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Applying the ERP Business Software in the Analysis of Electric Drives Steady State

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Abstract: The paper presents the possibility of using ERP business software for the purpose of analyzing steady states of electric drives. A centrifugal pump is used as an example of active load. After reviewing previous research and presenting the basic principles of using the ERP model, the analysis of the operation of the centrifugal pump and the processing of the results of the propulsion measurements were approached. Two flow control options are considered and both methods are compared regarding energy consumption. After that, the method of calculating energy saving using the ERP model is shown. The calculation results provide data on different costs depending on the type of flow control. Since an induction motor with a frequency converter is provided for flow control by changing the speed, the final step is rough profitability estimate of the investment in frequency converter, which was also done directly in the ERP model.

Keywords: electric drives; energy saving; ERP model; induction machine

1 INTRODUCTION

Intense changes at the political and business levels require managers to make faster decisions. A particularly important area is energy saving, which has been a very current topic of research in all branches of industry for a long time.

Previous research on the possible use of Enterprise Resource Planning systems (ERP) for technical calculations and analysis has shown that the ERP system is able to give the desired results for the managerial level of consideration of technical problems. The authors in [1] especially point out that process is principally quicker the lesser the number of involved people and if the main protagonists use the corresponding tool familiar to them. In doing so, managers are recognized as natural ERP users, and as people who cannot afford to search for data on several different systems, as well as excessive dependence on assistants who should do the necessary research instead and prepare all the data for their managers. Nowadays, managers are looking for all the necessary information in one place. This thinking is confirmed by more and more research, especially [2], which states that top managers understand that they must not wait for perfect information - after receiving 65% information security, they make a decision.

The ERP model used in this paper is based on the principles presented in the literature [3-5]. It is a standard SAP ERP solution (SAP stands for Systems, Applications and Products in Data Processing), where with the functionality of Production Planning (PP module), Controlling (CO module) and Variant Configuration (LO-VC module) it is possible to achieve a complete simulation picture of the production part of the business with the necessary elements of technical calculations [6].

The basis for this paper is research presented in [7-9]. In [7], SAP ERP was used for the analysis of induction machines. It has been shown that by setting the so-called analytical ERP model, all parameters of the equivalent circuit can be reached, as well as the static torque characteristic, both based on the measurement results.

The paper [8] presents the idea of using the ERP model in order to improve the decision - making process in the production of power transformers. The principles of calculating the basic dimensions of transformers are shown, and it is pointed out that the obtained results can make three basic business estimates necessary for the decision to enter a new project: estimating the availability of production capacity, estimating the availability of production materials and estimating production costs.

In [9] it is shown in detail how the ERP model can be used to calculate the basic dimensions of an electrical machine based on the initial requirements, using standard principles of variant configuration.

The efficiency of electric drives is the topic of the review [10], because of great energy consumption for electric drives in the world. It presents the state of art in electrical machine modeling and analysis using electrical machine electrical equivalent circuit models, to define the high-frequency behavior of the machine. For the analysis of machine operation, the finite element method (FEM) method is often used as in [11], or the traditional analytical method as in [12], while a hybrid calculation method of radial electromagnetic force based on FEM and analytical method is proposed in [13]. A new analytic-numeric method for permanent magnet synchronous machines (PMSM) is presented in [14] and validated by experimental results. The importance of accurate modeling of the machine in the development phase of an electrical drive system, as well as in the designing of the electrical machines is highlighted in [15, 16]. An extended synchronous machine model that includes dynamic iron losses and their temperature dependence is presented in [15], while a design approach of the Bearingless Induction Motor is proposed in [16].

This paper deals with the possibility of using ERP models for the purpose of analyzing steady states of variable frequency electric drives. It shows the new and different method for calculation of energy saving and calculation of repayment time on investment in electric drives modernization or improvement. Both calculations are done by applying the ERP model.

After this introduction and the overview of related researches, the second chapter is providing the information about basic methods applied in this research. Third chapter describes the calculation of energy savings using the ERP model, and one of the possible ways to calculate the repayment time of the investment in a variable frequency electric drive. Conclusions are given at the end of paper.

2 CENTRIFUGAL PUMPS AND ENERGY CONSUMPTION

Fig. 1 shows the guiding idea of the whole research, obtained by comparing the dynamic (blue line) and static (red line) characteristics of the induction machine. Namely, just as the study of static characteristics is sufficient for a large part of the analysis of the behavior and driving capabilities of electrical machines, in the same way it is sufficient for managerial decision making to have the results of rough technical calculations available. In a time of unexpected and highly intense changes, decision making needs to be simplified and accelerated as much as possible.

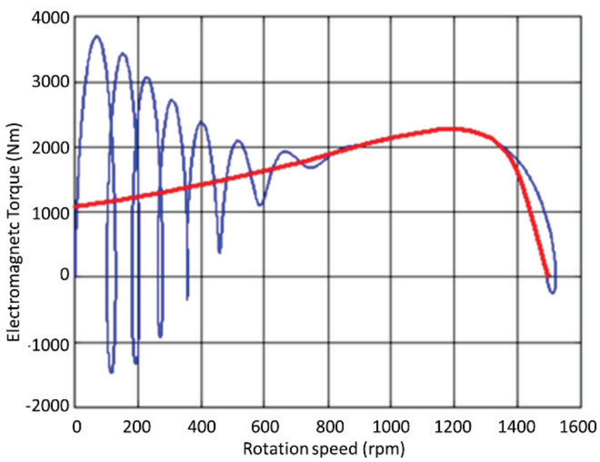

Figure 1 Static and dynamic characteristics of an induction motor [6]

Whether it is about companies that manufacture electrical machinery or companies that use electrical machinery, using a simplified method of analysis of machine operation, calculation of parameters and calculation of dimensions can achieve good enough results needed for managerial decision making.

2.1 Description of ERP Software Customization for Application in Technical Analyzes and Calculations

When customizing SAP ERP software for possible applications for technical analysis and calculations, two options were used. One consisted of the use of a LO-VC module and the other of a PP module. In both options, only the adjustment of system parameters was made, without additional programming.

Thus, for example, the standard SAP functionality of the Variant Configuration with additionally created dependencies and formulas was used to calculate the parameters of the equivalent circuit of an induction machine. The second method was then used to obtain the torque characteristic as a function of speed. The equivalent circuit parameters in SAP are defined as constants in the PP work center formula. Because of high level integration of PP work centers and CO cost centers (including CO activity types and CO cost elements), it was possible to use the standard form of CO cost calculation formulas to calculate basic technical parameters: slip, torque and current.

The torque characteristic is obtained as a result of the Kloss equation, which shows the dependence of the speed of rotation, i.e. slip, and on the torque developed by the induction motor:

$$\frac{T}{T_{\mathrm{b}}}=\frac{2}{\frac{s}{s_{\mathrm{b}}}+\frac{s_{\mathrm{b}}}{s}}. \tag{1}$$

Labels of variables used in an Eq. (1): T – torque, T_{b} – breakdown (maximum) torque, s – slip, s_{b} – breakdown slip.

In the ERP software, the method of simulating the functionality of confirming production orders, which is an integral part of the PP module, was used to obtain the steady state characteristic of a specific induction machine. All calculated dots can then be linked by additional programming in ABAP (Advanced Business Application Programming) to obtain a graphical representation (Fig. 2).

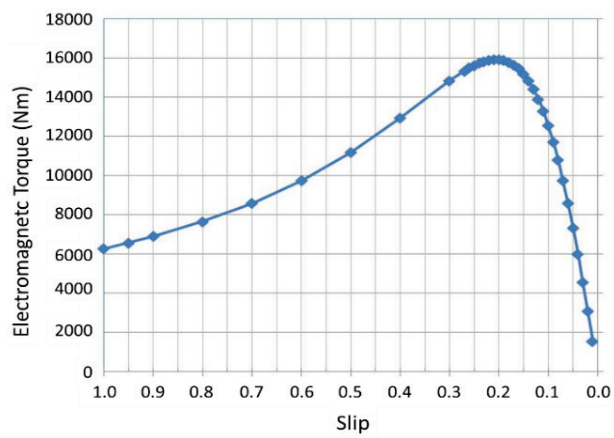

Figure 2 Induction machine torque curve obtained by ERP model [6]

In addition to the analysis of machine operation, the ERP model can also be used for dimensional calculations and cost estimate. Thus, in [9], the calculation of the basic dimensions of the power transformer is presented (made according to the adopted procedure [17, 18] defined in 19 steps). After defining the necessary specifications, by calculating all the elements of the core and winding, the final collection of data is obtained based on three results: the amount of copper, the amount of magnetic sheet metal and the amount of transformer oil.

Fig. 3 shows an example of using dimensional calculations in an ERP model for business decision making in the case of a large electrical machinery manufacturer.

From the dimension calculation, procedure moves to calculating the required resources, after which material availability check and cost estimates are automatically performed as necessary information for decision making.

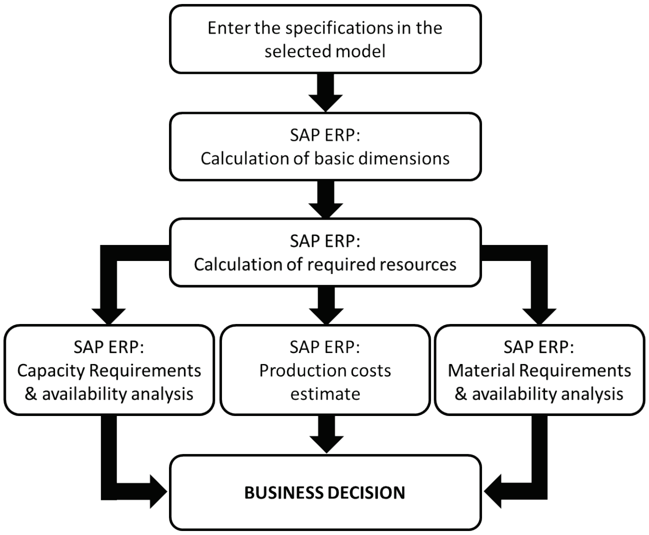

Figure 3 Using ERP models for business decision making [8]

Fig. 4 shows a more detailed presentation of the steps in the ERP model for obtaining data on the required quantities of materials and the required production times. Immediately after entering the desired specifications of the electrical machine, it starts with the calculation of dimensions and in parallel analyzes of historical records of production times by types of electrical machines. By including historical data in the ERP model, the calculation of the required working capacities for the production of the desired electrical machine was obtained.

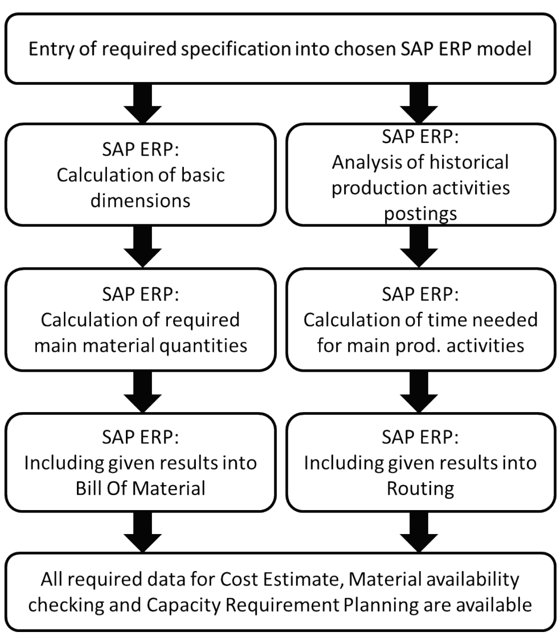

Figure 4 Key data preparation process [9]

Based on the cost of materials and production activities, the application of standard financial rules leads to an estimate of the total production price, or COGS (Costs of Goods Sold) in business language.

2.2 Application of ERP Model for Calculation of Energy Savings in Controlled Electric Drives

Variable frequency electric drives provide several significant options for possible savings. One possibility is seen in the control of fluid flow by varying the speed of rotation instead of damping. A centrifugal pump was used as an example of induction machine load in this study. Based on the results of operational measurements, the static characteristics of the pump and pipeline are obtained, which is then included in the ERP model, and further simulation calculations are approached.

Fig. 5 shows the process within the ERP model that aims to calculate energy savings and in the end return on investment.

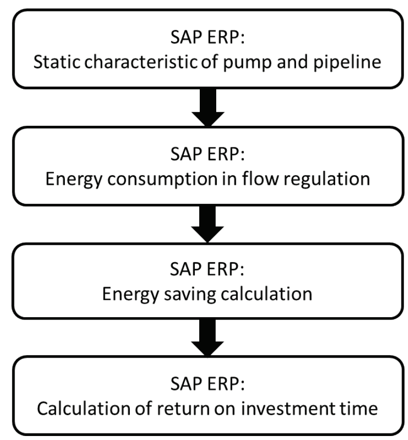

Figure 5 The procedure for calculating energy savings and return on investment

2.3 Centrifugal Pump Performance Characteristics

In the flow of incompressible fluids, the active force that allows flow through the pipelines is dependent on the pressure drop and the difference in geodetic height between the centers of the two pipelines.

Flow pressure drop in case of liquids is done by Eq. (2):

$$\Delta p = p_1 - p_2 = \left(\lambda_{\mathrm{tr}} \frac{L}{d} + \sum \varsigma \right) \rho w^2 + \rho g (h_2 - h_1). \tag{2}$$

List of variables used in an Eq. (2): λ_{tr} – friction coefficient, ς – loss coefficient, w – flow rate (m/s), ρ – fluid density (kg/m^3), L – length (m), d – diameter (m), h – geodetic height (m), g – gravity acceleration (m/s^2).

The active force for the transmission of liquids is obtained by the operation of the pumps and the corresponding height distribution of the pipeline. It can be seen from Eq. (2) that the pressure drop can be changed in two ways: by adding resistance to the system or by changing the fluid flow rate. Thus, the two basic options for fluid flow control are damping control and pump speed control, i.e. control via device that allows fluid transfer.

The basic quantities that characterize the operation of the pumps are the flow rate, the rotational speed and the delivery height. Since the flow rate is proportional to the speed of the pump, it follows that in order to control the speed, it is necessary to know the dependence of the flow and the delivery height of the pump on the speed. The flow rate is proportional to the speed of rotation of the pump (3), while the pressure, i.e. the delivery height and the speed of rotation are related by the square law (4).

$$Q = k_1 \cdot n, \tag{3}$$

$$H = k_2 \cdot n^2. \tag{4}$$

List of variables used in an Eqs. (3) and (4): Q – flow (m^3), H – delivery high (mWC), k_1, k_2 – coefficients of proportionality, n – rotation speed (rpm).

The power of the pumps delivered to the liquid is obtained from Eq. (5):

$$P = \rho \cdot g \cdot H \cdot Q. \tag{5}$$

List of variables used in an Eqs. (3) and (4): P – Power (W), ρ – fluid density (kg/m^3), g – gravity acceleration (m/s^2), H – delivery height (mWC), Q – flow (m^3).

A general presentation of the dependence of the delivery height on the flow is given in Fig. 6. The characteristic of the pipeline and the characteristic of the pump are shown. The intersection of these two characteristics gives the operating point of the pump.

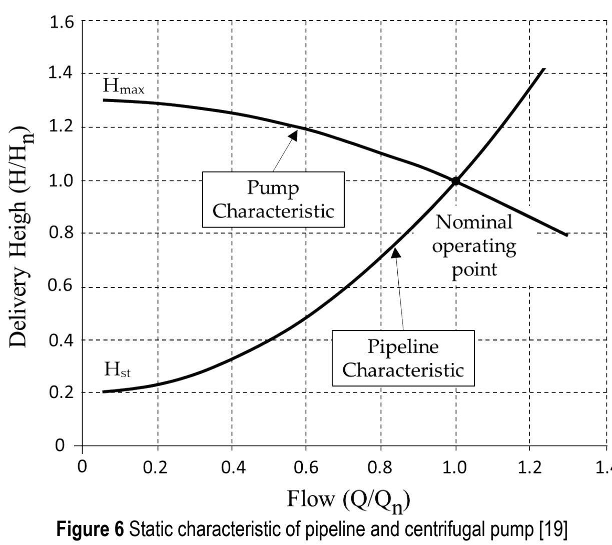

Figure 6 Static characteristic of pipeline and centrifugal pump [19]

Figs. 7 and 8 show two different ways of flow reduction, control by damping and control by speed. When using the flow control by damping (Fig. 7), the characteristic of the pipeline changes. Control is done by valves in the outlet line, by placing the valve in Position B instead of Position A, which adds new resistance to the flow line and thus reduces (dampens) the flow. With this method of control, it is moving along the pump curve at speed n_1 from the A system curve to the B system curve. The delivery height increases from H to H_2. This way of control, reducing the flow does not reduce the energy required for the operation of the pump, but is spent on overcoming additional increased hydraulic frictional resistances, due to the damping of the valves.

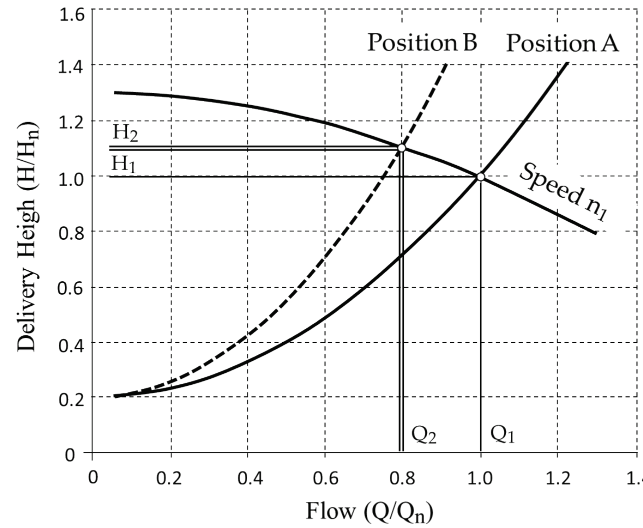

Figure 7 Flow control by dumping

By changing the pump speed of rotation (Fig. 8), the characteristic of the pump changes, and thus the amount of fluid supply, while the characteristic of the pipeline remains the same.

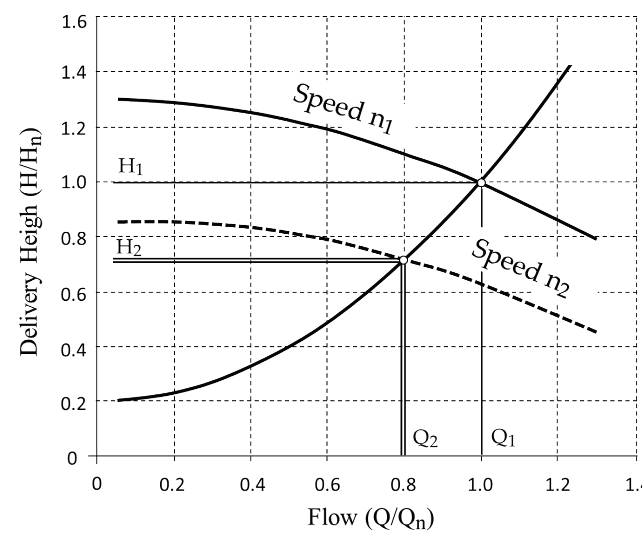

Figure 8 Flow control by changing the rotation speed

For a known pump characteristic at a certain speed, a new characteristic for a different speed, higher or lower than the nominal one, can be obtained on the basis of the law of similarity. The operating point will be at the intersection of the new pump characteristics and the pipeline characteristics. By lowering the vertical from this intersection, a flow corresponding to the new speed of rotation, n_2, is obtained. The delivery height decreases from H to H_1.

This method of control (reducing the speed of the pump to reduce the flow) reduces the energy required to operate the pump at a lower motor speed, thus achieving the desired energy savings: if the Eq. (5) for power on the pump blades is multiplied by time, energy is obtained.

3 CALCULATION OF ENERGY SAVING USING ERP MODEL

In this central part of the article, two basic calculations using the ERP model will be presented: energy saving and investment repayment time.

3.1 Centrifugal Pump Performance Characteristics

An example of the calculation will be an electric drive with an induction motor and a centrifugal pump with the following data [19]:

- nominal rotation speed 1485 rpm,
- flow at nominal speed 2500 m^3/h,
- delivery high at nominal speed 140 mVS.

From the measured static characteristics that show the dependence of the delivery height on the flow, the full "name" of the function representing a specific curve can be easily obtained via excel, with "Format Trendline" option. The resulting function name is then used in the ERP model, where a formula is created using a variant configuration. As an example of switching the formula from excel to the ERP model, the calculation of the delivery height value in the case of flow control by damping can be given. After loading the measured values into excel, the formula "given" by excel, using second order polynomial for having trendline, looks as shown in the Eq. (6):

$$y = -0.3 \cdot x^2 + 0.02 \cdot x + 1.30. \quad (6)$$

In order for Eq. (6) to be used in the ERP model, the following preparatory steps need to be done:

- creating characteristics for entering initial values (density, flow rate and time)
- creation of characteristics for calculation of derived values (delivery height at constant speed, delivery height at change of speed, energy consumption in control by damping, energy consumption in control by speed and energy saving)
- creating a configuration class and assigning the created characteristics to the configuration class
- creating dependencies with formulas for calculation of delivery height and energy saving
- assignment of created dependencies to characteristics
- creating a master record of the material that will serve as a simulation object
- assignment of material as simulation object to the class
- creating a configuration profile
- assigning a configuration class to the configuration profile
- assigning all defined dependencies to the configuration profile

Fig. 9 shows eight created characteristics. All characteristics are numerical format and all of them are grouped together for easier searching and finding.

Chars / Values	Desc.	Group	Char. St.	Format
UNIN_101	Density	UNIN_JN	Released	Numeric Format
UNIN_102	Heigh	UNIN_JN	Released	Numeric Format
UNIN_103	Flow	UNIN_JN	Released	Numeric Format
UNIN_104	Time	UNIN_JN	Released	Numeric Format
UNIN_105	Heigh 2	UNIN_JN	Released	Numeric Format
UNIN_111	Energy 1	UNIN_JN	Released	Numeric Format
UNIN_112	Energy 2	UNIN_JN	Released	Numeric Format
UNIN_113	Energy 3	UNIN_JN	Released	Numeric Format

Figure 9 Characteristics created in ERP model

Fig. 10 shows the five dependencies created.

Dep.	Description	S	Dep. Type
UNIN_102	Pipeline	1	Procedure
UNIN_105	Constant speed	1	Procedure
UNIN_111	Energy 1 (valve)	1	Procedure
UNIN_112	Energy 2 (speed)	1	Procedure
UNIN_113	Energy - delta	1	Procedure

Figure 10 Dependencies created in ERP model

With the system prepared in this way, it is possible to include Eq. (6) in the ERP model (Fig. 11).

Procedure UNIN_105 Constant speed

Editor

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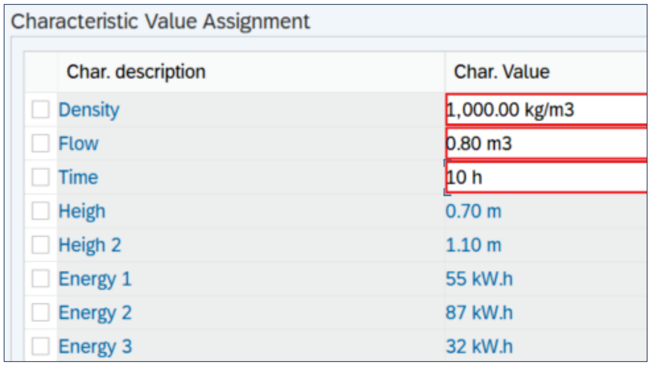
$self.UNIN_105 = -0.3 * $self.UNIN_103 * $self.UNIN_103
        + 0.02 * $self.UNIN_103 + 1.3
```

Figure 11 Eq. (6) after inclusion in the ERP model

Once the system is fully prepared, simulation calculations can be started. In order to calculate the energy consumption, it is enough to enter the relative value of the flow (amount of flow in relation to the nominal flow) and the desired length (time) of observation in the configuration table. As a result, the system provides the delivery height and the required power that must be delivered to the liquid, for both control modes. To facilitate the process, it can be assumed in the preparation of the model that it will work, for example, with water as a liquid, so the specific density is predefined. By entering the desired value of flow and the observed length of time, the value for the delivery height in both methods of flow control, the amount of energy consumed, and the savings themselves are reached.

Fig. 12 shows the result for 80% of the nominal flow for 10 hours. There is a difference in energy consumption. In the case of flow control by damping, the energy consumption for 10 hours of operation is 87 kWh, and in the case of flow control by rotation speed only 55 kWh. The difference in consumption is 32 kWh, or more than 35%.

With a system prepared in this way, it is possible to make quick checks for any other example based on the same physical basis. It is enough to make a correction of several parameters of the previously prepared system on the basis of operational measurements.



Characteristic Value Assignment

Char. description	Char. Value
Density	1,000.00 kg/m3
Flow	0.80 m3
Time	10 h
Heigh	0.70 m
Heigh 2	1.10 m
Energy 1	55 kW.h
Energy 2	87 kW.h
Energy 3	32 kW.h

Figure 12 Simulation calculation of energy savings

3.2 Calculation of Investment Repayment Time

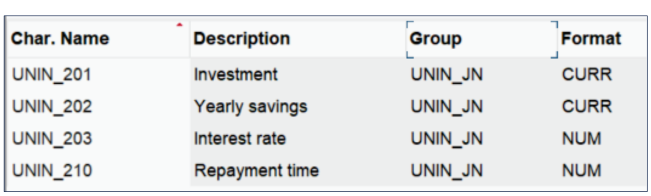
Frequency converters can be a significant investment, and managers want a quick calculation of profitability and investment payback time. Without going into more detail about economic regularities, it is enough to know that the profitability of an investment depends significantly on the interest rate on borrowed money. According to the methodology discussed in [19], the Eq. (7) is used for rough calculation of repayment time on investment:

$$T = \frac{\log\left(1 - \frac{IV}{YS} \cdot k\right)}{\log(1-k)}. \tag{7}$$

List of variables used in an Eq. (7): T – repayment time (years), IV – investment value (EUR), YS – annual savings (EUR), k – annual interest rate (%).

To calculate the repayment time, as in the previous calculations, an appropriate characteristic is created in the ERP model to which the previous formula is linked.

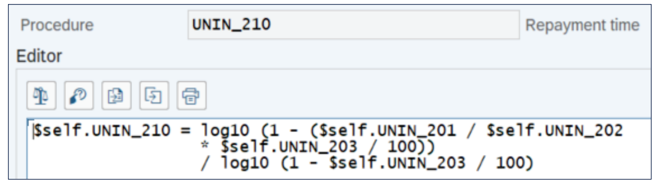
In the simulation calculation, the resulting repayment time is obtained by simply entering the interest rate and the value of the investment (assuming that the value of the annual savings is calculated in the previous step). The required characteristics in the ERP model are shown in Fig. 13 and Eq. (7) is presented in ERP model as in Fig. 14.



Char. Name	Description	Group	Format
UNIN_201	Investment	UNIN_JN	CURR
UNIN_202	Yearly savings	UNIN_JN	CURR
UNIN_203	Interest rate	UNIN_JN	NUM
UNIN_210	Repayment time	UNIN_JN	NUM

Figure 13 Characteristics created for the purpose of calculating the repayment time

The final result, i.e. the required payback time of the investment (Fig. 15) is obtained using the simulation procedure (standard functionality of the SAP variant configuration). Fig. 15 shows that for an investment value of EUR 80,000, with an annual saving of EUR 12,000 and an interest rate of 8%, a total of 9 years is required to repay the investment.

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$self.UNIN_210 = log10 (1 - ($self.UNIN_201 / $self.UNIN_202
    * $self.UNIN_203 / 100))
    / log10 (1 - $self.UNIN_203 / 100)
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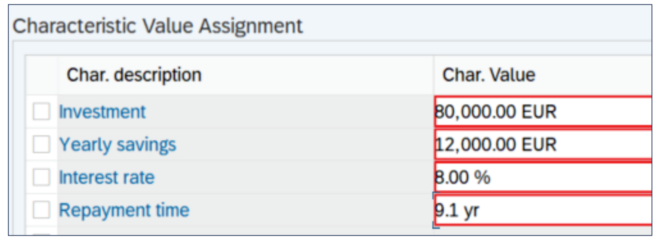
Figure 14 Formula for calculating repayment time



Characteristic Value Assignment

Char. description	Char. Value
Investment	80,000.00 EUR
Yearly savings	12,000.00 EUR
Interest rate	8.00 %
Repayment time	9.1 yr

Figure 15 Simulation calculation of investment repayment time

In general, the longer the pump would run in reduced flow mode, the annual savings would increase and the repayment time would be shortened.

4 CONCLUSION

This paper presents the current state of research in the field of possible applications of ERP models for the purpose of rough technical calculations and analyzes. The goal of creating an ERP model is to enable managers as natural users of the ERP system to more easily access the key data needed for quick decision making. In this step of the research, it was shown that with the help of a well prepared ERP model, managers can easily get a static analysis of electric drives, with an emphasis on possible savings in the case of variable frequency drives.

An electric drive with an induction motor and a centrifugal pump is analyzed here, but a similar methodology can be applied to other systems, e.g. in monitoring the development and installation of advanced systems in electric vehicles.

The results of rough calculations using the ERP model provide data on different energy consumption depending on whether flow control by damping or speed change is used. Since, in general, all types of savings usually require additional investments, the ERP model also enables a rough calculation of the investment repayment time. All the important steps that need to be taken in order to prepare an ERP model are presented. In future work, it is possible to consider what effect would have failures in electric drives on Recovery of Investment.

The authors estimate that the whole process could be a great help to managers in considering existing alternatives in decision making.

Future work will be focused on further improvements of ERP model, making it even more easy to use by managers.

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