16.5 & 22 \\
\hline
N_{sj} & 0.61 & 55.86 & 376.46 & 1197.27 & 2753.67 & 6527.22 \\
\hline
\Theta_{sj} & 0.54 & 254.45 & 1022.31 & 734.16 & 0.00 & 0.00 \\
\hline
\end{array}
\]

Table 3. Results of the specific power and specific energy calculation

According to these calculations the power values range from 126 to 230 W/m². For the following calculations we will take the lowest value \( N=126.54 \text{ W/m}^2 \).

The power generated by a wind plant Fuhrländer FL100 with a rated power of 100 kW is calculated as follows:

\[
N_{wpp} (V_{rb}) = N_{g.p.} (V_{rb})\eta_{ww}\eta_{h}\eta_{gen} = 0.125\rho \pi D^2_{ww} V_{rb} (t)^3 \eta_{ww}\eta_{h}\eta_{gen}
\]  

(9)
Electricity generation by a wind plant in this region according to the recurrence of the wind speed for period T is calculated as follows (kWh):

\[ E_{WPP}(T) = \sum_{j=1}^{N_{WPP}(V_{\text{min}})} [N_{WPP}(V_{\text{min}}) t(\Delta V_{j})] T \]  

(11)

The calculation of electricity generation by a wind plant Fuhrländer fl100 shows the result 294443 kWh.

The gross potential of the wind flow in the village of Shelkovskaya:

\[ E_s = 126,54 \cdot 8760 \cdot \frac{167,21 \cdot 10^3}{20} = 9267,534 \text{ MW} \cdot \text{h} / \text{km}^2 \cdot \text{year} \]  

(12)

The annual electricity consumption of a cattle-breeding complex for 800 head:

\[ W_y = P_{\text{max}} T = 257,6 \cdot 3400 = 875840 \text{ kW} \cdot \text{h} = 875,84 \text{ MW} \cdot \text{h} \]  

(13)

where T = 3400 h. is the number of hours at the peak load [7].

These calculations show that the village of Shelkovskaya has a significant wind energy potential which can be used as a source of electricity for a cattle-breeding complex power supplies.

5. **Power supply scheme based on smart electric power system with an active adaptive network**

A power layout of an agricultural facility with an active adaptive network based on the combined sources of energy which was developed on the basis of the calculations and the relevant electric installations (Figure 1).

This power layout works as follows. In a normal operating mode all three divisions of the facility get electricity from a wind power plant (WPP) and energy accumulates in a storage battery (SB). In case the weather is bad for the WPP the detectors of the wind velocity send a signal to the control element, “the brain” processes this data and reacting to the active components switches off the WPP. Using the special detectors the system checks the level of insolation for solar power redundancy. These actions come instantly. If the weather does not suit the solar power plant the controlling system switches on the diesel power plant (DPP). The DPP is switched on without delay because there are diesel dynamic uninterruptible power supply sources installed (DDUPSS). After some period of time when the sun comes out if there are no wind the relevant detectors monitoring the condition and the work schedule of the DDUPSS send a signal to the control element. In its turn the controlling system transfers the 3rd category load to the supply from the SB controlling the voltage of the SB. Simultaneously the system switches the 1st and 2nd category load in the solar power plant (SPP) which can get electric power directly from the SPP or the SB where the power has been accumulated from the SPP. All the commands mentioned above are executed through the smart active adaptive controlling system by means of the related detectors and active components.

The efficiency factors during the construction of SEPS AAN: demand management and loss reduction with the full elimination of commercial loss will reduce electricity consumption at least at 5%; active adaptive regulation of consumption mode will reduce the growth of the peak electrical demand reducing the required power input of power plants; significant capacity growth of power transmission lines and cross sections reducing the necessity of investing money in power lines construction; electricity supply reliability growth at the expense of preventive and adaptive management SEPS AAN and its elements will multiply reduce the damage from the system accidents and power supply interruptions.
6. Conclusion

Therefore by the means of gradual refuse of the centralized power supply, development of distributing generation systems and integrated introduction of alternative and renewable energy sources (wind and solar energy) we should create a flexible cross-functional and efficient smart system of complex monitoring and control of energy sources consumption and quality of electric power, which plays the key role in energy efficiency and conservation.

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