Use of Renewable Energy Resources to Power an Agricultural Enterprise in Russia

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Abstract- This Article covers issues concerning improvement in quality of power supply of the Russian Agricultural Enterprises (AEs) based on Renewable Energy Sources (RES). The Article describes the solution of three main problems encountered in the development of Electrical Power Supply Systems with RES: 1) Selection of Electric Installations to supply power to the specific AEs; 2) Provision of parallel operation of energy sources of different-types; 3) RES integration into the United Energy System (UES). The abovementioned problems have been considered with the specific reference to "Zhdanovsky" AE- Livestock Complex that specializes in milk manufacturing. The selection of Biogas Electric Installations and Solar Power Plants has been proven with the use of the procedure developed by the authors. The AE's Power Supply Diagram with selected Electric Installations (EIs) has been provided. Parallel alternative current operation of Solar Power Plant and Biogas EIs has been shown. The problem of RES integration into UES has been fixed by means of the AE's Electric Complex hooking up to Automatic Power Flow Control Station (APFCS). In case of RES energy deficiency, the APFCS shall provide the possibility of energy consumption from the United Energy System and in case of over-generation – its delivery to the United Energy System. The APFCS diagram in the electric distribution grid with AE and RES hooking up has been provided.

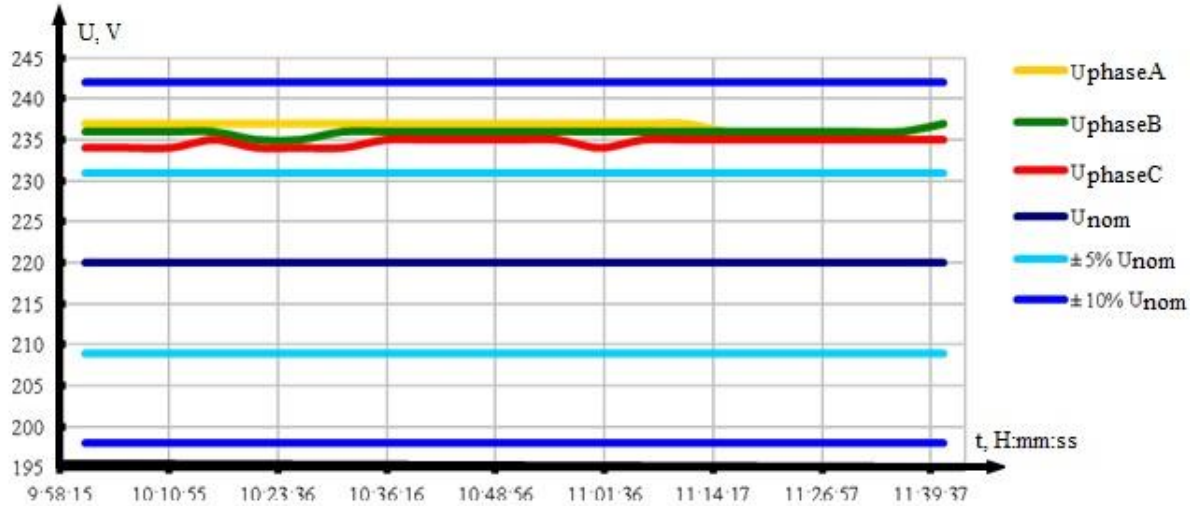
Keywords- the Agricultural Enterprise, Biogas Electric Installations, Solar Power Plants, Selection of Renewable Energy Sources, Parallel Operation of Renewable Energy Sources, Automated Power Flow Control Station.

1. Introduction

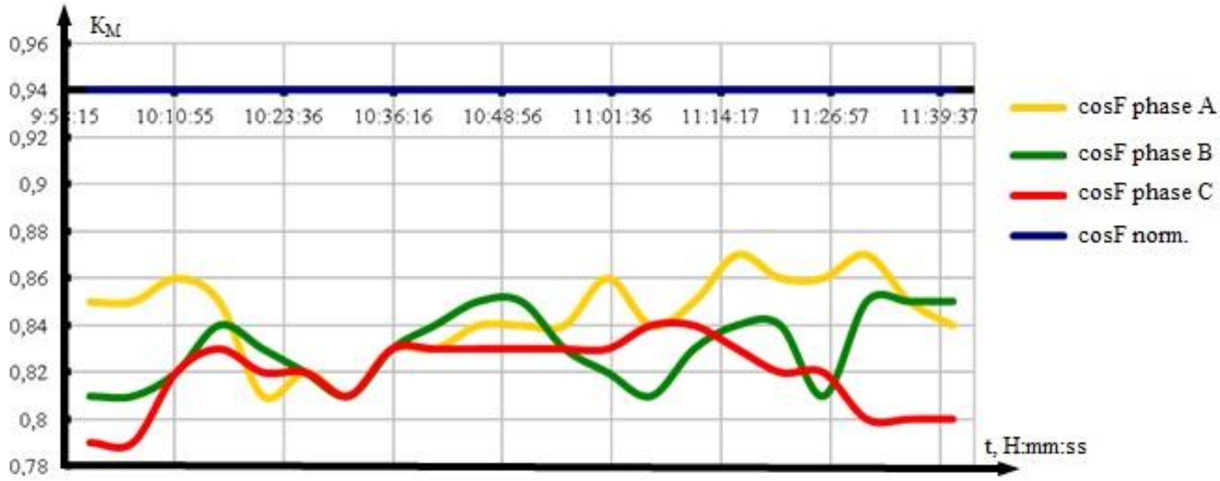
The agricultural industry is a contributor to the economy and social life in the Russia of today. "Rural Regions Sustainable Development for 2014-2017 and for the period until 2020", the Federal Target Program, has been established as part of the State Program [1]. This Program aims at infrastructures' improvement, high-tech job growth and population clusters economic development. In order to achieve goals designated challenges with regard to rural regions power supply shall be fixed on the first priority basis.

Russian rural electric grids are defined by long length low and medium voltage Electrical Transmission Lines (ETLs) with a good many Transformer Sub-stations (TSs). So, according to the specialists' research [3], in the early 21st century there have been about 2 million km of electric distribution grids of 0.4-35 kV, more than 7,130 TSs of 35/6-10 kV, and more than 515,000 TSs of 6-35/0.4 k. Major challenges of rural consumers' power supply are connected with repeated power supply interruptions and significant power losses accompanied with low quality.

The authors have conducted energy surveys of 10 large Russian agricultural enterprises (AEs). It has been found out that for 6 enterprises voltage and power factor variations do not comply with the requirements of Russian regulatory documents [4, 5]. The results of the research of electrical power quality for "Zhdanovsky" AE located in the Nizhny Novgorod region are shown in Fig. 1: voltage variation at bus bars of 0.4 kV TSs exceeds 5%, power factor (cosF) is lower than the standard value by 15%. Significant voltage variation and low cosF result in the increase in losses of both active and reactive power, decrease in the carrying capacity of electric distribution grids, reduction in electrical equipment overhaul life.



a)voltage variation



b) power factor

Fig.1. Results of the research of electric power quality for ''Zhdanovsky'' AE

Problems connected with poor reliability and low quality of agricultural consumers' power supply may be solved with the use of Renewable Energy Sources (RES) – wind Electric Installations (EIs), Solar Power Plants (SPPs), mini- Hydro Power Plants (HPPs), Biogas Electric Installations (BGEIs) [4]. The following science and engineering oriented tasks shall be solved in this regard:

1) Assessment of RES efficiency and its selection for specific conditions;

2) Provision of parallel operation of energy sources of different-types;

3) RES integration into the United Energy System [5, 6].

The abovementioned challenges have been considered with the specific reference to Agricultural Enterprise (AE) "Zhdanovsky" located in the Nizhny Novgorod region. It specializes in milk manufacturing. The power consumed by the AE varies from 120 kW in summer to 360 kW in winter. Power is supplied from a single source – TM-400/ 6/0.4 kV oil transformer with a rate power of 400 kVA. This results in frequent power failures at the AE. An average number of failures which cause the outage of 6 (10) - 35 kV high-voltage lines is 170 – 350 over 100 km of the line per annum. Interruptions in power supply resulted from emergency outages lead to the AE processes disruption: change in the microclimate in livestock houses, troubles in milking, feeding, which is detrimental to business. That is why it is vital that the issues related to the RES use for power supply to "Zhdanovsky" AE should be solved.

2. Assessment of RES Use Efficiency and its Selection for Specific Conditions

Efficiency of EIs operating on RES will be determined on the basis of the following criteria set: economical, technical and ecological ones [9]. Local RES energy potential for RES selection and optimum relationship between use efficiency criteria for EIs model selection shall be taken into consideration [10].

The authors have investigated an energy potential of local renewable energy resources. “Zhdanovsky” AE is located in the Nizhny Novgorod region. The area is free of hydro-resources and has low potential of wind resources. An average annual wind speed is 1.8 m/sec., which (with the start speed of most of wind EIs not less than 2 m/sec.) does not allow to use wind EIs as power supply sources.

An energy potential of solar radiation has been assessed. The results of the assessment are shown in Table 1.

Table 1. Energy potential of the solar radiation in the Nizhny Novgorod region [11]

City	Daily solar radiation, kWh/m^2/day												For year
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Nizhny Novgorod	0.64	1.45	2.75	3.95	5.34	5.60	5.50	4.27	2.69	1.45	0.75	0.45	2.91

“Zhdanovsky” AE is a Livestock Complex with 584 heavy beasts. The authors have estimated possible daily biogas output.

The daily biogas output is determined by the formula developed with the use of the procedure [21]:

$$V_{dom} = k_n \cdot m_i \cdot N_i \cdot \left(1 - \frac{W}{100}\right) \cdot P_{dom}/100 \cdot n_{dom} \cdot \nu_{sp}, \quad (1)$$

where k_n is an adjustment factor, which includes bedding and residual feed (1.3); m_i is manure produced daily by each beast (35 kg); N_i is a number of heavy beasts of a certain age and type (584 pcs.); W is humidity (88.4 %); P_{dom} is a content of dry organic matter in manure (94.4 %); n_{dom} is a content of dry organic matter in excrements (0.85 %); v_{sp} – specific yield of biogas at full destruction of organic matter (0.3 m^3/kg).

$$V_{dom} = 1{,}3 \cdot 35 \cdot 584 \cdot \left(1 - \frac{88{,}4}{100}\right) \cdot 94{,}4/100 \cdot 0{,}85 \cdot 0{,}3 = 742 \text{ m}^3\text{/day}.$$

According to the analysis of local RES energy potential, the daily solar radiation in spring and summer and potential daily yield of biogas make the use of biogas and solar energy installations perspective for “Zhdanovsky” AE.

The following stage is the solution of the issue related to the selection of optimum models of biogas and solar EIs. To solve this issue the authors have developed a procedure which allows to determine the optimum relationship between EIs use efficiency criteria.

The procedure goal is the following. Absolute values of the given factors of comparable EI models are converted into normalized units [10]. Value ratios are estimated for each EI factor by formula (2).

$$\nu_i = \frac{r_i}{r}, i = 1..N, \quad (2)$$

where r_i is a spread in i-factor, p.u.; r is a sum of spread values, n.u.

Spread in i-factor is determined by formula (3):

$$r_i = \frac{1}{N} \cdot \sum_{j=1}^{N} |P_{ij} - P_i|, i = 1..N, \quad (3)$$

where P_i is an average value of i-factor, p.u. determined by formula (4); P_{ij} is a value depending on the type and focus of the factor, p.u. determined by formula (5).

$$P_i = \frac{1}{N} \cdot \sum_{j=1}^{N} P_{ij}, i = 1..N; \quad (4)$$

$$\begin{cases} P_{ij} = \dfrac{p_{ij}}{p_{ij}^{max}}, P_{ij} \to max \\ P_{ij} = \dfrac{p_{ij}^{min}}{p_{ij}}, P_{ij} \to min \end{cases}, \quad (5)$$

where p_{ij} is a value of i-factor of the j-model in absolute units; $p^{max}{}_{ij}$, $p^{min}{}_{ij}$ are maximum and minimum values of comparable models factors, a.u.

The sum of spread values is calculated by formula (6):

$$r = \sum_{i=1}^{M} r_i. \quad (6)$$

An integral estimation of the factors of the comparable EI models is performed on the basis of the received value ratios:

$$K_j = \sum_{i=1}^{M} \nu_i P_{ij}, i = 1..N, j = 1..J, \quad (7)$$

According to the estimation results, the EI model, which has the largest Kj, is considered optimum.

The developed procedure allows to determine an optimum alternative of the EI on RES based on the total amount of operation and process parameters with regard to the “cost – operation efficiency”. The procedure is universal and can be used when selecting RES for any facility.

Hourly average generation of biogas is 742/24=30.9 m3/h. 5 Models of Biogas–Reciprocating Electric Installations (BGREIs) have been selected based on possible biogas generation (30.9 m3/hr). A comparative analysis of the selected BGREI models has been conducted as per the procedure developed on the basis of 6 factors: electrical capacity, bio-gas consumption, electrical efficiency, capacity factor, overhaul life and cost. Table 2 shows the results of the comparative BGREIs analysis. The best suited Model of the BGREI is Caterpillar G3306 which has the largest Kj value (0.89).

Table 2. Comparative BGREIs Analysis

EI model / Factors	Cento T80		Doosan Daewoo 100		Ricardo 100		Caterpillar G3306		Petra 74 C	
	p_{i1}, abs.u.	$v_i \cdot P_{i1}$, p.u.	p_{i2}, abs.u.	$v_i \cdot P_{i2}$, p.u.	p_{i3}, abs.u.	$v_i \cdot P_{i3}$, p.u.	p_{i4}, abs.u.	$v_i \cdot P_{i4}$, p.u.	p_{i5}, abs.u.	$v_i \cdot P_{i5}$, p.u.
Electrical output, kW	83	0.18	100	0.22	100	0.22	68	0.15	62.3	0.14
Biogas consumption, m^3/h	36.5	0.12	26	0.17	30	0.15	21.8	0.20	31.3	0.14
Electrical efficiency, %	35	0.13	27.9	0.10	35.4	0.13	27.9	0.10	32.9	0.12
Electrical capacity factor, p.u.	1	0.14	0.8	0.11	0.8	0.11	1	0.14	1	0.14
Time between overhauls, TBO, thou. hr.	55	0.21	40	0.15	40	0.15	60	0.23	60	0.23
Price, thou. r./kW	26.5	0.07	23.7	0.08	21	0.09	26	0.07	24	0.08
Kj, p.u.	-	0,84	-	0,73	-	0,89	-	0,78	-	0,82

The investigation of the AE's daily load curves has revealed that BGREI's capacity used fails to provide full energy independence of the Enterprise even for the period of minimal power consumption. They have arrived at the decision to use Solar Power Plants (SPPs) in order to ensure improvement in the AE's power supply reliability.

SPPs have been selected with the use of the automated database [9, 10]. Table 2 shows Solar Power Plants Comparative Analysis results.

Table 3. Solar Power Plants Comparative Analysis

EI model / Factors	TSM-230SB		RZMP-240-T		HH-MONO230		HG-250S		Saana-245LM3	
	p_{i1}, abs.u.	$v_i \cdot P_{i1}$, p.u.	p_{i2}, abs.u.	$v_i \cdot P_{i2}$, p.u.	p_{i3}, abs.u.	$v_i \cdot P_{i3}$, p.u.	p_{i4}, abs.u.	$v_i \cdot P_{i4}$, p.u.	p_{i5}, abs.u.	$v_i \cdot P_{i5}$, p.u.
Output, W	230	0.06	233	0.06	230	0.06	250	0.07	245	0.07
Electric current density, A/m^2	4.65	0.06	4.84	0.07	5.75	0.08	4.94	0.07	5.07	0.07
Voltage, max., working., V	38	0.14	32	0.12	27.6	0.10	31	0.11	30.2	0.11
Efficiency, factor, PET, %	17	0.12	17.1	0.12	15	0.10	17.4	0.12	16.2	0.11
Weight, kg	15.4	0.20	21.5	0.14	17	0.18	19.6	0.16	21.1	0.15
Cost, rubles/W	122	0.15	47	0.38	69	0.26	61	0.29	72	0.25
Kj, p.u.	-	0.73	-	0.89	-	0.78	-	0.82	-	0.76

Based on Solar Power Plants Comparative Analysis results, RZMP-240-T Model has been proved to be the best suited.

3. Provision of Parallel Operation of Energy Sources of Different-Types

This problem has been predetermined by different RES output parameters and the necessity to adjust them in accordance with the electric grid normal parameters.

Two approaches are widely spread in order to arrange parallel operation of energy sources of different-types – the use of the hook-up diagram on direct or alternative current side and the use of hybrid invertors [11].

Combination of RES of different-types on 1,000 V AC side shall be reasonable if gross capacity is more than 10 kW, in this case EIs shall be remotely distanced from each other. Two diagrams to hook-up energy sources to the AC Current Bus: direct-on-line and via the high frequency AC bus [12]. Direct-on-line hooking up has a negative effect on the quality of energy supplied to consumers. Due to the complexity of technology, the use of the high frequency bus increases energy costs.

As a rule, energy sources hooking up diagrams on DC current side are used to supply power to low and medium power consumers (up to 10-30 kW). All EIs operating on RES are connected with DC lines with the invertor hooked up to them. Insufficient flexibility relative to the change in sources combination and the System capacity expansions as well as the need for specific transducer elements for each EI operating on RES are the common drawbacks of these diagrams thus increasing the System cost.

Hybrid invertors grant definite advantages in comparison with hooking up diagrams on DC or AC side – they combine functions of the energy source, the controller and the standby Uninterrupted Power Supply (UPS). Top high-tech Models of hybrid invertors provide the possibility to combine EIs of different-types operating on RES, energy storage (accumulators) and the United Energy System into one power supply system. However, hybrid invertors' wide spread is limited by small permissible capability of consumers being hooked up and the possibility to connect only specific models of EIs operating on RES.

Consequently, those technologies that provide parallel operation of RES are being updated and improved due to their reduced functionalities with regard to types and capacity of EIs being hooked up.

Figure 2 shows daily load curves of the AE under investigation and the resulting power generation curve of the BGREI and SPP.

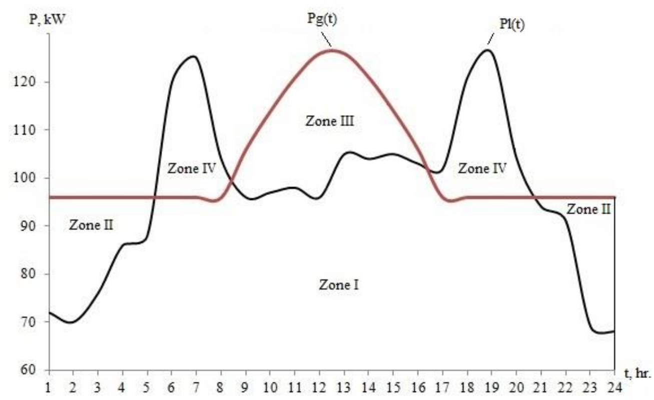
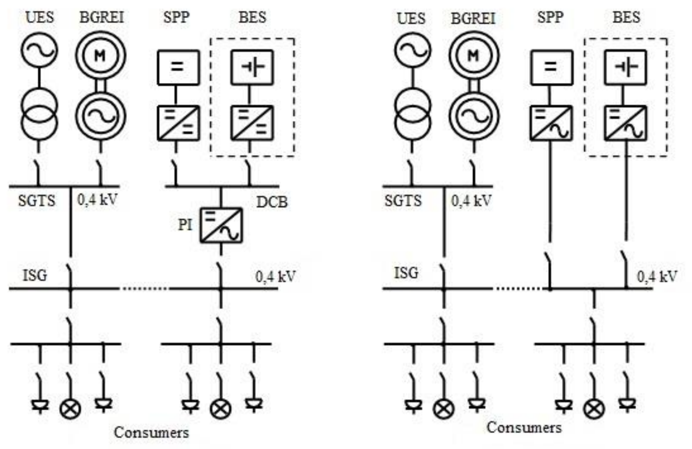


Fig. 2. The daily load curve of power generated and consumed at the Agricultural Enterprise
Pg(t) – the daily curve of power generated, Pl(t) – the AE's daily load curve, Zone I – Consumption of energy generated by Biogas-Electric Installations; Zone II – Energy surplus generated by Bio-Gas- Electric Installations;
Zone III – Energy surplus generated by Solar Power Plants; Zone IV –Future oriented zone for energy storage use

As it may be seen from Figure 2, the AE's energy consumption has not been consistent with electric energy generated by SPPs and have been partially consistent with electric energy generated by BGREI. So for the purpose to improve power supply reliability the Buffer Energy Storage (BES) has been additionally provided for.

Based on the daily load curve and taking the infrastructure of the investigated AE into consideration, two power supply diagrams have been proposed: BES and SPP on DC (Figure 3, a) and on AC (Figure 3, b).



a) Diagram 1 b) Diagram 2
Fig. 3. The AE' power supply diagrams operating on RES
SGTS – Switchgear of Transformer Substation, DCB - Direct Current Bus, ISG – Incoming Switchgear, PI – Power Inverter

Both Diagrams combine the EI operating on RES (BGREI and SPP), BES and UES. Diagram 2 excludes the extra step to convert electric energy, thus improving power supply reliability and providing the possibility to use electric energy surplus generated by BGREI. Electric energy quality problems at the point of SPP and BES interconnection have been eliminated in this regard since these elements are not dynamic EIs.

Parallel AC operation of RES of different-types (SPP and BGREI) shall be determined by two factors:

1) Gross capacity of EI operating on RES > 10 kW;

2) SPP and BGREI to be remotely distanced from each other.

Thereby, Diagram 2 has been selected for the AE's power supply; in this diagram SPP is combined with BES and SPP operates in AC parallel mode with BGREI.

4. RES Integration into the United Energy System

The possibility to ensure energy in-feeding to the AE from the United Energy System shall be provided for the purpose of guaranteed power supply in case of RES power system deficiency.

The following problems are encountered with the integration of EI operating on RES into the United Energy System (UES):

1) Output parameters of EI operating on RES (number of phases, voltage value, frequency, etc.) may differ from standard parameters of the United Energy System [13, 14];

2) In order to enhance efficiency of the AE's power supply system with RES over-generation, the possibility to transmit electricity to the United Energy System shall be provided for [15].

Existing engineering devices neither perform in full coordinating functions of any EIs operating on RES nor provide their integration into the United Energy System with regard to certain parameters (number of phases, voltage value, frequency, etc.).

The development of the Automatic Power Flow Control Station (APFCS) in the electric distribution grid has solved this problem [16]. The APFCS enables to integrate small power sources into the United Energy System and to control active and reactive power flows (including reversal flows).

Today the team of scientists from the Nizhny Novgorod State Technical University named after R.E. Alekseev (NNSTU) together with the authors are conducting scientific researches on the development of Automatic Power Traffic Flow Control Station in the Intellectual Distribution Electric Grid [19].

Figure 4 shows APFCS configuration and hooking up of the investigated AE's electrical power supply system.

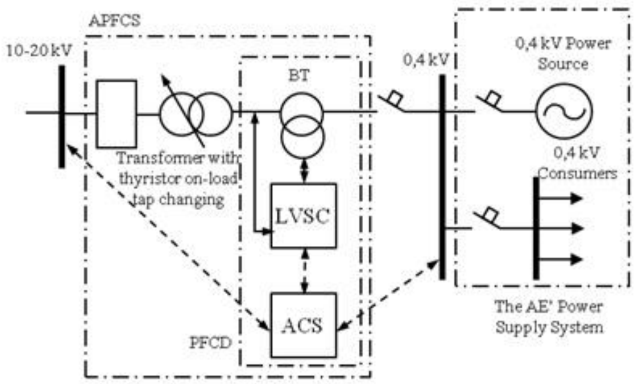


Fig. 4. The use of Automatic Power Flow Control Station (APFCS) in the electric distribution grid

The developed Automatic Power Flow Control Station includes the following main components:

- 10/0.4 kV transformer with thyristor On-Load Tap Automatic Changing [20],
- The Active/Reactive Automatic Power Flow Control Device (PFCD) based on the Low Voltage Semiconductor Converter (LVSC) with the Adaptive Control System (ACS) and three single phase service transformers (Boosting Transformers, BT) in each phase of the feed line.

In addition to (active and reactive) power flow control the PFCD shall provide shaping of sinusoidal voltage, smooth control of phase values of the voltage being shaped.

Hooking up of the investigated Agricultural Enterprise to the APFCS shall provide the possibility of power supply from the United Energy System in case of power system deficiency and its transmission to the United Energy System- in case of over-generation. So power generated by the Bioпas- Electric Reciprocating Installation (BGREI) since March to November has been insufficient; that is why there is need for electric power from the United Energy System. The period starting from April to September is the most favorable for SPP use. In this period there is power over-generated by BGREI and SPP; it is either transmitted for storages' charging or supplied to the United Energy System. In this case the quality of electric energy transmitted shall comply with standard parameters.

5. Conclusion

The Article covers issues concerning RES use for power supply of agricultural enterprises. The following tasks have been completed successfully and have been demonstrated with "Zhdanovsky" Livestock Complex: assessment of RES use efficiency and its selection for specific conditions and provision of parallel operation of RES of different-types and RES integration into the United Energy System.

Based on the procedure developed by the authors two Models of EIs operating on RES-BGREI (Caterpillar G3306) and SPP (RZMP-240-T)-have been selected for the power supply system of the investigated AE. These EIs operate most efficiently with regard to the following criteria: cost, electrical output, biogas consumption, electrical efficiency, electrical capacity factor and overhaul life.

Taking the AE' infrastructure and the daily load curve, parallel AC operation of BGREI and SPP has been selected. This has been determined by RES gross capacity of more than 10 kW and remoteness of Electric installations on RES from each other.

The task to integrate RES into the United Energy System has been completed by means of development of the Automatic Power Flow Control Station (APFCS). Hooking up of the investigated Agricultural Enterprise to the APFCS shall provide the possibility to supply power from the United Energy System in case of power system deficiency and transmit it to the United Energy System- in case of over-generation. The quality of electric energy transmitted shall comply with standard parameters.

Acknowledgements

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