Multi-Pump Control Applications for ABB ACQ 810 Industrial Drive
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Abstract—This paper describes new pump control applications developed for an ABB ACQ 810 industrial drive. The software developed includes algorithms and program modules for clear and wastewater processing. It implements monitoring, supervising and protecting of the pumping process and equipment. The applications provide the balanced control of a group of pumps for optimal energy consumption and decrease the maintenance costs caused by pumps wear. The designed architecture and functionalities are explained. Their benefits are shown based on a pilot commissioning at a working pumping stations operating in real conditions.

I. INTRODUCTION

Pumping systems cover a significant part of industry, commercial and residential applications. These systems are used worldwide for fluid transportation. About 22% of the energy supplied to electric motors is consumed by the pumping systems [1]. In many areas, from 20 to 60% of the total electrical energy is directed to the clear and wastewater processing. The growing water market, increasing energy costs and competition require new solutions in the pumping technology.

Variable speed drives (VSDs) play an extremely important role in modern pumping systems, providing a wide range of functionalities, like speed control, power quality improvement, as well as technology control and data processing [2]. The possibility of the programmable logic integration into the VSD results in a wide variety of approaches for the process and equipment adjustment. These approaches can be effectively implemented through the development of program applications focused on pumping – Pump Control Applications (PCAs).

The novel ABB ACQ 810 family covers the VSDs of the power capacity from 1.1 to 440 kW. This release ensures the presence of ABB on the market of industrial technologies and provides the supremacy of ABB over the competitors in the field of VSD. The aim of the described PCA software is to make the ACS 810 friendlier for application by designing ready for use instruments suitable for monitoring, protection and process control. PCAs should provide the following functionalities:

- running equipment ranging from 1 to 8 pumps
- process control upon the PID and manual referencing
- processing the actual data and setpoints
- monitoring the flow, pressure and power
- MODBUS communication between the system VSDs

Control of multi-pump systems is one of the most challenging tasks pump users face. Unfortunately many operators choose to run all of their pumps all the time rather than use the potential of missing process demands. As a result, many multi-pump systems have pumps that run outside their recommended minimum or maximum flows, ultimately leading to reduced pump reliability.

The objective of this paper is to develop an optimal control system of multi-pump applications.

The paper is organized as follows. First, current popular solutions for the pumping industry are analyzed. Next, principles of multi-pump systems and their benefits are described. Finally, the two cases of multi-pump utilities and a test stand for emulating the pumping processes are presented.

II. REVIEW OF EXISTING SOLUTIONS

ACQ 810 was designed as a new generation of ABB frequency inverters to implement novel motor control features and industrial communication options. One of the missions of the PCA development is to combine the advantages of existing solutions with innovative ideas of ABB.

Three types of pumping systems were compared from the point of view of multi-pump operation:
- VLT Aqua of Danfoss
- PS 200 of ITT
- ACS 800 of ABB

The first solution, VLT Aqua, is used at water treatment plants, desalination plants with ground water pumps, and wastewater pumps. It includes VSDs, extension modules, and built-in pump control software. The maximum VSD power reaches 1100 kW. Extension modules provide additional analogue and digital inputs/outputs, relay outputs, and fieldbus connections. The key features are as follows:

- integrated PID control
- pump cascade control (up to 8 pumps)
- pumps alternation
- dry run protection
- advanced pressure control
- flow calculation on the basis of actual motor power
- valve protection
- two-step acceleration and deceleration ramps
- pipe fill mode

The key features of PS 200 are as follows:

- integrated PID control
- PID multidrive pressure control
- advanced pressure control
- accident protection
- flow calculation based on the speed, torque and power data
- cavitations protection
- pump cleaning as the motor torque exceeds the specific limit value or automatically, when the specific time period elapses
ACS 800 VSD for pump control ranges from 1.1 to 440 kW VSDs. This solution is used in various clean and wastewater applications and involves the following functions:

- integrated PID control
- PID multistage pressure control
- protection functionalities: (a) inlet pressure protection against the low inlet pressure, (b) outlet pressure protection against the high outlet pressure, and (c) PI protection against too high error deviation
- flow calculation on the basis of shaft power or using Bernoulli low (difference of pressures at inlet and outlet of the pump)
- pump cleaning as a series of forward/reverse rotations to remove clogging substances from the pump impeller
- pump cascade control
- pumps alternation
- level control that provides fully automated filling or emptying of the tank based on multi-drive architecture

III. APPROACHES IN ARCHITECTURE OF AUTOMATION SYSTEMS FOR THE PUMPING PROCESS CONTROL

Most of the solutions in the pumping industry implement the following main approaches:

- drive adjustment based on the programmable logic controllers (PLCs)
- specialized VSD armed with pump control software

The first type of solutions is popular in the comprehensive projects enveloping complex processes, much circuitry and equipment, SCADA, and various networking and communication technologies [3]. Automation systems of sewage disposal plants are a typical example of such approach. Since many system integrators have much practice in this type of applications, they also apply similar methods in small tasks, like automation of rural pumping stations. PLCs here perform the following functions:

- collecting information from sensors, control panels, switches and potentiometers
- data transmission to/from SCADA and databases
- data transmission to/from VSDs and soft starters
- enforcing the relays, gate valves, and other mechanical equipment
- running the control logic to start/stop auxiliary pumps, open/close valves, prevent danger, activate/deactivate filters, etc.

Here, PLCs play a key role in data communication, processing the input and output signals, and running the control logic. From the viewpoint of pumping, the main disadvantage of this approach is in the fact that the PLC control logic must be recreated for each new project.

The main benefit of the VSD approach is that PCAs contain utilities for the control of the pumping process built in the VSD software [2]. Therefore, it is not required to develop typical algorithms, like conditioning the PID inputs, protection, and auxiliary pumps start/stop resulting in significant reduction of the design time and cost.

This approach is convenient in applications that do not require complex program logic and much interface circuitry (sensors and switches). The control logic runs inside the VSD. Typical control programs provide the following features [4], [5]:

- PID control
- conditioning of the PID inputs (setpoint and feedback)
- protection (providing monitoring of the input signals and reactions on extreme currents)
- speed ramping
- start/stop of the auxiliary pumps in the single-drive applications
- start/stop of the additional pumps in multistage applications
- calculation of relative values, like flow, runtime, energy consumption, etc.
- ability to create specific functions (or algorithms) using built-in editors on the basis of the structured text, programming language or blocks programming

Based on this analysis, all the software features of ACS 800 were decided to be implemented in ACQ 810. To enhance flexibility, some features from the competitors’ solutions including the pipe filling were added to meet the customer’s desires.

IV. USING THE VSD IN MULTI-PUMP APPLICATIONS

A variable-speed-driven pump typically refers to a centrifugal pump that is driven by an electric motor and a frequency converter. This kind of a system enables the speed adjustment of the pump-motor combination [2]. A typical structure of a pumping system is illustrated in Fig. 1. Here the centrifugal pump is located in a process system consisting of pipes, tanks and other piping circuitry. An electric motor is directly connected to the pump with a shaft coupling. A frequency converter is typically located in a separate facility. The pumping system is also equipped with measurement sensors that provide feedback for control and monitoring purposes.

![Fig. 1. Simple pumping system consisting of one pump](Image)

In a centrifugal pump, the energy of the fluid is raised by increasing the flow velocity with a rotating impeller, which generates the fluid flow. The impeller is located inside the pump casing. The most common pump type is a single-volute end-suction radial flow pump. It is often simply referred to as a radial flow centrifugal pump. In that kind of pumps, the impeller has radial vanes, which lead the incoming flow from the pump suction into the outer edge of the impeller and further into the volute casing. The impeller is connected to the pump shaft. The shaft has a sealing system around it, which prevents leakage of the pumped fluid outside the pump. This pump type is commonly used in the process industry as well as in clean and wastewater applications.

The most common electric motor type applied to a centrifugal pump is an induction motor [2]. The reason is in its simple construction, high reliability, and good efficiency. The rotational speed of an induction motor can be controlled in an accurate manner using a frequency converter.
Typically, an induction motor is considered to be operating at the maximum efficiency, when the load torque is approximately 75 percent of the nominal motor value. The efficiency of the motor will decrease when it is driven at a low rotational speed because of the higher values of constant-valued losses. The pump load torque curve has a squared relationship with the rotational speed. Thus, the resulting motor efficiency may be significantly decreased when a centrifugal pump is driven at a low speed.

An example of measurement results for a 2.2 kW, 14 Nm induction machine is shown in Fig 2 where the motor is driven with a frequency converter [6].

![Motor efficiency vs. load torque](image1)

As in the case of induction motors, the efficiency of a VSD is affected by the converter size as well as by the amount of the speed and torque required.

The maximum efficiency of a frequency converter in such kind of applications depends on the converter size. Typically it is 92–98 %, for 1–400 kW VSDs.

If the motor is driven at a low rotational speed, it has a decreasing effect on the efficiency of a frequency converter [6]. An example is shown in Fig 3.

Operation characteristics of a centrifugal pump are described by the following parameters:

- produced head vs. produced flow
- efficiency η
- shaft power consumption vs. produced flow

The location of the operational point of the pump is obtained by the readings of the actual head and the actual flow. The operational point at which the efficiency of the pump reaches its maximum is called the best efficiency point (BEP) [2]. The maximum practically reachable BEP of a centrifugal pump is 77 to 88 %, depending on the pump size and design [4].

It is reasonable that the best way to operate the centrifugal pump is to drive it at its BEP in order to optimize the energy consumption which is based on efficiency. In addition, the reliability of the pump is maximized when operating near the BEP since the risk of cavitation and the magnitudes of hydraulic excitation forces on the impeller are minimized. If the pump is working outside the preferred operating region, its efficiency decreases and the rate of mechanical wear increases [2]. The dependence of the service life of a centrifugal pump on its operation area is shown in Fig. 4. As can be seen, operation at 70 or 115% of the BEP decreases the characteristic life of the pump to tenth of its ideal value.
n a general case, the graph is relevant for a centrifugal pump built for chemical and process applications.

It is almost improbable that the pump operation in actual service would be at the BEP. But operation in the region which is close to the BEP can be provided by a system which has variable productivity (provided by alternating the number of working pumps) and consists of variable speed pumps [7]. By arranging different combinations of pumps running together, a larger number of different flow rates can be provided to the system.

V. MULTIDRIVE MULTI-PUMP SYSTEMS

Multidrive multi-pump topology is a relatively cheap solution to implement the PCA that provides the pressure holding on a desired level [7]. The solution consists of up to 8 pumps. Each pump is driven by a VSD (Fig. 5).

The system of pumps tends to hold the pressure on a desired level. The speed of pumps is changing according to the Actual value – Setpoint relation to provide the desired pressure. Productivity of the system can be changed by regulating the number of working pumps which should be increased to raise the productivity. Unnecessary pumps can be stopped if the actual productivity is higher than required.

Generation of the speed reference and regulation of the amount of working pumps is conducted by one of the VSDs called a master of the network. This kind of a solution provides several benefits [7]:

- Up to 8 small pumps can be used instead of one (or several) large pumps. It provides redundancy for the system because the system will continue functioning if one (or several) pump(s) fail.
- Flexible regulation of the productivity of the system can be applied. In the periods of low consumption, productivity of the system can be decreased by reducing the amount of working pumps (which will rotate at the speed close to the rated speed). It is more efficient than lowering the speed of one or several large pumps (which leads to greater mechanical and electrical losses).
- Large and small pumps can be combined to provide flexible productivity.
- Maintenance or replacement of small pumps is cheaper.
- Runtime of pumps can be equalized by enhanced algorithms of alternating the working/resting pumps.

To implement the system, 1 to 8 pumps may be used. Each pump is driven by a separate VSD. All VSDs in the system are connected into the network. One of the VSDs is a master of the network. The MODBUS communication technology is used for connections in the network. Each drive in the network can be a master.

The pressure sensor located at the outlet of the pump is the only feedback provider in that system. The sensor is connected to the analogue inputs of the VSD logic units. The pumps are connected in parallel to provide the common output to the system.

All pumps can follow the master speed. The master pump has the following objectives:

- to generate the speed reference according to the Actual value – Setpoint relation (using the software of the PID controller) for providing the pressure on a desired level
- to generate the start and stop commands for followers for regulation of the system productivity
- to send the speed reference to the followers for providing the equal speed of all pumps
- to provide autorotation of the starting order of all the followers to equalize the runtime of all the pumps
- to select the next follower to start or stop (to equalize the runtime of all pumps)
- to send the master status to other appropriate VSD in the case of breakdown
- to receive and process the commands from the user (operator, HMI or fieldbus)

Only one VSD at a time can be a master. Other VSDs are the followers the tasks of which are as follows:

- to follow the start/stop commands of the master
- to follow the speed reference of the master
- to provide the information about their state (enabled/disabled/faulted/runtime) to the master
- to become the new master when the old master cannot continue its operation

The system operates in the following order. The master drive is constantly working. Its speed is generated by the software of the PID controller which is integrated into the functionalities of the pump control application. The PID inputs are the Setpoint and Actual value (pressure).

The master’s productivity is limited by its maximum speed. When the productivity of the master is not sufficient for providing the pressure at the desired setpoint, the follower pumps are being started one by one [8].

The followers start in the following order. Insufficient productivity is accompanied by an increase of the pump speed. The PID tends to compensate the difference between the setpoint and the actual values by increasing the speed reference. When the speed exceeds the specific limit, it is a sign that the productivity is approaching its highest value. Productivity can be increased by raising the number of working pumps. Thus, one of the follower pumps is started by the master, which starts the next follower when its speed exceeds the specific limit defined by a user via the interface of a PCA. It is a “Start speed” in Fig 6.

Fig. 5. Block diagram of a multidrive multi-pump system
When the follower is rotating, the speed of both pumps can become lower but the productivity of the whole system increases. In such a manner, each of the seven followers can be started when the productivity of the working pumps becomes insufficient.

The procedure of the next follower starting consists of the following steps:

1. Detecting the exceeding of the Start speed.
2. Start delay. The delay time is defined by the Start delay parameter. If, during the Start delay, the speed of the master pump falls below the corresponding Start speed, the procedure is interrupted.
3. When the Start delay elapses successfully (the speed did not fall below the Start speed), the Start command for the next follower pump is generated.

Fig. 6. Starting the follower pumps (S1 – Start speed 1, S2 – Start speed 2, S3 – Start speed 3)

To stop the follower pumps, an inverse principle is implemented. As far as the demand of water decreases and the pressure falls, the productivity of the system should be decreased by stopping of one (or more) followers. Like in the increase case, to detect the need in the next follower stopping the monitoring of the master pump is executed. When the master speed falls below the specific limit (Stop speeds in Fig. 7), the Stop command is generated.

The procedure of the next follower stopping consists of the following steps:

1. Detecting drop in the speed below the Stop speed.
2. Stop delay. The delay time is defined by the user via the Stop delay parameter. If, during the Stop delay, the speed of the master pump exceeds the corresponding Stop speed, the procedure is interrupted.
3. When the Stop delay elapses successfully (the speed did not exceed the Stop speed during the delay), the stop command for the next follower pump is generated.

Here the fluctuations of speed (increase and decrease) are imposed by the PID controller which compensates the difference between the actual pressure and the setpoint (Fig. 8). Fluctuations of pressure are caused by the changing demand, income of water into the system, state of the pumping system, or piping circuitry [9].

To control the speed of the master pump, the PID controller has the following inputs:

- **Gain** - the gain for the process PID controller.
- **Integration time** – the integration time of the process PID controller.
- **Derivation time** – the derivation time of the process PID controller.
- **Setpoint** – the reference value that defines the desired pressure which must be provided by the system. Typically, this parameter is set manually via the user interface but it can also be obtained through the analogue inputs of the drive or via the fieldbus.
- **Actual value** – the feedback from the pressure sensor at the outlet of the pump system. It can also be obtained via the fieldbus.
- **Balancing value** – the PID balancing reference. The PID controller output is set to this value when the balancing mode is activated through the user interface.
- **PID ref freeze** – freezes the setpoint (reference) input of the process PID controller. This feature is useful when the reference is based on a process feedback connected to an analog input, and the sensor must be serviced without the process stopping.
- **PID out freeze** – freezes the output of the process PID controller. This feature can be used when, for example, a sensor providing the process feedback must be serviced without stopping the process.

Fig. 7 Stopping the follower pumps (S1 – Stop speed 1, S2 – Stop speed 2, S3 – Stop speed 3)

![Fig. 8. Pressure control](image)

![Fig. 8. Pressure control](image)
The follower pumps have the following three options to generate the speed reference.

- **Master speed** – copying of the master pump speed. The master’s VSD sends the speed reference to all the followers via the network. The followers receive the reference and scale it. The scaled speed reference is then used in the generation of the speed reference in the speed control unit. In this mode, the follower copies all fluctuations of the master speed. This mode provides the most flexible operation.

- **Constant speed** – in this mode the speed of the follower can be set to a constant value via the user interface and stays constant during the whole operation.

- **Copy of master** – the follower copies the master behaviour. It starts along with the master start and stops when the master stops. The speed of the follower is the same as the speed of the master in this mode. Since the followers start simultaneously with the master, this mode is considered as the most rapid solution for the pressure boosting.

The followers never utilize their own PID since they are not allowed to generate the speed reference independently of the master. Each follower’s VSD can be set to its own speed mode independently of the settings at other VSDs.

VI. SINGLE DRIVE MULTI-PUMP SYSTEM

The single drive multi-pump is a cheap solution for applications that must provide the pressure to be held on a desired level. The architecture of the solution is shown in Fig. 9. The system consists of up to 8 pumps. One pump is running by the VSD (main pump) and the others are auxiliary pumps connected directly to the power supply line [8].

The whole application is operated by the control unit of the VSD that runs the main pump. The system of pumps holds the pressure on a desired level.

The speed of the main pump is changing according to the *Actual value – Setpoint* to provide the desired pressure. The productivity of the system can be changed by regulating the number of working pumps, which is increased if a higher productivity is required. Unnecessary pumps can be stopped if the actual productivity is higher than required.

Only the master pump can adjust its speed according to the PID controller output. The principle of starting of the next pumps is the same as in the multidrive multi-pump application.

VII. EQUALIZING THE RUNTIME OF SEVERAL PUMPS

In the group of pumps, every pump is a node (unique node address is defined in each control unit). In the simplest case, the starting of the nodes is implemented in the following starting order:

- **Node 1** (or master) is started by an external signal (from the *Digital Input*)
- **Node 2** is started by the master’s command if higher productivity is required
- **Node 3** is started by the master’s command when additional productivity is required

Up to 7 followers can be started in such a manner. The stopping is implemented in the opposite order in the same sequence.

In the simplest case all pumps start and stop in the same order. It means that pumps which are located at the beginning of the starting order will have greater runtime than the ones that are at the end of the order. It leads to faster wear of the pumps which have smaller node addresses.

Sharing the runtime between all the system pumps helps to equalize and to bring down the wear of certain pumps [11]. This operation can be implemented by the autochange functionality which periodically reorganizes the starting order. In this way, the pumps which have high runtime are passed to the end of the starting order whereas the pumps of low runtime are passed to the beginning of the starting order to start sooner.

The starting order is generated in the master node which collects the information concerning the runtime and the actual state of all members of the network.

Three methods can be proposed to rotate the starting order [8]. The required method is selected by the user via the interface of the master node.

In the **Fixed method**, the starting order is left-shifted cyclically as the defined time elapses (Fig. 10).

![Fig. 9. Block diagram of the single drive multi-pump system](image)

![Fig. 10. Fixed mode](image)
In the new starting order, pump 8 is the first to start (instead of pump 1), therefore pump 1 will wait until the need for its starting (7 pumps are ahead of it in the starting line).

In the All stop method the starting order is changed when all VSDs stop and the external start command is removed from all pumps (Fig. 11).

![Diagram](attachment:image.png)

**Starting order: 1, 2, 3, 4, 5, 6, 7, 8**

- All pumps stop

**Starting order: 8, 1, 2, 3, 4, 5, 6, 7**

Fig. 11. All stop mode

In the Hourcount method, the nodes are sorted to start in an ascending order (regarding to the runtime of each node). The re-sorting (autochange) of the starting order occurs when the difference between the runtimes of any two nodes exceeds the critical value defined by the user of the master node.

Special functionality is implemented for limiting the autorotation. It helps to hold the specific pumps at the beginning of the starting order if there are several types of pump frames in the system and large pumps are preferable to start at the beginning of pumping. For that purpose, the nodes are divided into classes. The number of the class the node belongs to is defined in each node parameters. Autorotation can be held between the nodes which belong to the same class only. Rotation of the starting order occurs in each class separately (Fig. 12).

![Table](attachment:table.png)

<table>
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<th>node</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
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</table>

Fig. 12. Principle of classes in autorotation

VIII. PCA ARCHITECTURE

Typically the VSD is used as a processing unit in a PCA [10]. The VSD is responsible for processing the application data (readings of speed, analogue sensors and digital inputs). A PCA for ACQ 810 is ready to use software utility which is integrated into the VSD firmware. In the same way, the PCAs of other manufacturers are implemented. Also, there exist the OEM companies which produce their own software using the hardware of other companies. In this way, ITT applies the ABB 800 VSDs for its PS 200 PCA.

In the case of ACQ 810, the PCA contains the ready to use utilities to control the pumping process. The collection of utilities enables to build the following solutions:

- single pump boosting pumping system
- multidrive multi-pump boosting pumping system
- single drive multi-pump boosting pumping system
- multidrive multi-pump level control pumping system

There exist also software modules which provide the following useful functionalities for pumping applications:

- autochange of the pump starting order
- pressure and flow protection
- flow calculation
- pump cleaning
- pump sleep mode
- energy monitoring
- soft pipe filling

- The PCA runs in the control unit of the VSD utilizing its user interface and input/output circuitry. The typical architecture of the VSD integrated PCAs is shown in Fig. 13. It includes the following modules:

![Diagram](attachment:image.png)

**Communication**

**Technology libraries**

**Runtime**

**Pump control**

**Main utilities**

**Motor control**

- **Pump Control** is a collection of utilities which enable one to build various PCA solutions on the basis of the VSD.
- **Main utilities** and **Motor control** provide the power unit control.
- **Runtime** is the library that provides the software operation including data acquisition and output as well as the memory management. The runtime functionality is inaccessible for the user who cannot monitor the runtime processes.
- **Communication** module provides the software platform for various fieldbus means to be used to communicate with other members of the control system.
- **Technology library** is a collection of functions for logic development using the block programming methods. The library contains the blocks which are useful in control logic (counters, math functions, switches etc.). This functionality enables one to build the additional control logic which can run in parallel with the main PCA. The additional logic can provide more flexible control methods which suit the specific applications or sites. The block programming enables one to build the functionalities which can be used in laboratory experiments.
IX. THE TEST STAND

The test stand which enables testing the ACQ 810 applications is located in the Electrical Drives Laboratory of Tallinn University of Technology (Fig. 14).

The stand consists of:

- 5 pumps EBARA 120
- 6 frequency converters ABB ACQ 810, 1.1 kW
- valves for the pressure change emulation
- the pressure sensor and the manometer
- digital switches for tested application needs
- potentiometers for tested application needs
- relay circuitry for single drive multi-pump applications
- wiring (i.e. data cables for RS485 connection for multi-pump multidrive applications)

Technical data of the pumps:

- nominal power 0.9 kW
- nominal current 3 A
- nominal voltage 400 V
- nominal speed 2760 rpm

The purpose of the test stand is to test the ACQ 810 in the conditions close to the real operation. The stand enables one to simulate processes that are likely to occur during the pumping process:

- fluctuations of the demand
- breakdown of pumps (for testing the system redundancy)
- extreme values of pressure and flow

The switches and potentiometers implement the flexible control of the application. Also, they enable one to simulate the signals which provide the feedback from the process to the control unit.

Fig. 14. Test stand

CONCLUSIONS

Following the review of existing PCAs, the multidrive and the single drive multi-pump systems were described.

The ACQ 810 is an effective solution for running the multi-pump water and wastewater applications. It provides considerable advantages in the operation and maintenance of the pumping system. Since the solution includes the algorithms for pumping processes, engineering costs can be lowered on the designing stage.

The solution includes functionalities and features that provide redundancy for the pumping system making the process smooth and steady.

The developed functionalities for the multi-pump systems equalize the runtime of all pumps in the network which saves the maintenance costs and prolongs the equipment service life. The multi-pump system prevents the pumps from working in the regions that are far from the best efficiency point by changing the number of working pumps.

The methods proposed in the paper were tested using the pilot commissioning at the working pumping station operating in real conditions. The tests show that the ACQ 810 can be a platform for further development since it provides the onboard instruments for monitoring the operation of centrifugal pumps. Also, the developed methods for detecting the need for changes in the system’s productivity have a potential in further studies. The methods of running the follower speed depending on the motor state and rated properties also seem prospective for further investigation.

REFERENCES