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Improving Operating Modes of Automation Control of Technological Processes of Pump Equipment Based on Devices of Demand Side Management

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***Abstract*—The research is aimed at improving operating modes of automatic control systems of technological processes in power systems with the use of the patented devices of Demand Side Management - the normalizers of AC voltage of a new generation. As an example, a technological process on the base of pump equipment is considered, which is sensitive to the quality of electric network. The proposed approach allows to exploit executive mechanisms in partial execution modes and prolong the service life of the equipment in the conditions of the deviation from designed parameters of electric network. In this paper, under executive mechanisms the pump equipment is understood.**

Keywords—demand side management, technological innovation, the normalizer of AC voltage, resource consumption management, automation control of technological processes.

I. Introduction

Recently, the development of the economy has been associated with significant consumption of energy resources. This situation forces process designers to create high-performance Automatic Control Systems (ACS).

The existing methods of increasing the effectiveness of technological processes can be divided into two main directions: the installment of advanced executive mechanisms and the use of advanced ACS. Mainly, the advancement of ACS is connected with the introduction of additional channels of measuring the parameters of technological processes, as well as the use of more complicated regulation laws.

This work is devoted to solving the problem of increasing the efficiency and productivity growth of existing ACS of technological processes due to processing additional data of parameters in the electric network.

Processing the parameters in the electric network is carried out on the base of the devices of Demand Side Management - AC Voltage Normalization of the new generation in the Smart Grids, Smart Cities and Smart Homes systems. The novelty of the proposed approach lies in the fact that the devices of AC Voltage Normalization form additional signals, according to the characteristics of electric network, for correcting the setting parameters of ACS regulation law.

The proposed approach does not replace existing solutions to managing technological processes on the base of direct-feedback connections, with the use of regulating devices in the control loop, but expands and complements them.

As an example, the technological process of controlling pumping equipment is considered.

In the second section, existing approaches to managing technological processes on the base of the pump equipment are considered.

In the third section, the authors describe the proposed approach to improving the modes of automation management of technological processes with the use of intelligent blocks of the patented devices of demand side management - the normalizers of AC voltage. A technological process on the base of pump equipment is considered, which is sensitive to the quality of electric network.

Such an approach improves not only the modes of automation management of technological processes, but also allows to solve the problems of resource consumption management.

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In the conclusion, the main features of the proposed approach are given.

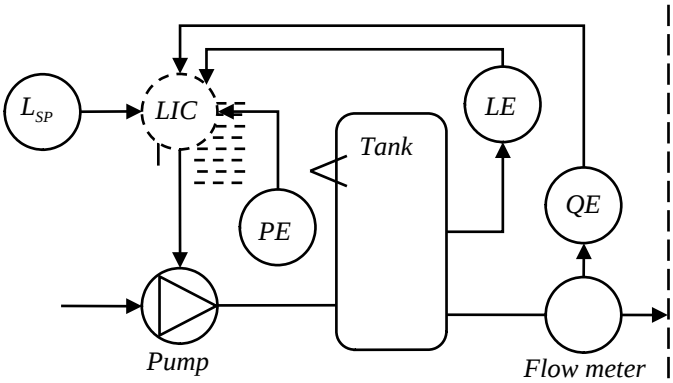
II. Existing Approaches To Managing Pumping Equipment

In technological processes, pumps are widely used for pumping or compressing various media (liquid, gas, etc.). Basically, the pump is driven by an asynchronous drive with a short-circuited rotor. The pump performance is controlled by a frequency-controlled drive (FCD). Under the pump performance, the flow or compression of different media (liquid, gas, etc.) per a time unit is understood. Management is mainly based on the classical proportional-integral law (PID-law) of regulation. To date, various studies and experiments are being conducted to replace the PID law of regulation with genetic algorithms, neural networks, and probabilistic programming methods that show better dynamics of the technological process [1]. However, industrial equipment control units are equipped with classic control methods that have been widely used in practice.

On the basis of the obtained data about a technological process, the regulation law forms control actions over executive mechanisms. The efficiency of the technological process and the quality of the target function solution depend on its implementation and settings.

Designers of automatic systems strive to improve the dynamics of technological processes by introducing additional measurement channels, integration with various information systems, etc.

Let us consider the functional scheme of process control with the use of pumping equipment as an actuator mechanism, shown in Fig 1.



Notes:
LIC – the pump efficiency control block.
L_{SP} – a set level of liquid in the tank(setpoint)
LE –device for measuring the level of liquid in the tank.
PE – device for measuring pressure in the pipeline.
QE – device for measuring the flowof liquid.

Fig.1. Functional diagram of the pump control to maintain the level in the tank.

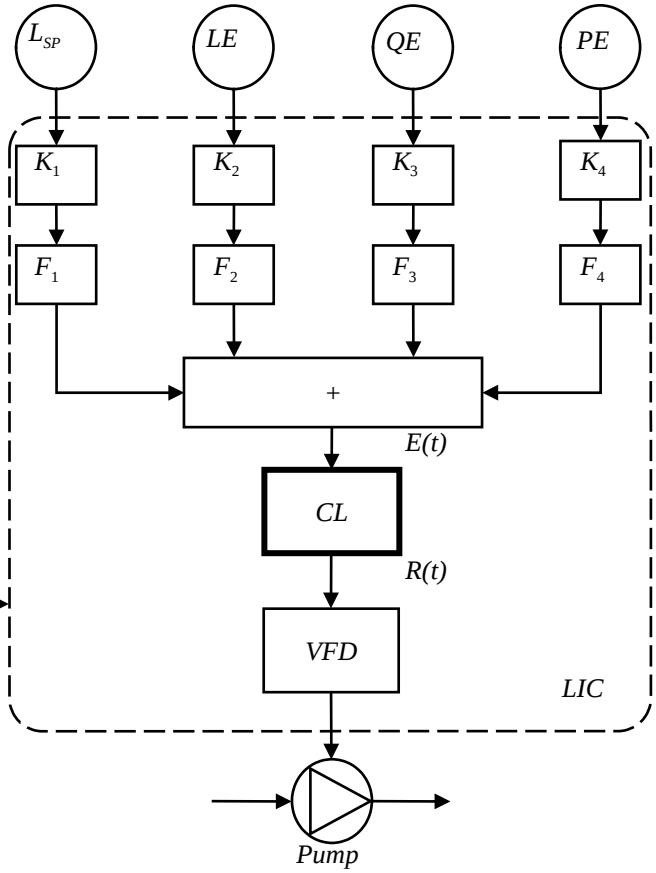
The principle underlying the technological process for managing pumping equipment is to maintain a specified level of fluid in the tank (LSP). The pump performance control unit (LIC) receives a signal from the liquid tank level (LE)and compares the received value with the set value (LSP).

To improve the dynamics of the control system, two additional signals were introduced: the pressure signal in the supply pipeline (PE) and the liquid flow signal in the outgoing pipeline from the tank (QE). The pressure signal in the pipeline is a stabilizing signal, its task is to help the regulator maintain a constant pressure in the supply pipeline. The signal for the flow of liquid in the pipeline is the leading one, its task is to form a leading signal for changing the pump operation mode. The combination of three measuring signals and one task allows to form a control action that changes the arbitrariness of the pump.

The dynamics of the pump control system operation is determined by the applicable law of regulation and its settings. It is used to calculate the control effect for the actuated equipment.

Let's consider the principle of operation of the control unit, which is used in existing schemes for automatic regulation of technological processes on the example of a pumping plant.

The structure diagram of technological process control block (LIC) is presented in Fig 2.



Notes:
K1…K4 – scaling coefficient of input parameters.
F1…F4 – high frequency filters of input parameters.
E(t) – error value depending on time.
CL – regulation law (Control Loop).
VFD – variable frequency drive.
R(t) – result and managing action depending on time.
LE – device for measuring the level of liquid in the tank.

PE – device for measuring the pressure in the pipeline.
QE – device for measuring the flow of liquid.

Fig 2. The structure diagram of technological process control LIC.

The input of the process control unit (LIC) receives three signals from measuring instruments (LE, PE, QE) and one signal that establishes the set level of the liquid tank (LSP). Each signal is scaled using the scaling coefficients of the input parameters (K1, K2, K3, K4). The high-frequency components of the signals are filtered using high-frequency filters of the input parameters (F1, F2, F3, F4) to exclude the influence of interference when calculating the control effect. All input signals are summed after scaling and filtering.

This way the error value (E(t)) of the control system is calculated. The received error is sent to the input of the control law (CL Control Loop), in our case, the PID-control law is considered. The task of the control law is to calculate the control action that will be performed by a frequency-controlled drive (VFD). The VFD, in turn, provides the required speed of the pump.

The considered control scheme does not take into account the parameters of the electrical network, which significantly affect the performance of the pump and the reliability of the entire system as a whole. The main parameters of the electrical network, that affect the mode of operation of the technological process are the network voltage and the deviation of the carrier frequency (50-60 Hz), i.e. the appearance of higher harmonics or interference. When the mains voltage is lowered, the pump efficiency decreases, and the power consumption increases due to increased current consumption. In this case, the stator winding of the pump motor may overheat and fail.

If the voltage is too high, the pump motor rotor may overheat and wear out faster.

III. The Proposed Approach to Improving the Operating Mode of the Pump Equipment Based on Using of Patented Devices of Demand Side Management the Normalizers of AC Voltage

For solving problems with deviation of power grid parameters, voltage stabilizers that operate independently of the process equipment control system are usually used.

Papers [2, 15] present in detail the results of scientific research and long-term practical experience in the use of patented devices of Demand Side Management AC voltage normalizers NORMEL™®© in electrical networks with a voltage level of 0.4 kV [16, 22].

Table 1 shows the comparison of characteristics of normalizers of AC voltage NORMEL™®© and standard stabilizers with the capacity 55 kVA.

AC Voltage Normalization devices are a high-tech, low - cost, fast payback and the solution unique in the world to ensure guaranteed stable power supply and reliable protection of electrical equipment.

The main effects of using AC Voltage Normalization devices:

1) significant savings in electricity consumption (from 7% to 24%) and compensation for the shortage of generated capacity in the power supply of localities, enterprises, institutions, equipment (from one unit of electrical equipment to a complex of buildings);

2) elimination of failures of any equipment and production defects associated with voltage surges in the electrical network;

3) increase in the service life of any electrical equipment (up to 6 times).

Papers [23, 24] present solutions to a new class of tasks related to improving the efficiency of technological processes and the ability to manage resource consumption in Smart Grid, Smart Cities and Smart Homes systems based on the use of AC Voltage Normalization devices equipped with smart blocks and new functions.

TABLE I. Comparison of Characteristics of Normalizers NORMEL™®© and Standard Stabilizers with the Capacity 55 kVA

Characteristic	Standard Stabilizers	Normalizers
Capacity	55 kVA	55 kVA
Reduction of expenses on electrical energy	do not reduce expenses, as they themselves are users of electrical energy	up to 25 %
Joint economic effect	---	up to 60 %
The quality of the received energy	something they are sources of higher harmonics	according to interstate standards EN 50160:2010 "Removal of higher harmonics"
Efficiency coefficient	95.0 %	99.7 %
Dimensions	---	3-6 times less than standard stabilizers
Weight	250 kg	70 kg
Service	monthly examination and tuning of the equipment	only one prophylactic examination per year
Increase of service life of attached equipment	1.5 times more.	2 – 6 times more
The time of payback	is not paid back, as they themselves are users of electrical energy	6 -24 months due to energy saving

A distinctive feature of AC Voltage Normalization devices of the new generation is the ability to collect data from primary metering devices of technological processes of electricity consumers (current, voltage, temperature, resource consumption, etc.) and the transfer of the collected data via digital communication channels to the Data Processing Center (DPC) based on enterprise computing resources or cloud technologies.

A significant difference of AC voltage normalization devices of the Second generation is a fundamentally different circuitry [25]. The previous generation of AC Voltage Normalization devices had a non-commutation circuit solution for controlling the device's operating modes only on the high-voltage winding, while the low-voltage regulating winding performed its regulating functions by direct switching, that is, short-term breaks in the circuits of actuators. This led to significant

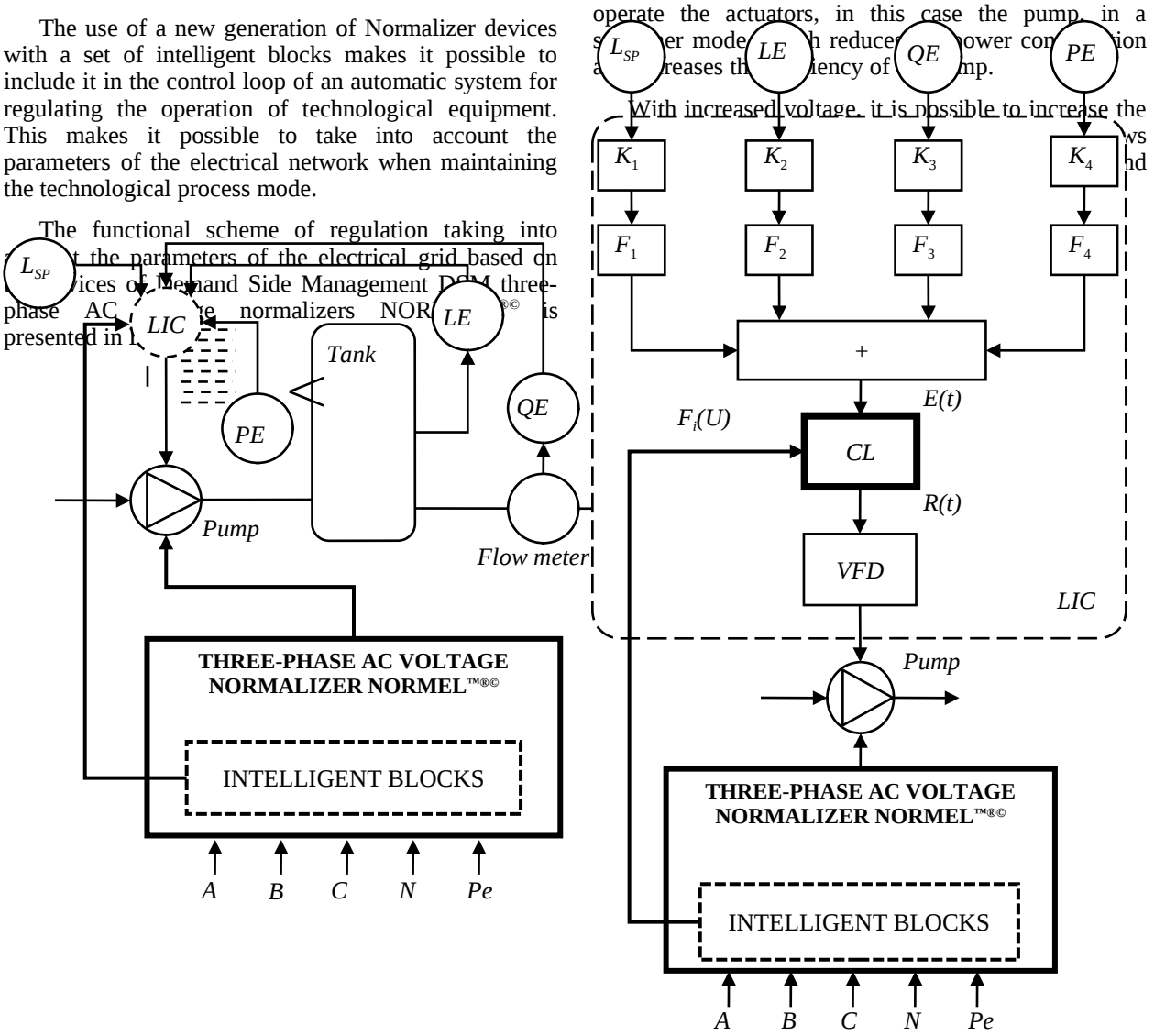
current surges caused by transients in the electrical circuits of the Normalizer.

This problem was solved in a new generation of devices by introducing (realizing) a circuit for continuous regulation of the low-voltage winding. This solved the problem of transients in the device as a whole. As a result of this evolution, the following positive effects were obtained:

- reducing the number of components in the electrical circuit of the Normalizer, which led to an increase in its reliability characteristics;
- increasing the working life of the actuators that are part of the device and the Normalizer as a whole, by eliminating current and voltage surges in the circuit elements associated with transients.

The use of a new generation of Normalizer devices with a set of intelligent blocks makes it possible to include it in the control loop of an automatic system for regulating the operation of technological equipment. This makes it possible to take into account the parameters of the electrical network when maintaining the technological process mode.

The functional scheme of regulation taking into account the parameters of the electrical grid based on devices of Demand Side Management DSM three-phase AC voltage normalizers NORMEL™®© is presented in Fig. 3.



Notes:
A, B, C – phases.
N – neutral, working zero.
Pe – zero protective conductor, protective ground.

Fig. 3. Functional scheme of regulation taking into account the parameters of the electric network based on devices of Demand Side Management.

In existing technological process control schemes, it is possible to adjust the settings of the control law [26]. You can set the dependence of the adjustment coefficients of the regulator settings (Fig. 2) on the network voltage and carrier frequency deviation. In the simplest version, the following approach is implemented: when the voltage in the network decreases, the dynamics of the control system should slow down, and when the network voltage increases, the dynamics of the control system should increase.

The presented approach is shown in Fig. 4.

The approach is implemented by adjusting the appropriate settings of the regulator using functional dependencies on the network voltage (Fi (U)).

This approach allows you to maintain the process mode at low network voltage, reacting to external disturbances with a slowdown. This allows you to operate the actuators, in this case the pump, in a smoother mode, which reduces power consumption and increases the efficiency of the pump.

With increased voltage, it is possible to increase the

Notes:

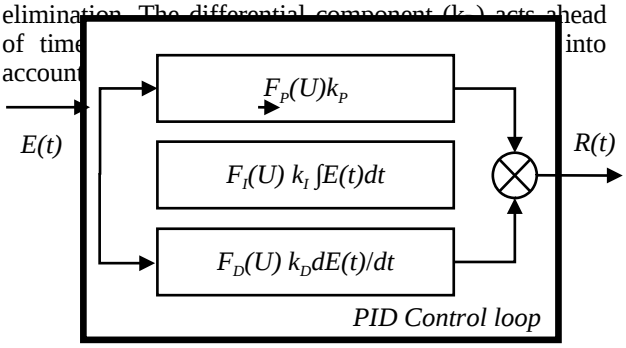
Fi (U) – dependence of the correction factor of the regulator setting on the voltage.

Fig. 4. Adjusting the controller settings based on devices of Demand Side Management.

In this way, the operating time of the pump in transient modes is reduced, which extends its service life and reduces the operating time of the pump not in optimal mode.

A variant of the proposed approach based on the PID law of regulation is presented in Fig. 5.

The proportional component (k_P) changes the error proportionally. The integral component (k_I) accumulates the existing error at a certain rate for subsequent elimination. The differential component (k_D) acts ahead of time [illegible] into account



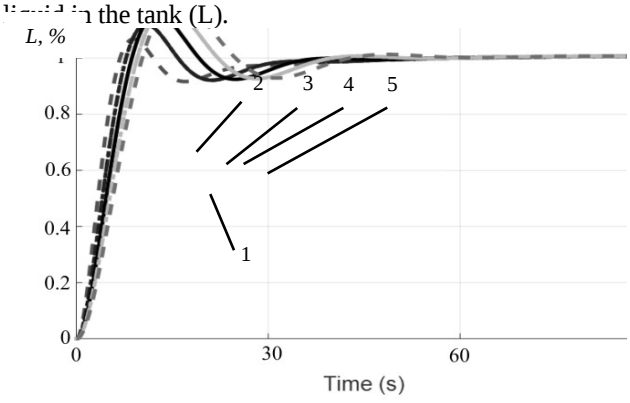
Notes:

$F_P(U)$, $F_I(U)$, $F_D(U)$ – the dependence of the correction factor on the regulator setting on the voltage.
k_P, k_I, k_D – proportionality coefficient, integrating coefficient and differentiation coefficient.

Fig. 5. Adjusting the settings of the PID law of regulation.

To reduce the dynamics of the system of regulation, if the voltage drops, corresponding coefficients should be reduced, and when the voltage increases, the coefficients of the control law must be adjusted towards a higher value [27].

Let's consider variants of correcting setting parameters of ACP law regulation with the help of intelligent blocks of AC voltage normalizer. Fig. 6 presents the result of modeling changes in the level of liquid in the tank (L).



Time, seconds

Fig.6. The transient process of the change in the level of liquid in the tank (L) with the change of the task in the regulation system by 1% in reference to the set level of liquid in the tank.

In fig.6 line 3 characterizes a transient process of the change of the level of liquid in the tank with the initial setting parameters of the regulation system. With the help of correction coefficients, which are calculated on the intelligent blocks of AC Voltage Normalizer, it is possible to change dynamic characteristics of the transient process [28]. For example, Lines 1 and 2 demonstrate an accelerated transient process of the change of the level of liquid in the tank by 15% in reference to Line 3. The change of the dynamics of the transient process is in direct proportion to the parameters of the regulator setting. The right calculation of correction coefficients (F_i), taking into account the change of electric network characteristics, provides the stability of the technological process [29].

IV. Conclusion

The paper considers an approach to improving the mode of operation of the automatic control system of the technological process for Smart Grids systems depending on the parameters of the electrical network. The correction of the operating mode is carried out by adjusting the coefficients of the control law depending on the voltage level in the network of the carrier frequency deviation.

In contrast to the existing systems of automatic regulation by technological processes, which form control actions only on the basis of measured parameters of the technological process, the proposed approach takes into account the parameters of the electric network.

In the frame of this research, the authors plan to make a number of experiments on a real technological process on the base of pump equipment with the set capacity 54 kWt.

The implementation of this approach is possible on the basis of the device of Demand Side Management - three-phase AC voltage normalizers of a new generation with a set of smart blocks. This allows you to operate the actuators in more gentle modes and extend the service life of the equipment in conditions of deviation from the calculated parameters of the electrical network.

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