White Paper

Comparative evaluation of automation concepts for water industry systems

Tools for optimising life cycle costs

Contents

1. Introduction

Energy efficiency and the optimisation of specific production costs are important commercial and business challenges which we must face for a variety of reasons. Energy-efficient technologies are often more expensive than traditional technologies in the investment phase. However, measures to increase efficiency and reduce life cycle costs (LCC) throughout the entire life cycle of a production plant usually pay off.

The expected total costs of production plants over their life cycle, which can be up to 25 years (Figure 1) for municipal water and wastewater treatment plant and process plants, can vary significantly based on the design of the plants and the automation components and systems used. The system or automation variant with the lowest investment costs is not always the best commercial solution over the entire life cycle of the system when considering the total life cycle costs.

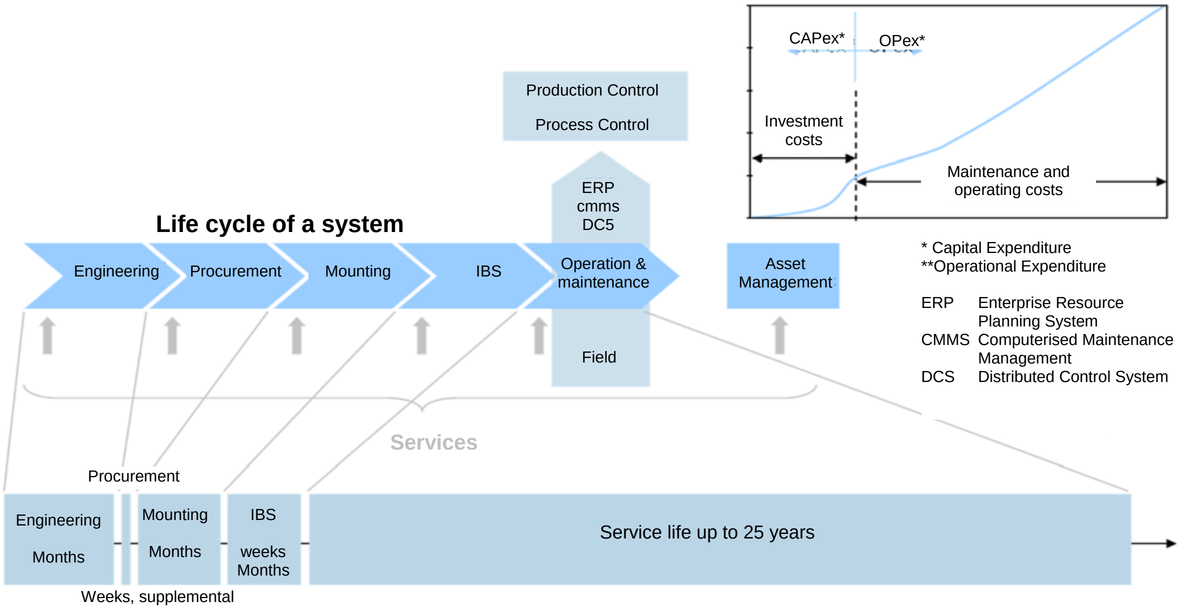
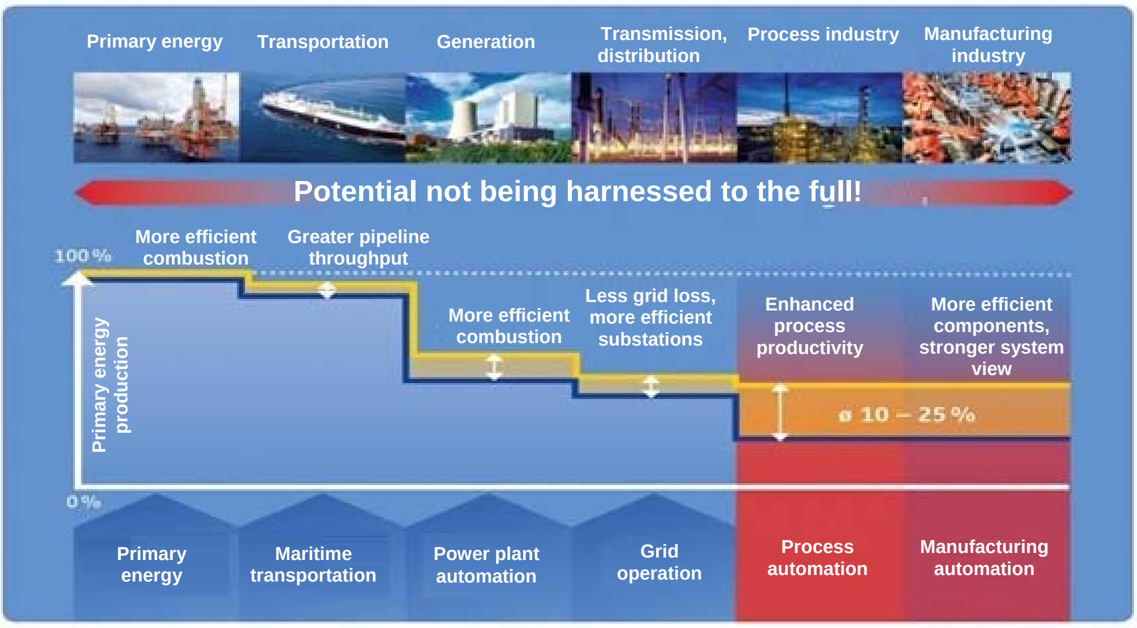


Figure 1: Schematic diagram of the life cycle costs of production plants.

It is therefore not enough only to consider the investment costs when evaluating alternative technologies, as this can lead to the wrong conclusions when trying to reduce LCC. Nowadays, investment decisions are frequently made solely based on the investment costs, even though public sector procurement regulations require that the LCC and energy efficiency are also considered when evaluating alternative technologies. In practice, however, this is not always the case.

2. Potential for optimising electrical energy efficiency in wastewater treatment plants

Losses occur in the various sections of the energy flow chain, from primary energy generation to conversion of electrical energy into thermal, kinetic, potential energy etc. For example, when transporting energy through pipelines or when primary energy is converted to electrical energy in power plants. The greatest potential for increasing energy efficiency is in the actual process engineering and production processes [1].



Potential efficiency gains in industrial processes are especially high

Output without measures

Output with measures

Source: ABB Group, ZVEI.

Figure 2: Potential for energy efficiency increases [1].

The potential can be exploited with a variety of measures, such as

- Using energy-efficient individual components (e.g. energy-efficient motors)
- Automation systems that enable plants to be operated in line with the respective requirements (e.g. oxygen infeed to wastewater treatment plants subject to the actual pollution load)
- Modified technical system designs (see also subsequent examples)

Other characteristic values from a 2006 study by the Federal Department of the Environment show the enormous potential for opportunities to increase efficiency based on the example of municipal wastewater plants [2]. On average, municipal wastewater treatment plants consume 4,400 GWh, which corresponds to

- 0.7% of the national consumption of electricity,
- 20% of the consumption of electricity by municipalities and
- is equivalent to 3 million tonnes of CO_2.

The largest energy consumers in wastewater treatment plants are

- Pressurisation equipment
- Pumps and agitators
- Sludge treatment.

There are generally two ways of improving energy efficiency in wastewater treatment plants. On the one hand, according to [2], the generation of fermentation gas and its conversion into electricity produces approx. 865 GWh (roughly 20% of the overall consumption) in the plants themselves. This potential can definitely be expanded further. On the other hand, experts estimate the opportunities for saving electricity at up to 20%. If we compare this with the increases offered by energy generation from fermentation gas, it is clear that measures to boost energy efficiency can achieve the same result as doubling the generation of electricity from converting fermentation gas into electricity.

That shows that energy efficiency pays off. At the same time, it shows that there is a need to use energy monitoring systems. Only things which can be measured can be optimised. Only by constantly monitoring the effects of energy efficiency measures can we create a greater understanding and a lasting awareness among operating personnel of the topic of energy efficiency. More vigorous and, in particular, more consistent work towards energy efficiency and the optimisation of LCC is therefore crucial.

3. Tools for evaluating the LCC of alternative technologies

At present there are still substantial barriers which are preventing the adoption/implementation of methods to evaluate measures for the minimisation of LCC during investment decisions, particularly in public sector procurement. These include:

- A kind of “blueprint mentality”, which means that possible new and more efficient technologies are not incorporated into the planning process. When it comes to optimising project engineering costs, generally traditional solutions are used with which engineers and operators are familiar.
- Lack of experience in the evaluation of alternative technologies. Operators of water or wastewater treatment plants are seldom required to make an investment decision. The need to take such decisions often only arises once every five years. As a result, there is little or no experience in evaluating alternative technologies and becoming familiar with the methods to evaluate alternative technologies is very complex for steps that are rarely undertaken. This means that the workload is usually not tackled; instead, familiar processes are used and the evaluation is made solely based on investment costs.
- Lack of incentive systems for optimising plant technologies. The planning services are compensated according to prescribed fee systems, which are based on the total investment costs. The prescribed fee systems do not currently incentivise the promotion of investments in energy efficiency and LCC optimisation, which in turn leads to a blueprint mentality.

In order to promote the adoption of energy-efficient technologies and the LCC concept in tendering processes, particularly those of public bodies, the ZVEI (the German Electrical and Electronic Manufacturers' Association) together with the consultants Deloitte have devised a user-friendly tool which illustrates in transparent form all kinds of alternative technologies with regard to energy efficiency and LCC and compares them in financial terms over a given period.

The main features of this Excel-based tool are as follows:

- Mapping of the complete life cycle of a plant, from the engineering, installation and operating phase to the deinstallation phase
- Consideration of all relevant economic cost factors, such as personnel, materials, energy, external services, financing etc.
- The option to systematically consider and analyse selected main and secondary cost categories
- The ability to configure features which permit a comparison at a key date, e.g. discounting rate
- Evaluation using reference data with appropriate graphical representations

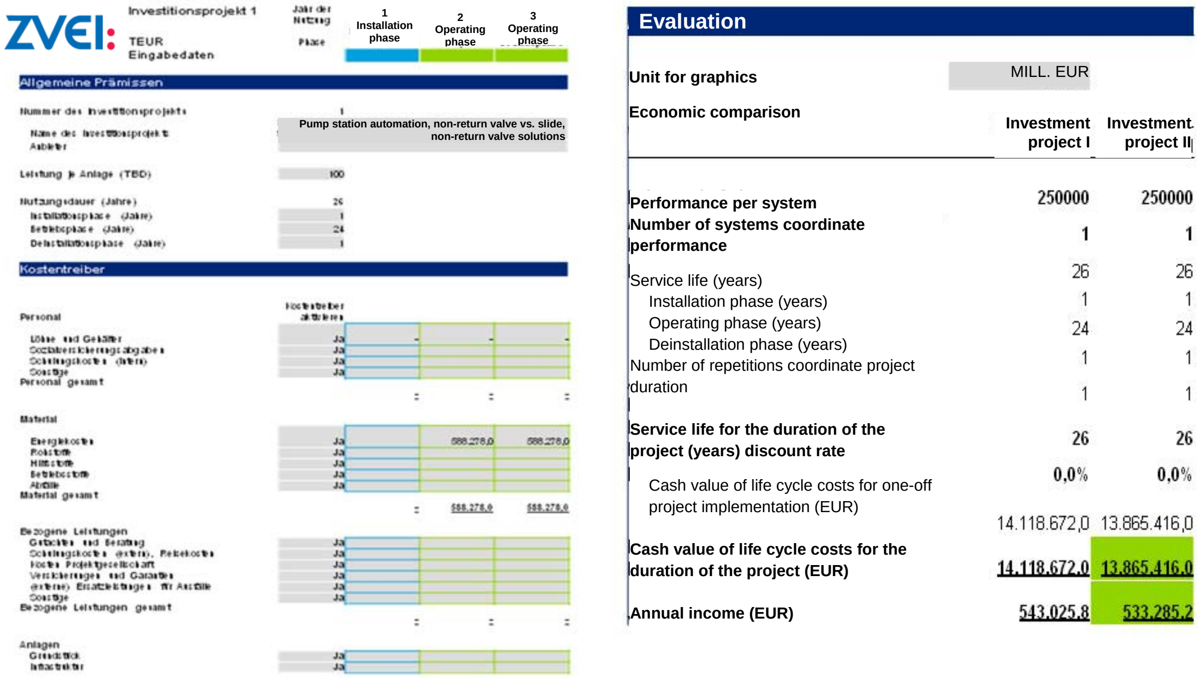


Figure 3: Input screen and presentation of results of the Excel-based ZVEI tool for the evaluation of alternative technologies in terms of energy efficiency and LCC.

The major advantage of the tool is that it not only makes allowance for individual components (speed-controlled actuators, energy-efficient actuators etc.) but it also makes it possible to undertake a comprehensive study of completely different measures within the plant and evaluate these in monetary terms over a given life cycle.

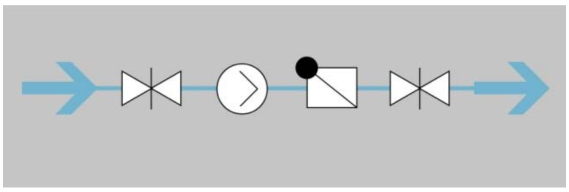
4. Optimisation of the LCC and increasing energy efficiency in the Böblingen-Sindelfingen wastewater treatment plant

The example of the Böblingen-Sindelfingen wastewater treatment plant shows how plants can be modernised in practice and how this benefits the operator. The wastewater treatment plant treats the wastewater of 250,000 citizens. Apart from the mechanical and biological cleaning stages and the sludge treatment, a downstream flocculation filtration stage has been added as an extra cleaning phase to improve the water quality of the River Schwippe. Upstream of this flocculation filtration stage, an activated carbon treatment process was introduced to eliminate most of the micropollution.

Figure 4: Trickling filter system.

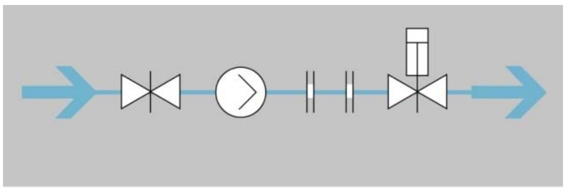
The configuration shown below was implemented in the central pump system of the Böblingen-Sindelfingen wastewater treatment plant. After primary treatment, the wastewater is pumped to the seven trickling filters (Figure 4).

This is carried out using six centrifugal pumps installed in the pump cellar. Of these, depending on the capacity utilisation, three to five pumps are operational, while one pump is retained as redundant. The characteristics of each pump are: nominal output 90 kW, nominal voltage 400 V, pump capacity 500 l/s with a pump head of 8-9 m. The nominal size of the pressure line is DN350. The default design of the pump unit before the modification was as follows (Figure 5):



Slide-Pump-Non-return valve-Slide

Figure 5: Schematic diagram of the pump configuration **before** the modification.



Slide-Pump-Pipe section-Pneumatic slide

Figure 6: Schematic diagram of the pump configuration **after** the modification.

The situation before the modification was characterised by:

- Frequent pressure drops, and thus energy losses through the non-return valve
- Reduction of the effective pipeline diameter via the flap in the volume flow
- Water hammers on closing the flap with corresponding vibrations of the pipeline system
- Gas formation upstream of the flap on extended pump downtime. This prevents the non-return valve from opening automatically and it then has to be opened manually.
- Greater installation effort needed because of the personal safety devices required for the moving parts of the non-return valve.

Based on experience, the service life of the non-return valves is approx. 12 years. However, continual wear is not apparent, i.e. leakages which occur are not detected.

As the non-return valve was due to be replaced, the overall configuration was re-examined from a technological point of view. The result was that the pneumatic automation of the existing knife gate valve fully replaced the functionality of the non-return valve (Figure 6). An additional air pressure reservoir was installed to provide sufficient reserve to actuate the knife gate valve, even in emergencies. With the modified pump configuration, the abovementioned disadvantages of the original installation will be avoided in future. At the same time, the service life is also extended.

The energy efficiency advantages are significant, too. Overall,

- 2% of the overall electricity consumption of the wastewater treatment plant is saved each year.
- 4% of the overall electricity consumption of the pumps is saved each year.
- The investments:
    - At least EUR 18,000 for replacing the non-return valves with a new valve.
    - Approx. EUR 25,000 for a modification as described (Figure 7).
- The power costs saved total approx. EUR 11,300 per year.
- Thus, the ROI is less than one year.
- The operator estimates that up to 10% of the annual pump energy can be saved thanks to more favourable hydraulic system conditions.

Figure 7: Pump unit after modification.

In addition, the entire layout of the pump unit (Figure 7) is far clearer. It also saves space and significantly reduces the noise level. As the knife gate valves close tightly, there are no longer any undetected leakages during operation.

5. Comparison of different actuator technologies for water treatment (Kleine Kinzig Water Supply Association)

The University of Braunschweig compared different actuator technologies for a new sub-system of the Kleine Kinzig Water Supply Association [3]. In the study, electric actuator technology was compared with pneumatic actuator technology based on the typical parameters for this plant. The primary treatment section consists of eight filter basins laid out on two levels.
Every filter basin is equipped with seven open/close valves and one control valve. The valve switching frequency is extremely low, sometimes just 1/d. The study took the following parameters in the individual phases of the plant's life cycle into account:

- Purchasing and installation costs
  - Project engineering
  - Procurement
  - Assembly and commissioning
- Utilisation phase
  - Energy costs
  - Inspection and maintenance costs, repair costs
- Dismantling and disposal costs

Figure 8: Kleine Kinzig water treatment plant

A key point for examining the life cycle costs of plants is the functional delimitation of the system studied. The above example assumes that the plant will remain operational even during power failures. An appropriate emergency power supply has been used in the comparison for this purpose. The plant was examined thoroughly with regard to the expected engineering and assembly costs. A detailed engineering plan was carried out, together with calculations of cable and tube lengths, the infrastructure required and definition of local distributions etc.

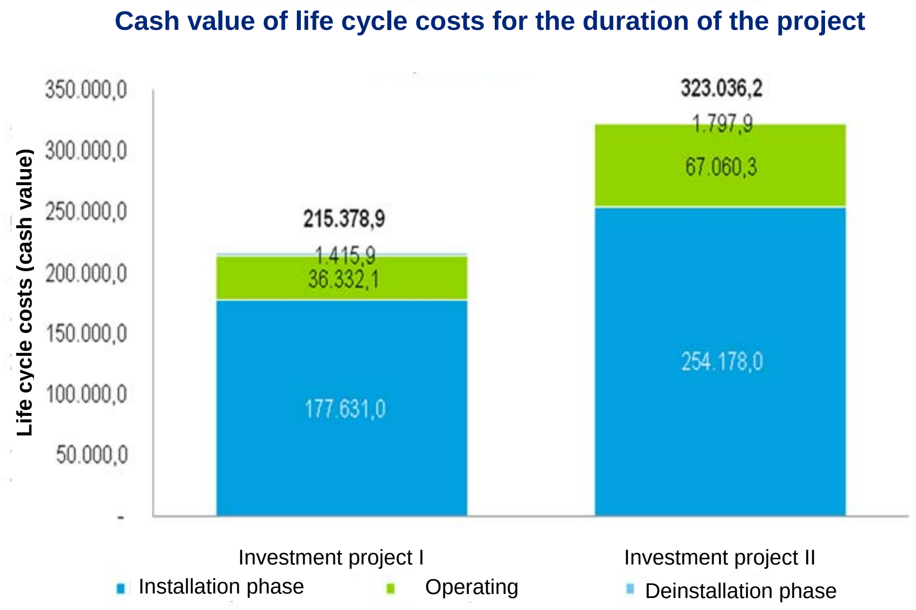


Figure 9: Comparison of the LCC (in EUR) over a period of 25 years

- o Investment project I: Pneumatic actuator technology
- o Investment project II: Electric actuator technology

A comparison of the LCC (Figure 9) over a period of 25 years for this plant shows that

- the operating costs including maintenance costs are far less significant than the investment costs
- the costs for electrical and pneumatic energy are negligible for plants with low enough switching frequencies.

Please note that these results only reflect the situation at this particular plant. While it certainly is possible to transfer the results to plants with similar characteristics, they are not applicable to plants with different characteristics, as other parameters could play a far more important role. The energy consumption in the plant studied is negligible because of the low switching frequency of the valves. The costs during the operating phase are therefore far lower than the investment costs. At least the last statement is not applicable to production engineering systems as these have a far higher ratio of energy costs to investment costs. The results can therefore not be automatically transferred.

6. Automation of solid bed filters under special conditions

Fixed-bed filters of open or closed design are an important part of water treatment in water and wastewater treatment plants. They remove turbid and non-biodegradable substances and soften, de-acidify or harden the water. Depending on the task at hand, the filling material can consist of sand, gravel, hydro-anthracite or activated carbon in one or more layers.

Five to eight process valves are usually required to control a fixed-bed filter (Figure 10). Of these, up to three are operated in closed-loop control, while the others are operated in open/close mode. The main types of valves used are concentric wafer type butterfly valves or double-offset valves, with annualar piston valves used as control valves at the filter outlet. In the case of an open design and a large basin, gate valves without housing or flap weirs are frequently specified for the inlet and for sludge discharge.

Pneumatics offers greater functionality for controlling process valves. With pneumatics, safety-relevant functions can be force controlled as appropriate for the operating situation. This applies in particular to the performance of the process valves in the event of a power failure when no emergency power generator is available.
The control valve (Figure 11) for the filter outlet is equipped with a pneumatic actuator and an electropneumatic positioner. The positioner continuously compares the target signal with the actual position of the quarter turn actuator in closed loop mode, and reacts accordingly. Any deviations can automatically trigger an error message and emergency stop. If the power fails, a pre-defined safety position of the process valve can prevent incalculable process conditions.

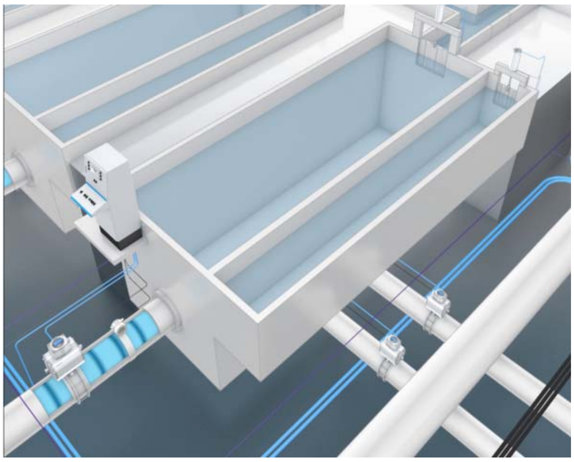


Figure 10: Structure of a solid bed filter.

Figure 11: Control valve.

But how can a solid bed filter be controlled if the power supply is not sufficiently reliable? Yet this is often the case with projects for water treatment plants in developing countries. Added to this are special requirements such as:

- **Quick assembly and set-up** even with
  - Insufficient electricity supplies
  - Missing parts, e.g. control systems
- **Manual operation** via operating panels with compressed air only
  - In emergencies (e.g. voltage failures)
  - On delayed installation/delivery (e.g. control system)
- **Sturdy solution** for control circuits without high maintenance requirements
- **Savings over the life cycle** of the systems, i.e. in the investment costs and also in the operating and maintenance costs

Operation only with pneumatic actuating elements additionally requires a modification of the actuation and control principle of the regulated flap in the outlet of sand bed filters. Traditional actuation via an electropneumatic positioner is not possible here, as it would not meet the operator's requirements for operating the system without electricity/electric controls. The control function was mapped close to the process in the control system software. Figure 12 shows the changed control circuit structure which, in addition to the abovementioned advantage of easy operation without control systems/electricity, also offers other advantages in terms of:

- Lower investment and therefore also life cycle costs
- Lower compressed air quality requirements
- Control flap can be moved faster

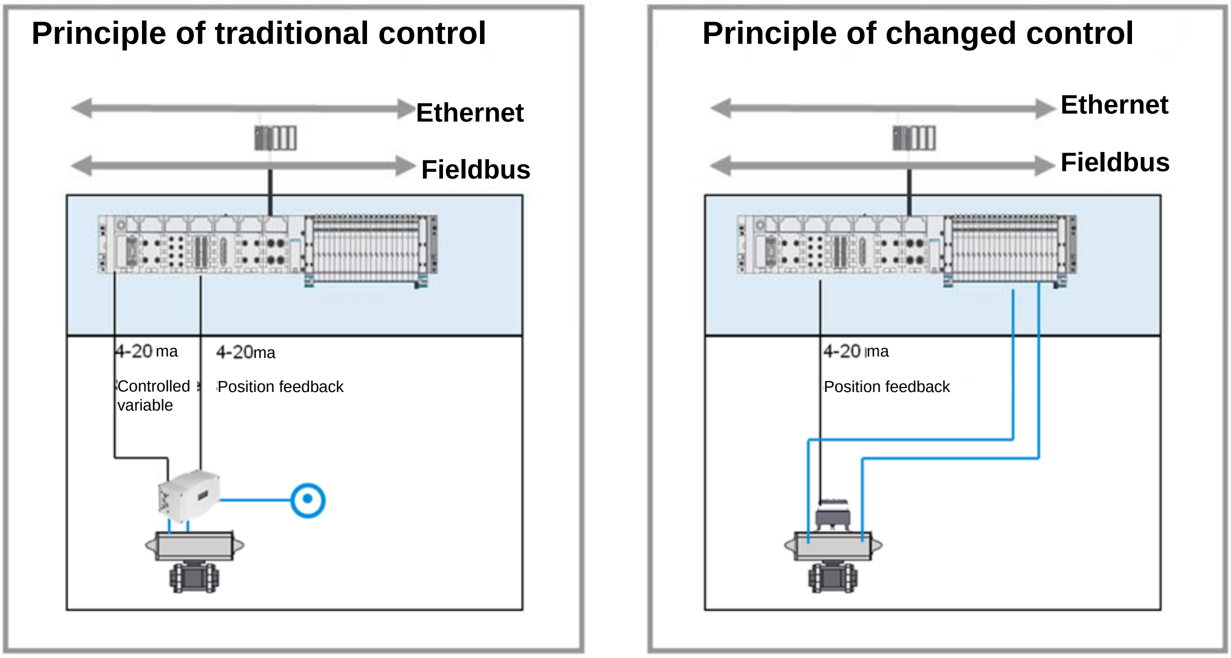


Figure 12: Change in the control circuit structure.

7. When is automation of decentralised rainwater retention basins worthwhile?

Rainwater retention basins store the water from heavy rainfall in order to prevent overloading the wastewater treatment plants under exceptional conditions. These basins are often not automated. This section highlights the issue by considering different types of electricity supply and automation, and provides tips on when energy-autonomous electricity supplies make economic sense.

In addition to these general considerations, there are also special requirements for the selection and project engineering of automation solutions. These can be, for example, economic criteria for the automation of decentralised plant components and their integration into a plant network when no energy supply is available because of the decentralised location of the plant (e.g. rainwater retention basins in water management systems) or when an energy supply can only be provided at an economically non-viable cost.

7.1 Energy-autonomous automation of decentralised rainwater overflow basins

Rainwater retention basins collect the excess water during heavy rainfall (surface or sewer system) and protect the wastewater treatment plants and natural waterways against overloading. When the wastewater treatment plant has enough capacity again, the stored water is fed to the wastewater treatment plant for treatment. For historic reasons, or because they are in locations where no cost-effective connection to the public energy supply network is available, they are often only operated with mechanical flow controls. This technology has several disadvantages from the point of view of operational management, for example:

a On-site inspection of system function required after system load
b Specific flush cleaning requires on-site manual intervention
c The rainwater retention basin is drained to the sewage treatment plant without coordination
d There is no information on the current water level and other parameters of the retention basin
e Operation of the basins in the treatment plant network is generally quite difficult in comparison with automated systems
f Visual monitoring using remote devices (e.g. webcams) is not possible
g There are no data available on precipitation and the amount of water held in the basins

Given these factors and the present state of technology, it would be advantageous to automate these plants. This requires electrical and pneumatic power supplies which can be connected to the plant in different ways. These forms of energy can be produced decentrally by using renewable energy sources such as solar energy. Or electricity can be obtained by connecting to public energy supply networks.

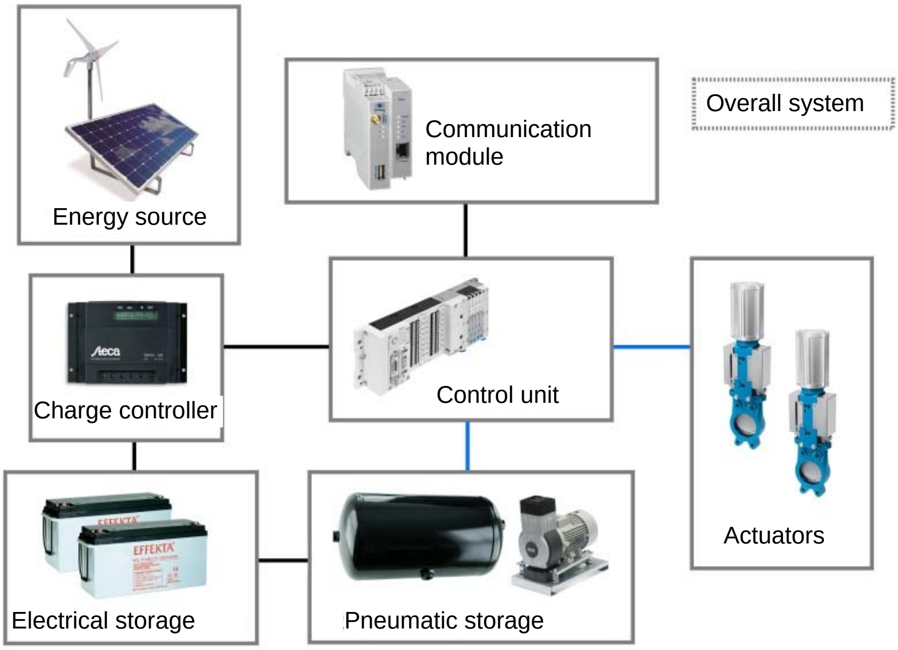


Figure 13: Energy-autonomous automation concept for a rainwater overflow basin in southern Germany.

The design steps for the automation system of the plant (Figure 13) were as follows:

- Definition of the operator's requirements for the switching frequency and the operating time of the plant, if necessary without energy generation (e.g. at night)
- Dimensioning of the energy storage facilities (batteries and compressed air) in accordance with these requirements
- The required power generation (size of the solar panels etc.) was determined taking into account the geographic data of the location and the corresponding meteorological data
- Connection of the plant to the master control system of the wastewater treatment plant via GSM.

Solar power is used to generate electricity, which is partly converted into pneumatic energy by compressors. The energy is stored in energy storage devices and made available as required for switching operations, alarms or monitoring functions. If the power supply from the renewable energy sources fails, an integrated emergency function ensures that the slide valves can continue to be operated several more times.

Using a GSM modem, the entire system can be controlled and monitored remotely from the control room of the wastewater treatment plant. A data logger continuously records the charge status of the batteries and documents the charging behaviour and relevant plant parameters. The running times of the air compressors are also monitored. Leaks, power supply failures and other faults can thus be detected promptly and rectified. The outlet flow control gate valves are actuated by pneumatic linear actuators, some of which are equipped with positioners.

The advantages of the energy-autonomous automation of these decentralised devices are:

- Saving of the investment costs of connecting to the public power supply grid
- Central operation and monitoring, i.e. saving of costs of manual operation and monitoring,
- Continuous monitoring of the plant and the automation system
- Avoidance of all disadvantages a – g (see above).

7.2 Evaluation of the life cycle costs: a comparison of the operation of rainwater retention basins

7.2.1 Implementation of the autonomous power supply concept (variant a) vs. connection to the public power supply grid (variant b)

The difference between these two variants is the way electricity is generated. This means that the following costs must be compared:

- Variant a: solar panels, charge controller, storage of electricity vs
- Variant b: laying cables to the next connection point of the power supply grid (low voltage level), switching cabinets for energy distribution in the plant

The results (Figure 14) show the marginal costs up to which a cable connection is more cost-effective than an energy-autonomous automation solution. For example, if the nearest connection point to the power supply grid is 400 m away, with expected laying costs of more than EUR 50/m, the solar solution is less expensive than connection to the public grid over a period of 20 years.

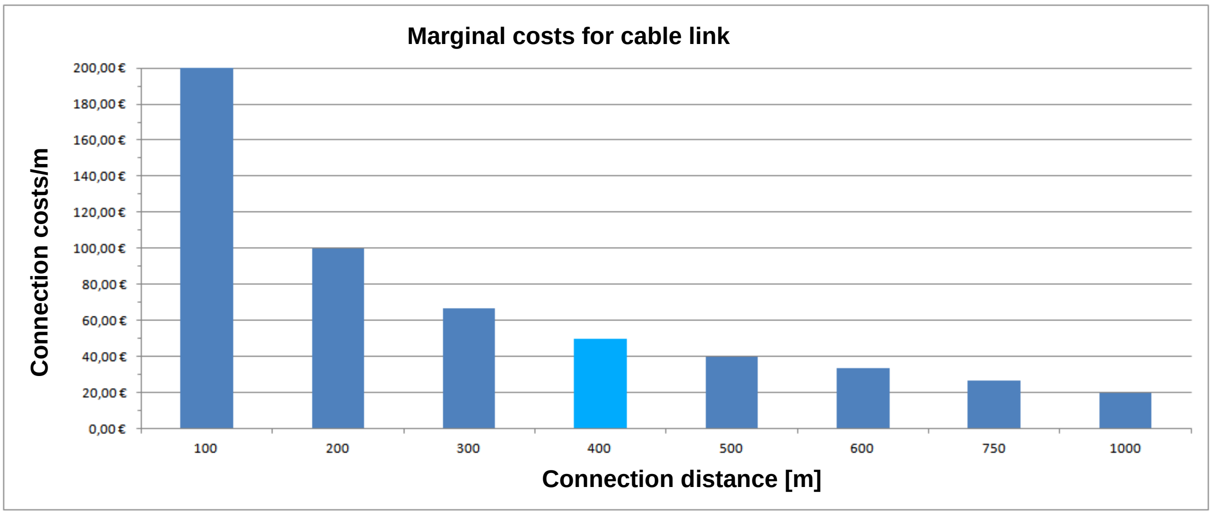


Figure 14: Marginal costs per low-voltage cable to be laid.

7.2.2 Implementation of the autonomous power supply concept (variant a) vs continued manual operation of the plant (variant b)

The difference between these two variants is the technology and thus the manual work required after heavy rainfall. The following costs must therefore be compared:

- Variant a: all investment and maintenance costs of decentralised power generation vs
- Variant b: Manual intervention for routine monitoring of the plant in the event of heavy rain

The results (Figure 15) enable a rapid estimate to be made about the economic viability of the energy-autonomous automation of an overflow basin. The costs are accumulated over a period of 20 years. On the assumption that neither the daily routine inspection via remote monitoring nor the error messages give any indication that the functionality of the rainwater retention basin is impaired, it is possible to do without routine local inspection under heavy rain conditions. However, variant a includes the costs of 6 site inspections at EUR 50/inspection (personnel and other costs). The study shows that over a period of 20 years, assuming that 25 site inspections at a cost of EUR 50 will be carried out, the costs of the non-automated plant are higher.

Apart from purely monetary advantages, it is clear that the automated plant also has the advantages that

- Specific flush cleaning is possible
- The inflows from several basins into a wastewater treatment plant are easier to coordinate
- All plant parameters and long-term trends are automatically recorded and can used for appropriate studies and evaluations of local conditions and infrastructure.

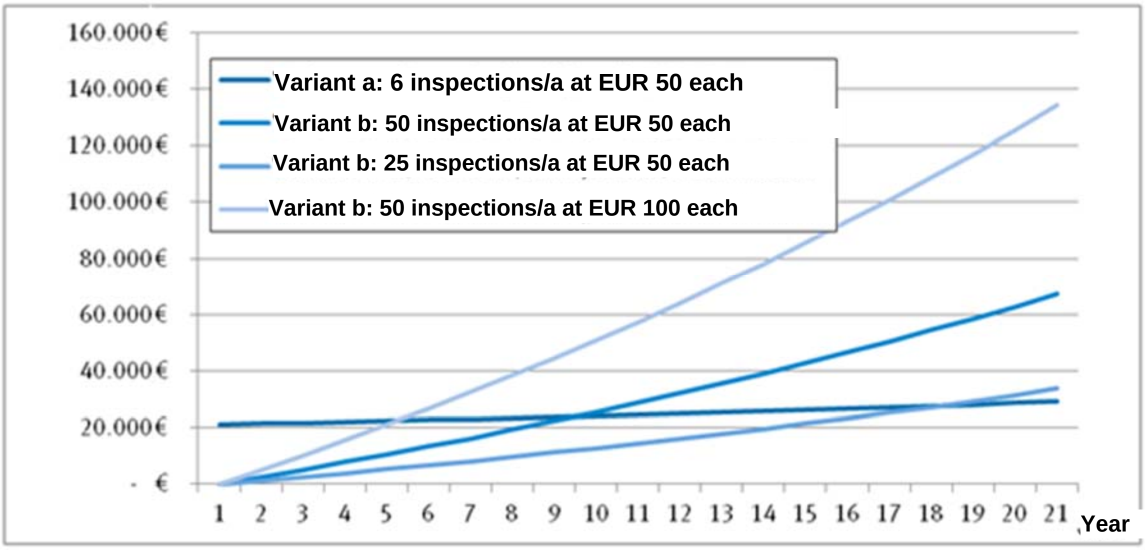


Figure 15: Cumulative investment and maintenance costs for the automated variant (a) and various sensitivity studies for the non-automated variant (b). The parameters of the sensitivity studies are the number of inspections in the case of heavy rainfall and the resulting associated inspection costs per year.

8. Summary

Boosting energy efficiency and optimising the LCC will, in future, be the key to

- Decreasing CO_2 emissions
- Reducing the demand for power plant capacity
- Increasing the competitiveness of the industry sector

But before the energy consumption can be optimised, a clear picture of the current (efficient) energy consumption is needed first, as knowledge creates awareness. After all, only that which can be measured can be optimised Transparent energy consumption is absolutely essential in all production plants.

However, in order to move further towards optimising the LCC, we need to change our thinking and our actions, away from the blueprint mentality and towards a stronger awareness that

- Energy efficiency and economy are not mutually exclusive
- Energy efficiency and LCC optimisation pay off
- LCC studies are an integral component of the planning and tender process for investment projects.

The premise of the tool created by ZVEI is that it breaks down any existing barriers that prevent the LCC from being taken into account during the planning and decision-making process. Solutions to optimise the LCC can be compared with one another logically and methodically. That should result in a strong push for an increase in the future use of enabling technologies such as automation, based on energy efficiency and LCC.

The tool is not restricted to public sector investment projects, but can be used for projects of all kinds.

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