Agent-based approach for analysis of electricity distribution technological processes in power systems

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Abstract. The question of minimizing the loss of the active component of power in power transformers of distribution networks is considered. Authors’ attention is focused on the reduction of additional losses due to the non-sinusoidal nature of the load. The proposed solution is based on the application of the principle of level decomposition for the system “digital substation - distribution network”. There are three logical levels distinguished, which are described in terms of the agent approach within the framework of this system. At the single-phase consumer level the solution of the combinatorial problem of dynamic connection of consumers by means of agent metaheuristics is offered. It is proposed to integrate an intelligent agent into the transformer substation. The main functions of the agent are to control the launch of agent metaheuristics and adaptive filtering of higher harmonic components of the current. Also, the integration of an intelligent agent is offered at the digital substation level. Its task is to synthesize a new configuration of the distribution network, subject to receiving information from agents of transformer substations. For the coordinated work of all agents, the organization of their interaction through a wireless network is proposed.

1. Introduction
Modern electronic equipment in most cases is a non-linear electrical load for the power supply system, that is, it consumes a non-sinusoidal form, which creates distortions in the supply network and, as a result, voltage distortion that affects other equipment that receives electricity from a common source [1, 2]. The situation with power consumers, distorting the quality of electrical energy, is continuously deteriorating [3, 4, 5]. In recent years there has been a significant deterioration in the quality of electrical energy in the networks of non-industrial consumers - shopping complexes, office buildings, educational institutions, residential buildings [6]. Such a load generates high harmonics of current into the electrical network. Thus, every year specific weight of such a load increases in the overall structure of power consumption. [7]. Quantity and characteristics of nonlinear power consumers change, and, consequently, the harmonic composition of currents and voltages change too [3]. Deterioration of the quality of electricity in the distribution networks is typical for most developed countries [8, 9], since there are less and less power consumers with linear current-voltage characteristics [10].

High harmonic components of the current cause the following undesirable consequences:
- distortion of the form of the supply voltage [1, 8, 11, 12];
- occurrence of overheating and destruction of the zero working conductors of supply lines [1, 2, 8, 11 - 13];
- increased wear, swelling and premature destruction of capacitors of reactive power compensation installations [3, 11-14];
- false operation of fuses, circuit breakers, residual current devices, relays and electronic units [11–15] and erroneous operation of measuring devices [2];
- interference in telecommunications networks, provided that power cables and telecommunications cables are laid close to each other [1, 9, 11 - 13, 16];
- resonance phenomena in 0.4 kV electrical installations [12, 15];
- reducing the power factor of electrical installations [12, 15];
- increase in resistance of earthing switches [13];
- increased acoustic noise in electromagnetic equipment [1, 17];
- increase in voltage drop in supply wires due to the skin effect [14].

The continuous growth of the installed power of non-linear, asymmetrical and rapidly alternating loads is not accompanied by the timely implementation of solutions aimed at correcting the quality of electrical energy [23]. Each individual electrical receiver influences the network slightly, but their combination has a significant impact on the electrical distribution network [24], since when the power of a nonlinear load does not exceed 10 - 15% of the power of the power supply system, significant changes in the operating mode of the system do not appear, but with the share of non-linear load exceeding 25%, negative and sometimes accidental consequences occur in the power grids [8, 21].

Recently, there has been a tendency of the prevalence of higher harmonic components of the current of non-linear small receivers over the highest harmonic components of high-power consumers. In connection with the recent increase in the number of used household appliances, a tendency of growth in the influence of higher harmonic components on the part of consumers on the operation of low and medium voltage networks is expected [25].

Considering the intensive distribution of semiconductor converter technique, in recent years, the improvement of the quality of electric power has become a pressing and important technological challenge. This is due to the decrease in the influence of higher harmonic components on the operation of electrical equipment [26, 27]. The current situation in electrical networks requires research aimed at improving the methods for assessing the influence of non-sinusoidal nature of electrical quantities on the loss of active power and electricity in the equipment of electrical networks.

2. An object, subject and research task

The research object is the electric power distribution system of electric energy, which is a combination of “digital substation - distribution network” (CP-PC). The distribution network includes distribution transformer substations (TS), power lines connecting them to the CPU, as well as many electricity consumers that receive electricity from the TS (Figure 1).

The subject of research is the technological process of transmission and distribution of electricity to consumers and increasing its efficiency by reducing electricity losses caused by the harmonic components of the current.

The objective of the research is to develop a concept based on the use of multilevel solution approaches to the synthesis of an effective trajectory of the technological process of transmission and distribution of electrical energy from the CPU through the RS to consumers, which will be based on the principle of reducing additional losses of the active component of power in two-phase power transformers of distribution networks caused by current components.
3. Anticipated decision
To solve the problem of minimizing electric power losses in the electric power system CP-PC, caused by non-sinusoidal load, we propose its logical division into a number of subsystems in accordance with the basic principles of level decomposition in computer science and application of agent-specific algorithms that are different for each level.

3.1 Levels decomposition
Within the framework of the CP-PC system, it is logical to distinguish three sublevels/subsystems with the aim of further detailing the solution of the research problem (Figure 2).
Figure 2. The selection of logical levels in the CP-PC system

The first level of the CP-PC electric power system includes a multitude of single-phase consumers (SC), which are connected to the L1, L2 and L3 phases of the TS (related to level 2) by means of lines rated for 0.4 kV and receiving power supply through them. The third level is formed by a digital substation and a network of distribution power lines designed for one of the medium voltages and intended for power supply of the transformer substation.

At level 1 (Figure 2), it is proposed to apply the distribution of SC to the phases so that their superposition on each of the three phases L1, L2, L3 and on the TS as a whole creates a connection configuration that minimizes the total losses of active electricity in power transformers of the distribution network at the level 2. It is assumed that in the distribution network (for example, an apartment building), the mechanism of dynamic switching of the final SC of electricity between the phases works.

The proposed solution is based on one of the ways to reduce the negative impact of higher harmonic components of current and voltage, which is to ensure the symmetrical operation of the three-phase power transmission system [1, 28]. In order to balance the loads across the phases and at the same time ensure the minimum current in the neutral conductor and the minimum harmonic content in the output current and, as a consequence, voltage, appropriate control and management circuits are necessary [28]. It is also known that harmonic current components different electrical consumers differ in phase, and as a result, when they work together on the same network, the total harmonic components in it can be mutually suppressed [14].

The development of a solution regarding the configuration of the SC connections is planned by reducing the indicated problem to the combinatorial optimization problem and its solution based on agent metaheuristics [29, 30]. Solving such a task will require the organization of a separate computing resource for each TS or a specialized cloud service to service all TSs of the CP-PC system in the complex.

After obtaining a reconfiguration of the SC connections in phases at level 1, the residual harmonic components of the current on the low voltage windings of the transformer substation are minimized at level 2 - using adaptive filtering. This decision is due to the fact that the main means of attenuating higher harmonic components in power supply systems are harmonic filters [26]. One of the most effective examples of such equipment are filter-compensating devices. In turn, passive, active and hybrid filters are distinguished by the presence of active elements [28]. To set up filter-compensating devices, it is necessary to have information about the harmonic composition of the mains current. To this end, before introducing filter-compensating devices in existing power supply systems, one should have information on the levels of the main harmonic components present in them [31]. The use of ac-
Active filters, sometimes referred to as active harmonics smoothers (active power filter - APF) [32], seems promising. Active harmonic filters in contrast to passive filters contain controls that allow you to change the frequency characteristics of the filter. The development of power electronics: GTO-thyristors and IGBT-transistors, determined the element base, which is the basis for the construction of active harmonic filters. The wide possibilities of the functional properties of the active filter make it possible to apply it not only to reduce the level of harmonic components, but also to compensate for reactive power [28].

It is assumed that it is permissible to reduce the magnitude of the harmonic components of the current at levels 1 and 2 cannot be achieved by economically justified methods. The elimination of the residual harmonic components of the current is assumed at the third level based on the procedures for dynamically changing the configuration of TS connections [33] within the framework of the corresponding distribution network (Figure 1), by changing the network topology using reclosers.

3.2. Ideology of agents
At level 2, it is planned to integrate the software and hardware complex into the TS, which in the aggregate is an intelligent TS agent, indicated in Figure 2 as 🙃. This agent is authorized to perform the following functions (Figure 3):

1) «Control» - measurement of the magnitude of the harmonic components of the current and voltage for each phase;
2) «Calculation» - calculation, on the basis of the results of claim 1, of the value of additional losses of the active component of power in two-phase power transformers of the distribution network, caused by harmonic components of the current;
3) «Analysis» analysis of the current situation (each situation is determined by one of the states of the control logic variable F):
   - «000» - it is necessary to start reconfiguration of the SC connections by phases;
   - «100» - requires the inclusion of adaptive filtering;
   - «110» - it is necessary to transfer the command to take measures to minimize additional losses of the active component of power, caused by harmonic components of the current, to level 3;
4) «Reconfiguration» - determination of the need to start reconfiguration of the SC connections in phases and transfer (if necessary such) of the corresponding command to level 1, setting for F the value «100». After that, clauses 1 and 2 are re-executed and the decision is made to turn on the adaptive filter at level 2 («Filtering» command) and then transfer the command to take appropriate measures at level 3 («to level 3» command);
5) «Filtering» - enabling the adaptive filter, setting for F the value «110»;
6) «To level 3» - transfer of a command to level 3 on the need to take measures to combat residual phenomena of the harmonic components of the current (F = «111»);
7) «Initialization» - initialization of the state of the control logic variable F (F = «000»).

It is also supposed to introduce a separate agent in the composition of the CPU, indicated in Figure 2 as 📊. The main function of this agent is the direct synthesis of a new distribution network configuration linking the TS group and the CPU in a circular pattern (Figure 1), subject to receiving commands from all TS agents.

For the coordinated work of all agents, it is assumed that their interaction (exchange of data and commands) is synchronized via a wireless network.

4. Conclusion
1. The current situation in the distribution electric networks, associated with the intensive spread of semiconductor converter technique, requires research aimed at improving the methods for assessing the influence of the non-sinusoidal nature of electrical quantities on the loss of active power and electricity in electrical network equipment.
2. Concept is based on the principle of logical decomposition of the "digital substation - distribution network" system in order to multilevel solve the problem of synthesizing an effective trajectory of the technological process - supplying electricity to consumers, with minimizing the loss of the active component of power in power transformers of distribution networks caused by harmonic components current, using solutions based on agent-based algorithms and metaheuristics proposed.
3. The presented work is conceptual in nature and contains a description of the basic ideas for solving this problem.

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