Energy Center Structure Optimization by using Smart Technologies in Process Control System

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Abstract. The article deals with practical application of fuzzy logic methods in process control systems. A control object – agroindustrial greenhouse complex, which includes its own energy center – is considered. The paper analyzes object power supply options taking into account connection to external power grids and/or installation of own power generating equipment with various layouts. The main problem of a greenhouse facility basic process is extremely uneven power consumption, which forces to purchase redundant generating equipment idling most of the time, which quite negatively affects project profitability. Energy center structure optimization is largely based on solving the object process control system construction issue. To cut investor’s costs it was proposed to optimize power consumption by building an energy-saving production control system based on a fuzzy logic controller. The developed algorithm of automated process control system functioning ensured more even electric and thermal energy consumption, allowed to propose construction of the object energy center with a smaller number of units due to their more even utilization. As a result, it is shown how practical use of microclimate parameters fuzzy control system during object functioning leads to optimization of agroindustrial complex energy facility structure, which contributes to a significant reduction in object construction and operation costs.

1. Introduction

Competitive production development efficiency is largely determined by the level of its automation. Building of a new production facility in this days requires a pre-investment feasibility study involving professional experts at all stages and, especially, at front-end engineering design stage. This allows to determine all main parameters of the project at an initial stage with sufficient accuracy, which contributes to significant cost reduction, confirms data reliability for potential creditors and counterparties, significantly shortens designing and construction time, since equipment basic composition and basic technical solutions are identified immediately. In addition, involvement of experts with advanced knowledge of how to use smart control technologies, innovative solutions in construction and structuring of automated process control systems (APCS), ensures significant benefits associated with resource optimization, and significant costs reduction at the stage of built object operation [1, 2].

The article purpose is to consider practical use of a fuzzy logic controller-based control systems to optimize agroindustrial production processes which structurally includes its own energy center. To show possible cut of investor’s costs at project feasibility study stage in a specific context of a new greenhouse complex construction with the use of up-to-date smart object control systems allowing to optimize energy center structure.

The experts examined the project to justify agroindustrial greenhouse complex construction investments. Construction of this agricultural enterprise is planned using an “open field” principle, i.e.
2. Feasibility study

Several options for object power supply – the greenhouse complex – were estimated as part of the project examination. In particular, the options that take into account possible connection to external power grids, as well as installation of own power generating equipment with various modifications. The estimation showed: one of the main problems is that there are power consumption surges in current process resulting in extremely uneven daily power consumption schedule (figure 1).

Figure 1. Daily power consumption schedule.

Figure 2. Annual power consumption schedule.

Such a daily utilization of the energy center (figure 1) and uneven average monthly consumption (figure 2) showed that operation according to third party consumer power supply schedule is inefficient, and taking into account process connection costs and current power consumption costs the project turns out to be nearly cost-ineffective, since the main costs of the greenhouse facility are energy supply.

Alternatively, building of own gas reciprocating unit-based (GRU) energy center was estimated. Initially, the investor planned to install four GRUs of 8.18 MW each (figure 3, figure 4) based on the object needs. This particular equipment is used due to external reasons, which will not be dwelt on separately herein. However, the use of four GRUs with a total capacity exceeding 32 MW has many negative consequences:

1. Evident power redundancy: low utilization of the fourth unit throughout the year: 79% - the first unit, 55% - the second one, 31% - the third one, 5% - the fourth one (with 8000 hours and above of annual utilization estimated). Energy center peak utilization exceeds 90% (in winter daytime).
2. If current daily utilization of the energy center is kept, operation according to third party power consumption schedule is impossible, which greatly complicates solution of the problem through selling surplus power on the side. A prerequisite is availability of consumers in local power consumption area with clear schedules of daily and annual power consumption. Even if such a consumer is available now there is no guarantee of its permanency.
3. The energy center capacity exceeds 25 MW. Selling power from such facilities to the retail market is generally not allowed by a power market regulator, while power sale price in the wholesale market is 2-3 times lower than the retail one. To work at retail price, it is necessary to reduce the installed capacity or to unify the greenhouses and energy center into a single process enterprise and a separate legal entity that can sell surplus power in the retail market. This is accompanied by significant legal risks and dependence on the power market regulator in the future.
A financial model was developed for the investor to allow a comparative analysis of various options for energy hub arrangement. The options providing for installation of two, three and four GRUs were estimated with peak loads covered by purchasing missing capacities in the power market and selling surplus power. For the four GRUs option, several sub-options with and without connection to external power grids and possible partial selling of surpluses were estimated (table 1).

Conclusions of preliminary assessment of the various options:

1. From the point of view of energy self-sufficiency and safety against game rule changes and price fluctuations, the most preferable option is operation in “power island” mode, where no complex power selling schemes are required, possibility of autonomous operation with no external power supply infrastructure is ensured.

2. The least efficient options are construction of energy center with four GRUs and selling surplus power to the market, or refuse to sell (the fourth unit is backup).

3. In any case EBITDA calculated on the basis of reduction of cost for power purchasing due to GRUs generation is between 200 and 400 million rubles depending on the power hub configuration.

### Table 1. Comparative analysis of the energy hub arrangement options.

| Name                                           | Basic option* | Option 1 | Option 2 | Option 3 | Option 4 |
|------------------------------------------------|---------------|----------|----------|----------|----------|
| Installed capacity, MW                         | 32.7          | 16.4     | 24.5     | 32.7     | 32.7     |
| Construction cost, million rubles              | 2408.80       | 1284.00  | 1607.60  | 1931.30  | 2090.50  |
| Power required for process connection / power distribution scheme, MW | 27.86     | 18.57    | 9.3      | -        | 9.3      |
| Process connection cost / power distribution scheme, million rubles | 477.5     | 318.3    | 159.2    | -        | 159.2    |
| Power purchase on the market, million rubles per year | -          | 144      | 30.6     | -        | -        |
| Power sale to third party consumers, million rubles per year | 163.1      | -        | -        | -        | 121.1    |
| Need to optimize power consumption schedule    | -             | -        | -        | yes      | yes      |
| Payback period, taking into account process connection, years | 6.6          | 5.2      | 5.3      | 6.4      | 6        |

From the point of view of economic factors combination and confidence in power supply, the investor was advised:
1. To optimize greenhouses power load schedule (peaks decrease, dips mitigation) by change of a greenhouse facility process control system. To do this, it is advised to involve automated process control systems construction experts to develop equipment functioning optimal algorithms. The goal is to optimize the system operation, taking into account refusal to use the fourth unit with redistribution of the remaining units utilization.

2. Development of a legally reliable organizational scheme for working in the retail power market for the three GRUs energy center option.

3. Various technical solutions based on thermal energy consumption schedule analysis, after comparison with electrical energy consumption schedule. Including the use of carbon dioxide from the units exhaust gas to increase greenhouses performance up to 25%.

3. Fuzzy logic control system
As a result of the above recommendations, studies to develop a fuzzy algorithms-based control system with automatic modification of the process system to reduce energy costs by optimizing power consumption were carried out [5].

For ACS experts a requirements specification was drawn up. It provided for development of the fuzzy algorithm and a production rules system on its basis, the implementation of which in real time would ensure a more even consumption of electrical and thermal energy, which would result in energy costs reduction through the GRUs operation optimization. Fuzzy control system generalized structure can be illustrated by the following chart (figure 5) [1, 3].

![Figure 5. Structure chart of the fuzzy logic system.](image)

Development of the fuzzy control system provides for the following issues to be solved [1, 3, 5]:
- presentation of the information used for control in terms of fuzzy logic (fuzzification task);
- framing of a fuzzy inference rule base taking into account process engineers’ expert knowledge and control actions determination algorithm (control actions development task taking into account resolutions history);
- description of control in terms of fuzzy logic to get physical control actions in the system (defuzzification task).

Resolution of the above issues is related to the need to carry out studies and to develop appropriate mathematical models applicable to processes control [3, 5, 6].

At the initial stage of fuzzification in respect to greenhouse complex process parameters control, a general list of regulated parameters, linguistic variables and terms structure to describe the control object state, conditions for its functioning and control actions were determined taking into account the results of process features analysis. At this stage a complete list of parameters that can be regulated by the developed control system is determined. Main power-consuming parameters were chosen:
temperature inside the greenhouse (especially at the soil level);
- greenhouse illumination;
- humidity of soil and air inside the greenhouse;
- external perturbing factors (environmental impact).

Membership functions of information and control signal physical values in linguistic variable terms were determined taking into account degree of interrelation between these components and expert estimates. After solving the problem of fuzzification, linguistic variables and their terms were stated to describe process microclimate parameters condition and to control them, and functions of membership connecting process physical parameters with linguistic variables were obtained.

Implementation of the algorithm next stage allowed to develop a rule base for describing a control algorithm of the fuzzy controller on the basis of experimental data and experience gained by process experts. The obtained rules determine microclimate parameters combination selection inside the object based on the environmental parameter values and effect of each parameter on all the others.

The solution to the next task of fuzzy inference rules development is to determine a resulting function of membership for control actions using the rule base and fuzzy operations. The resulting rule base unit contains a set of linguistic rules reflecting system operation algorithm.

During fuzzy inference, the fuzzy controller determines the control actions membership function value through temperature, humidity and illumination control channel in terms of fuzzy control. To determine a control actions physical value, defuzzification is performed for control actions logical values. Defuzzification is associated with conversion of the control membership function for each control channel into physical value of control action on the actuators [3, 5].

Based on the results of the object main parameters study, a system of fuzzy control of the object process microclimate parameters is proposed. General structure of the greenhouse complex microclimate parameters fuzzy control system is shown in figure 6.

![Figure 6. Greenhouse complex microclimate parameters fuzzy control system.](image)

4. Conclusion Findings

According to the estimations, introduction of the proposed control system will significantly improve the situation regarding GRUs uneven utilization during winter season, which in turn will allow us to speak with a high degree of confidence about possible operation of the energy center with three GRUs (option 2) and to optimize its structure using smart technologies. Optimum control of the energy center
operation will result in peak load decrease in winter season to a level sufficient for stable operation of the control object in these conditions (figure 7).

**Figure 7.** Schedule of power generation and consumption after optimization of the object control with the use of the fuzzy control system.

The figure shows that the peak loads are reduced, power consumption dips are smoothed.

Thus, development of the greenhouse complex processes smart control system based on fuzzy logic, taking into account best practice employed by process engineers in the form of the knowledge base, results in real optimization of the energy center structure and, accordingly, the level of expenditure.

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