GUIDE for ENERGY SAVINGS in MOTOR-DRIVEN SYSTEMS at MUNICIPAL WASTEWATER TREATMENT PLANTS

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Purpose of this guide

This guideline is meant to be a resource for decision-makers, managers and operational staff who are responsible for the planning, management, maintenance and operation of municipal wastewater treatment plants (WWTPs). The purpose of the guide is to provide information on how to reduce energy consumption in WWTPs, specifically through the maintenance and/or replacement of motors. Importantly, this guide answers the critical question of 'when should a motor be rewound instead of replaced?'

The guide complements other work being undertaken by SAGEN on municipal energy management systems and energy management in WWTPs.

Introduction

The treatment of wastewater is an energy-intensive process. Wastewater treatment and pumping is usually the largest single consumer of (electrical) energy for a municipality, ranging from 30% to 60%[1] depending on the size of the municipality and the complexity of the infrastructure in the urban area. The optimisation of energy use in WWTPs is therefore important in order to reduce municipal energy consumption and hence costs. Additionally, South Africa is a water-scarce country which has a very high ratio of water use in relation to replenishment. If this continues, it will become one of the world's most water-stressed countries. Rising electricity costs and the need to use resources prudently have compelled municipalities to review their electricity usage, and, hence, the optimisation of both water and energy use at WWTPs could play an important role in the financial and environmental sustainability of municipalities.

1 Based on figures derived from the Western Cape Energy Consumption and CO_2 Emissions Database Report 2012.

Why motors?

In a typical WWTP, up to 85% of all electricity supplied is used to drive motors and motor-driven equipment. This would include all equipment needed for the aeration process. Electricity is also consumed by lighting, laboratory equipment, office equipment and security systems. The motors of activated sludge-type plants consume between 40 and 75% of electricity of the plant through the use of aerators alone. Understanding the overall plant operation and how each motor is operated for a particular end use is essential in developing strategies to reduce energy consumption at WWTPs.

What approach should I take towards motors?

It is important to understand that motors operate within a system – motors are typically connected to a mechanical device that is used to fulfil a part in the production process as illustrated in Fig.1. For example, an electric motor will drive a Return Activated Sludge (RAS) pump that will transport sludge back to the inlet of an aeration basin. In addition, the control of that motor can either be automatic or require human intervention. Given this, process optimisation opportunities should therefore be investigated throughout the motor system as a first step to increasing energy efficiency. Simple operational opportunities such as training the Process Controller (in manual control) to switch off a motor when not required, or installing a relatively low-cost technology such as a feed-back O_2 sensor (controlling zone oxygen concentration in reactors to around 2 mg dissolved O_2/L) in an aeration basin, to optimise aeration, would realise a reduction in energy consumption of the motor. Optimising components in a motor system can yield a wide variance in energy savings from 5% up to 70% in some cases, in comparison to replacing an electric motor with a more efficient unit, which may only realise energy savings of between 1 to 5% (UNIDO Motor Systems Optimisation Training Course (2016)). Hence, an integrated systems approach should be taken when reviewing the operation and replacement of motors at a WWTP.

Where should I start?

For large municipalities and metros, there are usually a number of WWTPs distributed within the municipal area. In addition, the types of plants are usually varied, the most common being:

- Activated sludge-type plants – the major motors include aerators (or blowers) typically consuming between 40 and 75% of total plant electrical energy
- Trickling filter plants – the major motors include the pumps and scrapers associated with the sludge transport process
- Membrane bio-reactor-type plants – the major motors include high-pressure pumps associated with "pushing" wastewater through the filters as well as blowers/air compressors used to clean membranes between cycles.

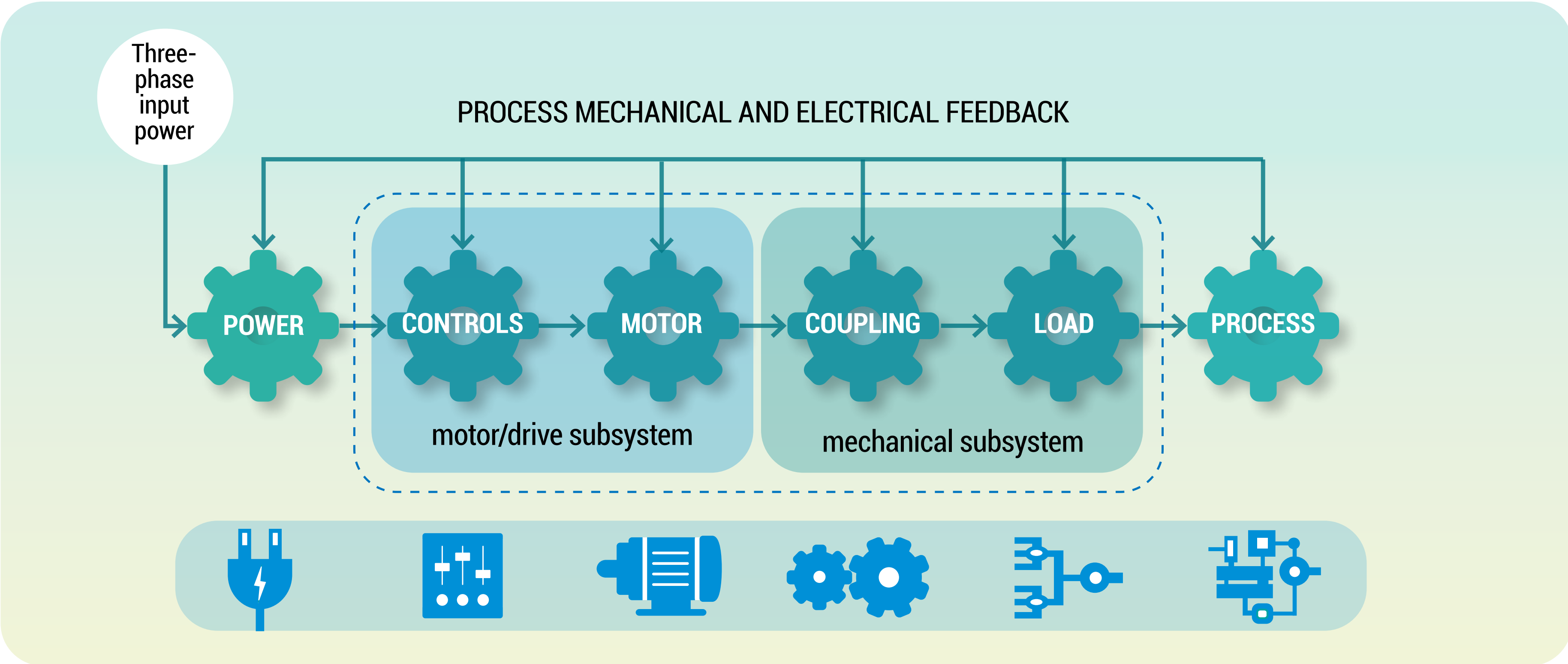

Figure 1: The Motor System (UNIDO, 2012)

An integrated approach to managing energy at these plants should typically consist of the following:

- Developing an overarching energy management policy for all WWTPs within the municipality.
- Identifying and quantifying energy usage per site and per equipment at each WWTP.
- Implementing a performance monitoring system for each WWTP.
- Conducting applicable energy efficiency training and certification for personnel. Training should include how Process Controllers can shift demand outside of peak times.
- Developing implementation plans with associated budgets for improving performance.
- Developing a procurement policy for repair or purchase of new motors.

What operational actions can I perform to ensure optimal operation of existing motor systems at WWTPs?

Inspection and regular monitoring of motors

- Ensure that motors are clean and free of debris and dirt. Motor casings are designed to allow heat to be dissipated from the motor. Covering a motor will result in overheating, lower efficiency and shortening the life of the motor. Mud and dirt should be removed from the motor
- Clear motor flow paths of debris that restrict flow. Flow restrictions cause the pumps to work harder and in turn result in higher energy consumption of the electric motor
- Ensure that the fan end is open and has access to fresh air. The fan provides continuous cooling for a motor while it is in operation. Blocking up the fan will result in overheating and premature failure of the motor
- Ensure that motor controls such as timers, thermostats and other sensors are in working order. Motor controls provide a safety as well as an operational function. In some cases where the control is not functioning, the operator will bypass the controls and force the motor into an operating mode outside of its design specification. This could also result in higher losses and shortening of motor life. Where motor control is executed manually, make sure that the correct operating procedure is applied
- Look for oil leaks under bearings and gearboxes. Loss of oil will result in under lubrication and affect energy performance of the motor because of increased frictional losses in the gearbox.

Listen for noises from the motor

Excessive noise is an indication that the motor is not operating within its specification.

- ***Noises from pulley belts.*** Belts that are slipping will usually make significant noise. Correcting the poor tension of pulley belts can sometimes achieve the same savings as the purchase of a higher efficiency class motor
- ***Noises may be from bearings.*** Incorrectly lubricated bearings will increase the mechanical load on the motor, causing it to consume more energy. Both under-lubrication and over-lubrication will result in losses
- ***Noises may be from poor shaft alignment.*** A large mechanical force such as a heavy object falling on the motor may cause misalignment. Engage the appropriate service provider to re-align the shaft.

Monitor motor load current

- ***Regularly inspect motor control rooms*** and review motor load currents on the distribution board. Make note of load currents that have suddenly changed (increased or decreased) away from the normally observed load currents. Engage the appropriate service provider before the motor fails
- ***Follow operational procedures.*** Develop a set of Standard Operating Procedures (SOPs) appropriate to the WWTP operation. Ensure that personnel have been trained and follow all procedures
  Using a systems approach, the energy-efficient operation of a motor may also be achieved by inspection and regular monitoring of mechanical equipment being driven by the motors such as pumps, blowers, screens, conveyors, mechanical rakes, and skimmers
- ***Monitor operating parameters.*** Ensure that operating parameters are within specification during operations. Check the discharge and suction pressures of pumps, and the pressure, flow and temperatures of blowers and compressors. Monitoring operational parameters can provide an early indication of an out-of-specification condition that may lead to premature motor failure.

What change options exist for motor optimisation at a WWTP?

Options that are typically considered are switch-off options; demand shifting; system optimisation (including variable speed drive (VSD) opportunities); and motor replacement.

Understanding plant operation is essential to optimisation and identifying opportunities related to the first two options. These options should be considered not only in terms of energy and financial savings, but should also weigh the 'cost' of complexity introduced into the system.

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SWITCH-OFF OPTIONS

Simply switching off motors when the process is not required is usually the most cost-effective energy efficiency strategy that can be applied. Generate a list of equipment like pumps and conveyors that are not required to operate full time and develop a procedure to ensure that each item of equipment is switched off appropriately.

Examples of equipment include:

- Sludge pumps – Return Activated Sludge (RAS) and Waste Activated Sludge (WAS)
- Aerators in sequential batch reactors
- Mixers and aerators in aeration basins when not needed
- Mechanical screens and inlet screws during periods of low influent volumes e.g. at night
- Conveyors and belts used in dewatering.

DEMAND SHIFTING

While it is not an energy-saving strategy per se, demand shifting involves changing the time at which an energy-intensive task is performed in order to take advantage of varying energy costs at different times of the day. The consumption of energy is not reduced, rather its consumption is shifted to a different time in the day. Usually the load will be shifted to a period where energy is cheapest, or at the minimum out of the high-cost periods. It may also be used to reduce the actual peak demand and thereby the demand costs associated with the supply of energy.

Demand shifting is especially relevant for WWTP that have balancing dams that allow for storage of wastewater.

Demand shifting may also be useful at times of load shedding, where energy-intensive tasks at the WWTP may be shifted to periods outside of the energy supply curtailment time.

SYSTEM OPTIMISATION

Using a systems approach, energy-saving opportunities exist where the process can be adjusted without compromising final water quality. Analysis of operating conditions often reveals that there is an oversupply of a particular element in a process under normal conditions, usually because of large safety margins and systems already set up for expected plant expansion. Overdesign was typical in the past where electricity was abundant and cheap and led to operating pumps at higher-than-required pressures or flows, an oversupply of oxygen in aeration basins, and over-chlorination of the final effluent.

These now represent opportunities for improvement where operating setpoints can be modified to match actual requirements rather than plant design requirements, or where equipment can be replaced with a correctly sized unit to reduce inefficiencies in operation.

Operating setpoints could also be adjusted according to a cycle, dependent on the process requirements, usually the volume of the incoming influent. Where multiple equipment types operate in parallel, one or more may be switched off. Typical opportunities during periods of low-flow would include reducing the number of pumps in use and switching off one of the inlet screws or mechanical rakes.

Poorly specified equipment may result in large system energy losses. Changing the motor load attached to the motor (like a pump or blower) to a more efficient unit can often yield better energy savings than replacement of the electric motor itself.

Replace motor control technology

As an alternative to the replacement of equipment, replacement of motor control technology may also yield significant energy savings. As an example, a poorly specified oversized pump will produce much more flow than required. To reduce the flow to the appropriate rate, throttling valves and bypass loops may have been installed or the pump may simply be operated with high frequency on/off cycle. A more energy-efficient control method using variable speed drives should be considered for these applications. While energy savings larger than 20% are typical of these technologies, care must be taken to ensure that it is the correct solution and that it is properly applied in order to achieve optimum energy savings.

For activated sludge-type WWTPs, the single biggest energy consumer is aeration. This activity forms the core of the water treatment process. The optimisation is complex and must be completed using a systems approach, which could include one or more of the following actions:

- Installing primary settling tanks to reduce chemical oxygen demand (COD) of wastewater entering the activated sludge reactors and hence reducing aeration requirements where these systems are properly controlled
- Improving system controls by using feedback loops to monitor critical parameters like dissolved oxygen (DO)
- Installing variable speed drives to allow better matching of the aeration requirements with the air supply from compressors or blowers
- Changing the diffuser or bubble-making process within the aeration basin
- Replacing motor/compressor motor/blower combinations with more efficient units.

Motor replacement

Motor replacement is viewed as the last optimisation opportunity. This is usually because of the high capital cost involved, and the because of the low percentage energy savings generated. However, when a motor fails, the cost of replacement has to be incurred. Under these circumstances, the extra cost involved in purchasing a high-efficiency motor should be considered, since it is only the difference in cost between a normal motor and a high-efficiency motor that would be evaluated against the potential energy savings.

> "In general, motors that have failed and have to be replaced are good candidates for upgrades to a higher efficiency class."

What is motor efficiency?

The first law of thermodynamics states that "energy can neither be created nor destroyed, it is merely transferred from one form to the other". In the case of the electric motor, not all the electrical input energy is converted to output energy during operation due to "leakage". The lower the "leakage" the more efficient the motor. In recent years, new technology and materials have enabled the manufacture of higher efficiency motors. Figure 2 below shows the international standard for efficiency classification of induction motors. Most modern motors will have the efficiency class (IE1, IE2, IE3 or IE4)[2] stamped onto the nameplate, providing an indication of the motor efficiency. Older motors will not have this classification and are assumed to be standard efficiency (equivalent to an IE0).

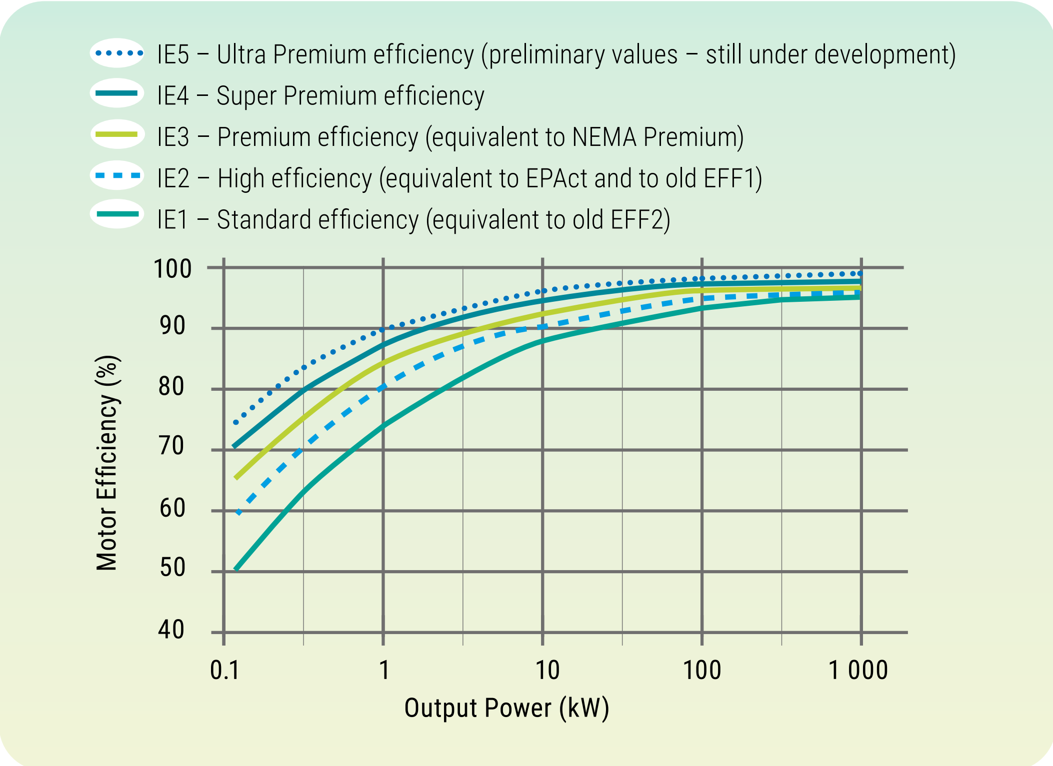

Figure 2: Induction Motor Efficiency Classification IEC 60034-30-1 {2014} – (UNIDO, 2012)

European countries have stipulated that only IE3 class motors can be purchased as new or replacement units. Currently, no minimum standard exists in South Africa. Hence, a procurement policy for electric motors is recommended where a municipality can specify the minimum efficiency required for new motors.

The motor size is important in determining whether to purchase a high-efficiency motor or not. From the figure above, a 10 kW motor will realise a 4% (0.4kW) improvement in efficiency moving from and IE1 to an IE3 motor. Similarly, for a 100 kW motor, the change in efficiency for IE1 to IE3 is about 1.5% (1.5kW). Although the motor is 10 times bigger the savings are only 2.5 times more.

The actual annual operating hours also need to be taken into account to calculate the actual energy savings and this should then be compared with the cost of a new motor. In South Africa, experience has shown that for a high-efficiency replacement of a motor that operates non-stop, simple paybacks of four years or more are common. Motors operating at only a fraction of the total annual hours will have much longer paybacks generally, and are not suitable for direct replacement.

> "Poorly specified equipment may result in large system energy losses."

2 IE's are for 4-pole motors of 50 Hz only.

When a motor fails, should I repair or replace?

A ***motor management plan*** provides a structured approach to the repair and maintenance of motors. However, if no motor management policy exists, then each motor failure should be evaluated on its own merit. Repair costs tend to be lower than replacement costs but come at the risk of poor quality. The decision to repair is influenced by three factors, viz. low cost; good quality; and short repair time. If all three factors can be achieved by a repairer, then repairing a motor is a good option. However, depending on the quality of workmanship, each time a motor is repaired, up to 2% of efficiency can be lost.

A good-quality repairer will also have the following:

1. A good-quality temperature-controlled oven for removing the windings
2. Standard approved methodology for repairs
3. Good spares inventory
4. Technical skills and appropriate certification
5. Issue a test certificate following repairs.

Even when a motor is so badly damaged that it ought to be scrapped, in some cases it may still be repaired as a temporary measure until a replacement can be found. Figure 3 shows a sample decision tree for repair or replacement of a motor. Using a decision tree allows for a more unbiased evaluation of motor failures for replacement or repair. This type of evaluation tree can form the basis of a motor management policy.

Why have a motor management policy?

- It provides a mechanism to improve motor efficiency over time
- It provides a structured approach to the repair and maintenance of motors and allows for the use of life-cycle analysis as a tool for financial evaluation
- It engages senior management to endorse a philosophy with regard to the introduction of high-efficiency motors at the site

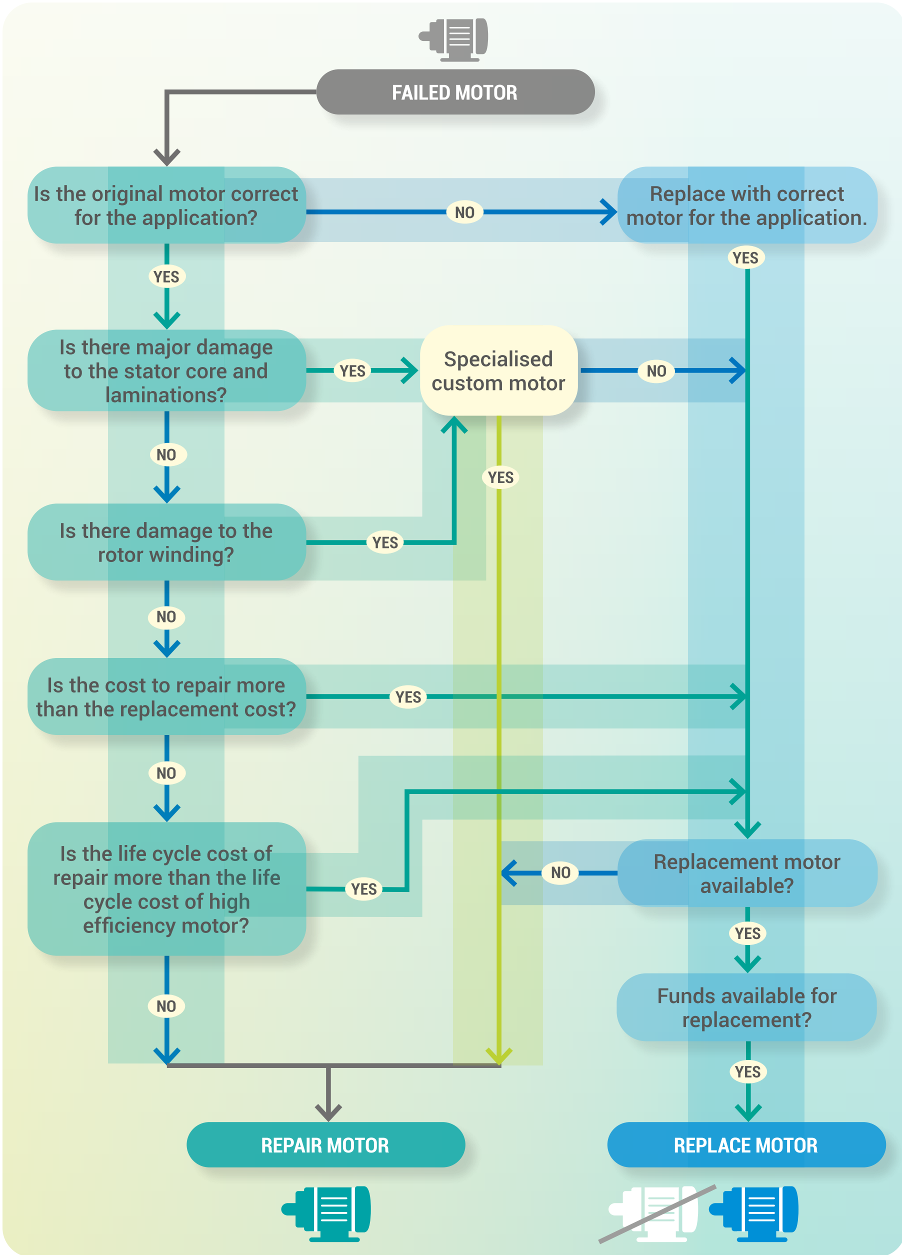

Figure 3: Motor Failure Decision Tree

- It can be used to define roles and responsibilities for the evaluation of motor failure
- It empowers engineers to influence the purchasing decision in favour of high-efficiency motors.

How do I create a motor management policy for the WWTPs in my municipality?

Start by developing a technical and financial methodology for evaluating each motor failure. Historical failures can also be used to develop this methodology, where a review of the decision-making process is undertaken. An initial decision tree can then be developed from this methodology, and then refined over time. Decision trees provide a visual approach that is more understandable and often more readily accepted. They will be unique for each municipality depending on the size and complexity of the wastewater network, and the organisation structure and capacity of the municipality. Larger municipalities that have functional design engineering capability will usually have the local expertise to develop an in-house decision tree. Smaller municipalities may require the services of an external consultant. An example of a generic motor failure decision tree is presented in figure 3.

The financial evaluation should include a life-cycle analysis. Traditionally purchase decisions have been based on the initial purchase price. For motors operating non-stop, the initial purchase price represents less than 15% of the life-cycle cost of that motor, with more than 80% of the cost being attributed to the cost of energy over a 10-year life cycle. By using a life-cycle approach energy consumption thus becomes an important factor in the purchasing decision. A good motor management policy will be endorsed by senior management within the municipality and will incorporate both the technical and financial aspects.

The decision tree to replace or repair would include:

- Life-cycle costing of repair/replacement
- Urgency of repair/replacement
- Availability of and quality of repair facility.

What do I replace it with?

Replacement of an electric motor could be one of the following:

- Exact replacement
- High-efficiency replacement
- New technology motor.

The decision regarding which replacement option to choose would incorporate life-cycle cost and technical feasibility. Specific criteria in the decision tree would include:

- Energy savings vs extra cost of high-efficiency motor or new technology motor
- Training required to operate new motor
- Maintainability
- Spares availability
- Manufacturing guarantees.

Frequently Asked Questions

What should I measure?

Measurement is the key to the quantification of optimisation opportunities, however, measuring equipment is costly. As part of an initial energy measurement, municipalities should instead calculate or approximate consumption levels for no or low capital investment decisions. Expensive data collection should be reserved for large capital investments where the time and costs may be justified. An initial energy review can be done by estimating motor nameplate data for small motors (<1 kW) and undertaking spot measurements for larger motors using an average power factor. This should be compared to total energy consumption using bills. This information can be used to construct an initial energy balance, which will provide a good indication of energy-intensive equipment that will form the focus of more detailed analysis

Resource: A Practical Guideline for Energy Efficiency Audits at Wastewater Treatment Works https://www.sagen.org.za/publications/99-a-practical-guideline-for-energy-efficiency-audits-at-waste-water-treatment-plants

Where can I find information for a motor if the nameplate is missing or illegible?

There are several options for finding nameplate data. The first source of data is the operating manual. If this cannot be located, information can be sourced from nameplates of identical motors used elsewhere in the plant. Design reports, asset registers and tender documents will also contain information on the motor specifications or at least the make and model, and using this information, the supplier can be contacted to provide the details required.

What is full and half load and how is it determined?

Every motor has a defined operating rated voltage, power i/p, current and power factor (in case of AC motor). Load means the current drawn by the motor to drive the load applied to it. It is the value i/p current drawn by the stator windings. Half load means that the load on the motor is applied such that the current drawn by it is half the rated current. A motor that runs on 100% of its design capacity is equal to full load.

How does load shedding affect motor optimisation?

Motors are quite robust and can withstand the effects of load shedding. However, the mechanical load that is attached to the electrical motor needs to be considered more carefully. If this load is too large, the motor may not be able to restart normally. The load may have to be manually cleared before the motor can be restarted. Other critical motors might have safety protection built in that requires manual intervention before the motor can be restarted. SOPs should be developed for the manual intervention of these motors, and where possible automation should be installed.

How do we get buy-in from municipal operators and maintenance staff that are resistant to change and increased complexity?

Promote an atmosphere of learning and continual self-improvement. Training and awareness are essential components in ensuring that existing and new motors are run within optimal ranges and are well maintained. Buy-in from Process Controllers is critical and this should be attained during the design and planning stage. Managers should ensure that there is suitable training and hand-holding while the operator becomes more familiar with operations. Process Controllers should also be encouraged to provide feedback during and after the commissioning phase to elicit long-term ownership and commitment.

What other common energy optimisation opportunities exist at a WWTP?

Improve the efficiency of lighting and HVAC systems. Consider moving toward net-zero energy. Biogas recovered from sludge digesters can be burned to produce electricity and heat. Install solar PV where space allows.

Resource: Anaerobic Digestion of Municipal Wastewater Sludge: A Practical Guideline https://www.sagen.org.za/restricted-files/96-anaerobic-digestion-of-municipal-wastewater-sludge-a-practical-guideline/file

Are Variable Speed Drives (VSDs) necessary?

Variable speed drives should ideally only be installed where there is a requirement for a variable speed application. In other cases where the motor is operating at less than full load for a fixed application it may be cheaper to change the motor size or gearbox ratio or pulley. Further, VSDs are complex in relation to traditional control methods. Their use at a location needs to take account of the skill level of the operational staff at that location. The environmental conditions such as temperature, cooling and moisture also affect the suitability of VSDs.

Resource: The Carbon Trust, Variable Speed Drives, 2011.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/376182/ECA764_Motors_and_drives.pdf

How can effluent regulation reduce WWTP energy consumption?

Managing upstream compliance could also affect the loading of the actual WWTP. Curbing the content and concentration of suspended solids in the waste will reduce the effort required by a WWTP to purify the water to an acceptable level, thereby reducing the energy consumption. Municipalities should implement and manage bylaws for effluent discharge by industrial polluters. As a start, a municipality could potentially implement a bylaw for the agro-processing industry to monitor effluent from plants such as abattoirs and dairy processing plants. As the municipality develops the requisite expertise and skills, the bylaws could then be further rolled out to other industries like chemical process plants and other water-intensive industries.

In addition, water infiltration from sources such as storm water and groundwater should be curbed to reduce the hydraulic load to the plant which results in additional energy demand.

List of Resources

1. FR Spellman. Water and Waste Infrastructure, Energy Efficiency and Sustainability. CRC Press. 2013
2. US Department of Energy Advanced Manufacturing Office. Improving Motor and Drive System Performance – A Sourcebook for the Industry. 2014.
   https://www1.eere.energy.gov/library/default.aspx
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   https://united4efficiency.org/resources/accelerating-global-adoption-energy-efficient-electric-motors-motor-systems/
7. The United States Environmental Protection Agency.
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8. Watereum Effective Utility Management
   https://www.watereum.org/resources/resource-toolbox/
9. The Water Research Foundation.
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