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APPLICATION OF SMART GRID TECHNOLOGY ON A LARGE DAIRY FARM

Research article

Abstract

Currently, the improved performance of renewable energy sources triggered their increased application. In most cases, however, they are combined with a centralized power supply. Therefore, power production from multiple sources and power consumption requires efficient coordination. A solution may be Smart Grid Technology. It allows improving efficiency, reliability, and stability of electricity generation and distribution under certain economic benefits. The study objective was to assess the practicability of establishing a smart grid on large-scale dairy farms with above 1000 cow stock. The study was based on the electricity consumption data obtained on the modern dairy farms in the Leningrad Region, Russia, associated with the electricity inputs, the energy distribution scheme on a dairy farm and the use of transformer substations. The conceptual scheme of the smart grid for a dairy farm was developed. The factors for assessing the local electricity generation resources were considered including a proposed comprehensive environmental indicator, which takes into account the volume of pollutants produced and the degree of their negative impact on the environment. The study verified the principal possibility and feasibility of establishing a smart grid for large dairy farms.

Keywords: smart grid technology, renewable energy, power supply, electricity consumer, energy generating resource, power, evaluation criterion, intensive machine-based technology, environmental indicator.

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ПРИМЕНЕНИЕ ТЕХНОЛОГИИ УМНЫХ СЕТЕЙ ЭЛЕКТРОСНАБЖЕНИЯ НА КРУПНЫХ МОЛОЧНЫХ СЕЛЬХОЗПРЕДПРИЯТИЯХ

Научная статья

Аннотация

В настоящее время повышение эффективности возобновляемых источников энергии привело к их более широкому применению. Однако в большинстве случаев они сочетаются с централизованным источником электроэнергии. Следовательно, согласованная генерация электроэнергии из нескольких источников и её последующее потребление требуют эффективной координации. Решением может быть технология умных сетей электроснабжения (smart grid technology). Это позволяет повысить эффективность, надежность и стабильность генерации и распределения электроэнергии с учётом экономического фактора. Цель исследования состояла в том, чтобы оценить целесообразность создания интеллектуальной сети на крупных молочных сельхозпредприятиях с поголовьем более 1000 молочных коров. Исследование основывалось на данных о потреблении электроэнергии, полученных на современных молочных сельхозпредприятиях в Ленинградской области, Россия (данные о потреблении электроэнергии, схемы распределения энергии на молочной ферме, использованием трансформаторных подстанций и т.п.). Разработана концептуальная схема умной сети для молочной фермы. Были рассмотрены факторы для оценки местных ресурсов генерации электроэнергии, включая предлагаемый комплексный экологический индикатор (показатель), который учитывает объем образующихся загрязняющих веществ и степень их негативного воздействия на окружающую среду. Исследование подтвердило принципиальную возможность и целесообразность создания умных сетей для крупных молочных сельхозпредприятий.

Ключевые слова: умные сети электроснабжения, интеллектуальные сети электроснабжения, возобновляемые источники энергии, электроснабжение, электропотребление, источники генерации электроэнергии, критерии оценки, интенсивные машинные технологии, экологический индикатор.

1. Introduction

Currently, power supply systems actively introduce the smart grid technology that allows optimizing the energy consumption and provides the electricity redistribution.

The main reason is the wider farm application of renewable energy sources, which are generally combined with a centralized power supply for economic considerations. Smart grid technology automatically adjusts the power supply depending on reduced or increased power consumption.

The smart grid is a technical system combining intelligent meters, information and computer complex, and control system. The smart grid provides the consumers with improved reliability of power supply and electric power quality; it is the resource for governing the energy consumption and for reducing the energy payments. The introduction of smart grid technology will allow more widespread adoption of renewable energy sources that reduce the negative impact on the environment.

Many publications address the use of renewable energy in agriculture [4], [6], [7], [8], [10]. Also many publications address the smart grid issues: designing [2], modeling [5], load management [1], implications of smart grid development [3]. Introduction of smart grid technology in rural areas and farming was also considered in several investigations and projects on a small scale [9]. Therefore, this topic is still urgent for large-scale agricultural enterprises, dairy farms in particular.

The study was aimed to assess the principal possibility and feasibility of smart grid application on large-scale dairy farms with above 1000 dairy cows.

2. Methods

Energy surveys (energy audits) of 54 dairy farms, located in the Leningrad Region of Russia, with the cow stock of at least 1,000 head were conducted from 2014 to 2019.

The energy survey included the checking of heat, electricity and water meters and metering systems; examination of heat, water and power supply systems; inspection of farm buildings and boiler station.

The energy audit included an analysis of fuel and energy consumption, a forecast of energy consumption, an assessment of the energy intensity of production and measures to reduce it according to the economic criteria – costs, annual economic effect, and payback period. Installed capacities of power receivers, the actually-used power capacities, and the annual electricity consumption were considered. The standard structure of electricity consumption was obtained by calculating the average values on the surveyed farms.

3. Results

According to the energy surveys of dairy farms in the Leningrad Region:

1. The installed capacity of power consumers (electrical receivers) on the farms ranges from 800 to 2,800 kW, with the average capacity being 1,500 kW.
2. The actual capacity used by electrical receivers is from 400 to 900 kW.
3. The amount of electric energy consumed per year is in the range of 2,850-5,700 MWh.
4. Power distribution networks of 10 kV voltage class are most common on the farms.
5. Electricity meters are installed on transforming substations of 10/0.4 kV, which may be 8 to 22 per farm.
6. Electricity consumers in the surveyed dairy farms are livestock, crop and feed production facilities; workshops and garages; administrative and residential buildings, which are the agricultural enterprise's property.
7. Electricity is mainly used for lighting, space heating, hot water supply, and for electric actuation of different equipment.

The structure of electricity consumption on dairy farms is presented in Fig. 1.

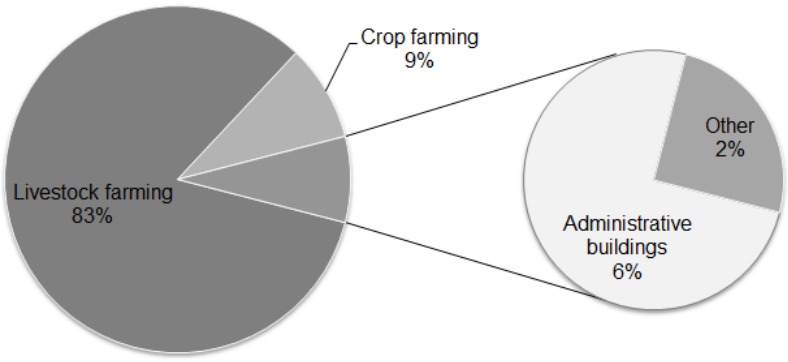

Figure 1 – Structure of electricity consumption on dairy farms

Based on the above survey results, a conceptual scheme of the smart grid for a dairy farm was developed (Fig. 2).

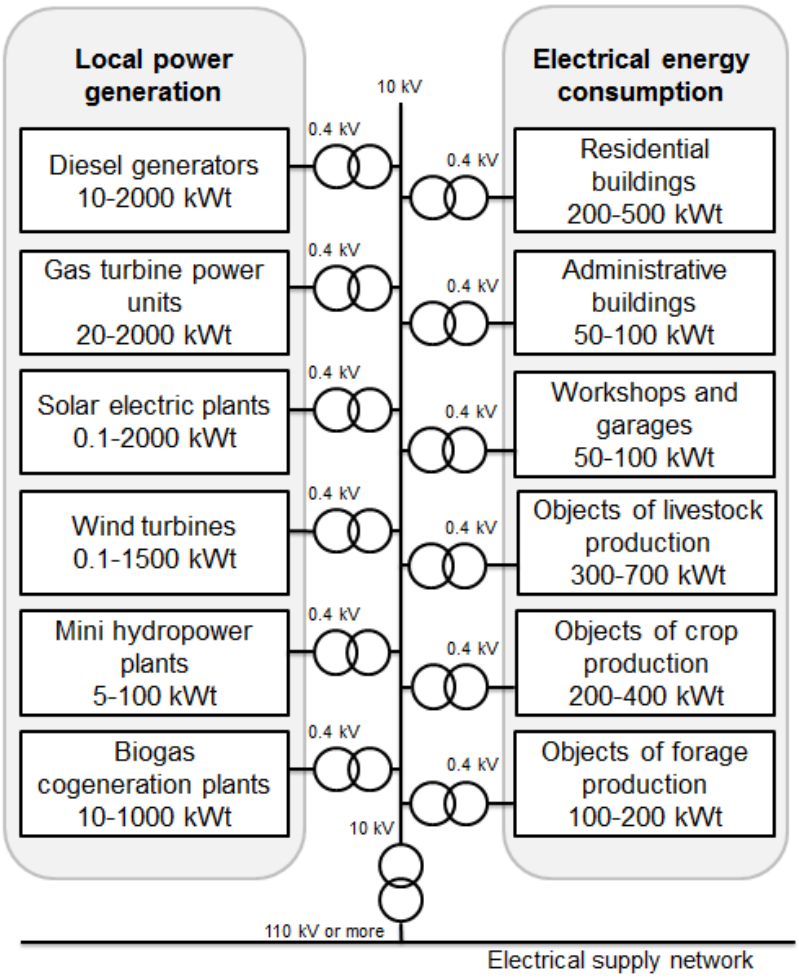

Figure 2 – Smart grid scheme for a dairy farm

Electric energy is supplied to the farm centrally from a national energy gird through the distribution networks of 110 kV. The voltage of electricity from the centralized grid is converted on a 110/10 kV transforming substation. Distribution networks of 10 kV voltage connect a centralized grid and local electricity generation resources into a single system.

The local electricity generation resources can be both traditional (gas turbine plants, diesel generator plants, etc.) and renewable energy sources – solar and wind power plants, mini hydro-electric stations, biogas cogeneration plants, etc.). Local electricity generation resources are connected to the common distribution network by transforming substations of 0.4/10 kV. Traditional resources generate, as a rule, electricity with a voltage of 0.4 kV.

Renewable energy installations should be equipped with an inverter as the generated electricity may be DC or AC with 12–100 V. Also, renewable energy installations should have a large stock of storage capacities, as the incoming energy (solar, wind and water energy) is not constant over time.

Fig. 2 shows the electricity consumers with the required power capacities. The developed scheme is conceptual in nature. It includes all potential energy sources and energy consumers.

Livestock production is the biggest energy consumer – up to 700 kW.

Usually, one livestock farm has 8–22 transforming substations of 10/0.4 kV. Sometimes livestock and crop production facilities of one farm (agricultural enterprise) are located in two or more settlements. The possible capacity of local electricity generation resources is presented in Fig. 2.

Theoretically, diesel, gas turbine and solar power plants can fully satisfy the farm's demand for electricity. The scheme and algorithm of the electricity supply system performance for a particular livestock farm may be designed and calculated by comparing the required power in time with the generated power from different resources.

When designing a smart grid, it is very important to identify the local electricity generation resources with due accounts for the following factors (Fig. 3):

1. Economic factor is the construction costs of a power plant per kW of power and the electricity generation costs per kWh.

2. Environmental factor is the amount of pollutant emissions during the electricity generation per kWh and the degree of environmental impact of these pollutants.

3. Factor of the area size occupied by the energy generating installation.

4. Factor of noise pollution.

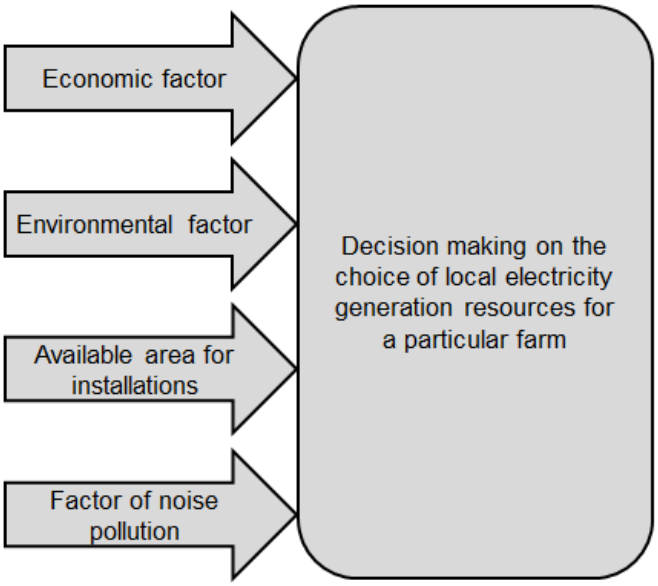

Figure 3 – Criteria for choosing the local electric power generating sources

Traditionally, the decision-making associated with the local electricity generation resources relied on the economic factor as the only or main one. However, the environmental factor should not be neglected in this respect. Comprehensive environmental indicator (coefficient) K_{env} is suggested, which takes into account the volume of produced pollutants and the degree of their negative impact on the environment. This indicator is calculated by the formula (1) and considers the six most significant pollutants:

1. Carbon dioxide (CO_2);
2. Carbon monoxide (CO);
3. Suspended particulate matter (dust);
4. Sulfur dioxide (SO_2);
5. Nitrogen oxides (NO_x);
6. Hydrogen sulfide (H_2S);

$$K_{env} = x_1 + 47x_2 + 431x_3 + 517x_4 + 1286x_5 + 29124x_6, \quad (1)$$

This formula has the constant values from 1 (for carbon dioxide) and up to 29124 (for hydrogen sulfide), reflecting their significance in the negative impact on the environment obtained by the expert estimates [11]. Variables X_1 to X_5 are the amounts of pollutants produced during the generation of one kWh of energy. This factor can be used for a comparative assessment of various energy generating resources. A lower factor value corresponds to a smaller negative impact of pollutant emissions from the electricity generation taking into account both the volume of formation of pollutants and the significance of the negative effects of each pollutant.

4. Conclusions

Survey of modern large dairy farms and relevant data analysis verified the principal possibility and feasibility of establishing a smart grid for large dairy farms. Conceptual scheme of a smart grid for large dairy farms was designed. The use of a smart power supply network and local renewable energy sources can reduce the negative impact on the environment in agricultural production.

The criteria affecting the choice of energy generating sources are considered and the use of a comprehensive environmental indicator when choosing the electricity generating sources and when creating a smart grid is proposed.

The use of the developed smart grid conceptual scheme, the considered factors for selecting local generation sources and the considered comprehensive environmental indicator allow to determine the specific parameters of the smart grid technology for modern large dairy farms with over 1000 heads of livestock.

Conflict of Interest | **Конфликт интересов**

None declared. | Не указан.

References

1. Amini M.H. Load Management Using Multi-Agent Systems in Smart Distribution Network / Amini M.H., Nabi B., Haghifam M.R. Proc. 2013 IEEE Power and Energy Society General Meeting. – P. 1-5.

2. Andren F. Engineering Smart Grids: Applying Model-Driven Development from Use Case Design to Deployment / Andren F., Strasser T., Kastner W. // Energies. V. 10, – 2017, No. 3.

3. Bappah, M. The potential of energy recovery from by–products of small agricultural farms in Nigeria / Bappah, M., Bradna, J., Velebil, J. et al. // Agronomy Research 17(6), 2019, 2180–2186. doi:10.15159/AR.19.165

4. Bigerna S. Socio-economic acceptability for smart grid development - a comprehensive review / Bigerna S., Bollino C. A., Micheli S. // Journal of Cleaner Production. V. 131, – 2016, – p. 399–409.

5. Chhaya L. K. Cross Layer Optimization and Simulation of Smart Grid Home Area Network / Chhaya L. K., Sharma P., Kumar A. et al. Modeling and Simulation in Engineering. – 2018, – 14 p.

6. Collotta M. The economic sustainability of small–scale biogas plants in the Italian context: the case of the cover slab technology / Collotta M. and Tomasoni G. // Agronomy Research 15(2), – 2017, – P. 376–387.

7. Dubrovskis, V. Biogas from wastes of pumpkin, marrow and apple / Dubrovskis, V. and Plume, I. // Agronomy Research, 2017, 15(1), – 2017, – P. 069–078.

8. Mikkola, H. J. Renewable energy from agro biomass / Mikkola, H. J. and Ahokas, J. // Agronomy Research. Biosystem Engineering Special Issue 1, 2011, – P. 159-164.

9. Rehmani M. H. Integrating Renewable Energy Resources into the Smart Grid: Recent Developments in Information and Communication Technologies / Rehmani M. H., Reisslein M., Rachedi A et al. // IEEE Transactions on Industrial Informatics (99). 2018. PP. 1-1. 10.1109/TII.2018.2819169.

10. Rugele, K. Application of industrial wastes in renewable energy production / Rugele, K., Bumanis, G., Mezule, L.et al. // Agronomy Research 13 (2), – 2015, – P. 526–532.

11. Энергоэкологическая оценка использования различных генерирующих источников в сельском хозяйстве / И. А. Субботин [и др.] // Инженерные технологии и системы. – 2019. Т. 29, № 3. – С. 366–382. DOI: https:// doi.org/10.15507/2658-4123.029.201903.366-382

References in English

1. Amini M.H. Load Management Using Multi-Agent Systems in Smart Distribution Network / Amini M.H., Nabi B., Haghifam M.R. Proc. 2013 IEEE Power and Energy Society General Meeting. – P. 1-5.

2. Andren F. Engineering Smart Grids: Applying Model-Driven Development from Use Case Design to Deployment / Andren F., Strasser T., Kastner W. // Energies. V. 10, – 2017, No. 3.

3. Bappah, M. The potential of energy recovery from by–products of small agricultural farms in Nigeria / Bappah, M., Bradna, J., Velebil, J. et al. // Agronomy Research 17(6), 2019, 2180–2186. doi:10.15159/AR.19.165

4. Bigerna S. Socio-economic acceptability for smart grid development - a comprehensive review / Bigerna S., Bollino C. A., Micheli S. // Journal of Cleaner Production. V. 131, – 2016, – p. 399–409.

5. Chhaya L. K. Cross Layer Optimization and Simulation of Smart Grid Home Area Network / Chhaya L. K., Sharma P., Kumar A. et al. Modeling and Simulation in Engineering. – 2018, – 14 p.

6. Collotta M. The economic sustainability of small–scale biogas plants in the Italian context: the case of the cover slab technology / Collotta M. and Tomasoni G. // Agronomy Research 15(2), – 2017, – P. 376–387.

7. Dubrovskis, V. Biogas from wastes of pumpkin, marrow and apple / Dubrovskis, V. and Plume, I. // Agronomy Research, 2017, 15(1), – 2017, – P. 069–078.

8. Mikkola, H. J. Renewable energy from agro biomass / Mikkola, H. J. and Ahokas, J. // Agronomy Research. Biosystem Engineering Special Issue 1, 2011, – P. 159-164.

9. Rehmani M. H. Integrating Renewable Energy Resources into the Smart Grid: Recent Developments in Information and Communication Technologies / Rehmani M. H., Reisslein M., Rachedi A et al. // IEEE Transactions on Industrial Informatics (99). 2018. PP. 1-1. 10.1109/TII.2018.2819169.

10. Rugele, K. Application of industrial wastes in renewable energy production / Rugele, K., Bumanis, G., Mezule, L.et al. // Agronomy Research 13 (2), – 2015, – P. 526–532.

11. Subbotin I.A. Energy and Environment Assessment of Agricultural Application of Power Generating Sources / Subbotin I.A., Briukhanov A.Yu., Timofeev E.V. et al. // Inzhenernyye tekhnologii i sistemy = Engineering Technologies and Systems. – 2019; 29(3):366-382. DOI: https://doi.org/10.15507/2658-4123.029.201903.366-382