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# THE ENERGY MANAGEMENT SYSTEM ACCORDING TO THE NORM ISO 50001

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**Abstract:** The final paper presents an approach to solving the problem of optimal use of electrical energy in the production process. An analysis of all important parameters, limitations, and goals was performed, after which a mathematical model was created and used in writing Matlab code to solve the problems. It is the basis for further upgrading following the needs of each organization and because of that, it can be very significant.

**Keywords:** Energy management, MATLAB, ISO 50001

## INTRODUCTION

Today's civilization is dependent on the quality of energy supply, among which electrical energy stands out the most. It is a transitional form of energy between primary energy and useful forms of energy. Electrical energy is, with the help of electric machines, extremely easy to convert, into light, heat, chemicals, and many other forms. The advantages of using electrical energy are multiple - transport with minimal losses, high availability, and the fact that the use of electrical energy promotes sustainable development. Since the consumption of electrical energy is very intense in all forms of human activity, it is concluded that it represents a high cost and that there is a constant tendency to reduce it. The amount of used electrical energy varies during the day. Given that there is a constant demand for a balance of consumed and produced electrical energy in the electrical energy system (EES), consumers seek to motivate themselves to reduce their consumption during peak load through price increases. This way, the power system is relieved during peak demand, and the risk of failure is reduced as well as the possible need to build additional power plants that will cover the "peaks" in the daily load diagram. In addition to the problem reflected in the increasing costs due to the use of electrical energy, the problem of environmental pollution due to the intensive use of non-renewable energy sources is becoming more and more pronounced. The current situation indicates that it will remain so in the near future, i.e., until the area of renewable energy sources experiences more significant progress. Thus, in addition to saving money, the planned and conscientious use of electrical energy reduces the negative impact on the environment. More research and scientific work are dealing with ways to save resources through "smart" disposal of electrical energy in residential and catering facilities. The essence is reflected in the fact that the use of appliances that represent the largest consumers in such facilities is moved to a period of lower demand for electrical energy in the power system and thus saves money. Unlike residential and catering facilities where energy management is relatively simple, achieving the same savings in industrial plants is not an easy task given that it is necessary to meet all requirements related to the quantity and characteristics of products. The problem of survival of companies is known, especially small and medium enterprises, which in many cases go bankrupt in the first few years of existence, due to profitability problems caused by failures in energy planning and management. Achieving savings when it comes to the use of electrical energy, while complying with all existing conditions, is a major challenge that many organizations have not yet accepted. As a result of all these findings, the ISO 50001 standard was created, which deals with this issue. By applying this standard, organizations achieve efficient use of electrical energy and achieve great savings.

This work describes an approach to solving the problem of optimizing the use and management of electrical energy in a factory using the *Matlab* program, which can serve as a basis for many organizations in solving the same problem and planning to operate following ISO 50001.

## 1. ENERGY

World energy consumption is constantly growing - it has doubled in the last 40 years and is predicted to increase by about 1.3% per year by 2040, mainly due to increased demand in developing countries [1]. These facts point to the great importance of energy for the human population. In today's world, energy is one of the key factors for the successful operation of all organizations and, often, represents a very high cost regardless of activities. What this is all about can be seen if one considers the energy use of an organization, from the raw material procurement

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phase through the production process to the recycling phase. In addition to analysing energy consumption in detail, it is important to ensure that the whole process is environmentally and socially satisfactory due to the constant depletion of limited resources and new problems, most notably noticeable climate change. About 85% of total energy consumption comes from coal, oil, and natural gas, which raises concerns about greenhouse gas emissions and fossil fuel consumption. Figure 1 shows the share of individual primary energy sources in the supply of energy to the human population [2].

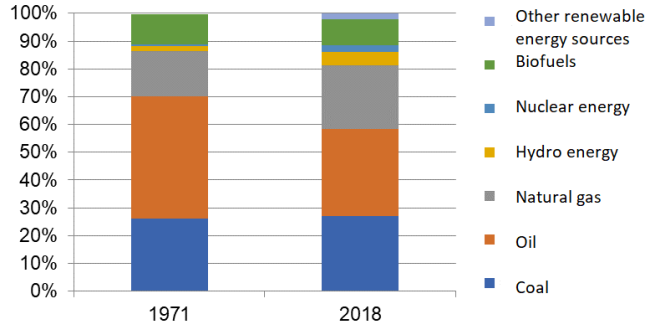



Figure 1: Graphic representation of the share of primary energy use

Individual organizations cannot control the price of energy, government policy, or the global economy, but they can improve the way they, here and now, manage energy. Improved energy performance can bring greater benefits to organizations by maximizing the use of their energy sources and energy assets, thereby reducing both production costs and energy consumption.

By acting to better manage energy consumption, a healthier and more beautiful environment is achieved, saving money for organizations and society as a whole. A study by the *ClimateWorks Foundation*, a non-governmental organization that uses the power of collective philanthropy to fight climate change, found that doing more to improve energy efficiency and reduce carbon emissions in the industrial and construction sectors alone could save annual money of about $ 3,2 billion [3].

### 1.1. Electrical energy

Electrical energy is a form of energy without which it is impossible to imagine today's life. Over time, it has become one of the crucial factors for a normal life, and its importance for the further progress of human civilization is indisputable. This suggests that the efficient use of electrical energy inevitably leads to large savings and that developing a strategy in this field is extremely important. Figure 2 graphically shows the current share of individual energy sources in generating electrical energy as well as the projection based on the current situation [4]. A significant amount of electrical energy is generated from coal, gas, and oil, which is not a positive indicator from the point of view of sustainable development.

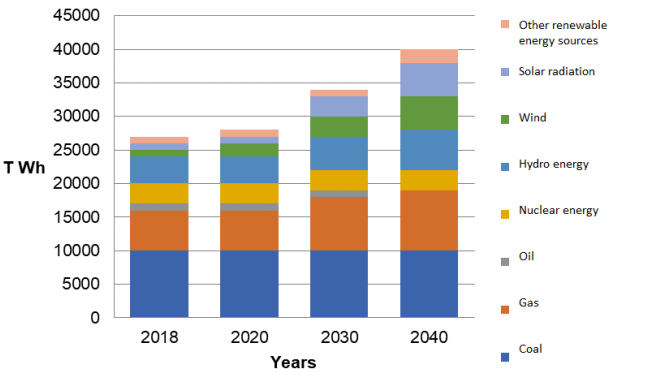



Figure 2: Graphic representation of the share of energy sources in generating electrical energy

Electrical energy is a transitional form of energy that is difficult to accumulate. As a result, many complex infrastructures have been installed to meet electrical energy needs and avoid the risk of power outages in the grid during peak demand. Investments in the grid will increase due to the inevitable need for power plants that will produce electrical energy in periods of greatest demand as well as all associated equipment. However, 10% of energy supply capacity will be used for only a few hundred hours per year, which is from 1% to 2% per year [5]. Thus, balancing demand and supply only on the supply side is not economically meaningful. Alternatively, demand-side management could improve the energy efficiency of the system and reduce the overall cost of maintaining the balance of supply and demand by encouraging consumers to modify the electrical energy consumption model. Consumer motivation is achieved by increasing the price of electrical energy during the peak load of the power system and reducing the price during low demand. Thus, consumers can "move" their use of electrical energy from a period of high prices to a period of low prices to reduce electrical energy costs. As a result, consumer costs and peak grid load can be reduced. The residential, commercial, and industrial sectors account for one-third of the market's electrical energy consumption. However, most research on the interaction between consumer behaviour and the market price has focused on reducing the cost of electrical energy in residential or commercial buildings by optimizing the schedule of appliances where possible [6]. Significantly less research work is based on production facilities because the schedule of production and consumption of electrical energy in factories is much more complex than in residential and commercial buildings. In production facilities, the number of products must be met, and tasks must not be interrupted at random, which makes planning very challenging. Furthermore, the infrastructure of today's electrical system is aging, which makes it difficult to meet even greater demand for electrical energy. Environmental issues, such as climate change, ozone depletion, the problem of

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"acid rain" and the depletion of non-renewable energy sources, should be considered when updating today's power system. As a result, a smart grid is emerging as a more intelligent, reliable, stable, and secure power system that will integrate electrical energy generated by renewable energy sources into the entire power system. This system will be able to meet environmental goals and respond quickly to growing demands for electrical energy generation and end-user electrical energy supply in a more efficient way. One of the key features of a smart grid is demand-side management. For example, smart meters have been installed to exchange data on electrical energy prices and electrical energy demand. As a result, consumers can be more informed when deciding on the use of electrical energy and can reduce their consumption during peak hours and redirect their demand to the rest of the day. As electrical distribution systems move towards a smart grid structure, these dynamic interactions between the behaviour of production plants and the price market led to the obvious need for detailed and constant planning of production in plants in case of additional savings. Therefore, the problem of production planning in a smart grid scenario consists of two aspects:

- optimizing production schedules based on time-varying electrical energy prices and
- changes in energy consumption in factories without their mutual communication can significantly change the market price of electrical energy compared to the assumed and create a counter-effect.

The first aspect will be described in detail and discussed in this undergraduate task. Getting involved in the whole optimization process brings additional challenges, but it also opens the opportunity for companies to achieve even greater savings on electrical energy costs.

## 2. INTERNATIONAL STANDARDIZATION ORGANIZATION

The International Organization for Standardization (ISO) is an international standard-setting body composed of 165 representatives of national standardization bodies. It was founded because of the agreement of 65 delegates from 25 countries. At the very beginning, it consisted of 67 committees representing groups of experts in the same fields [7]. ISO standards are the result of a consensus of experts in various fields who support innovation and offer solutions to global challenges. They cover and regulate many activities - product development, process management, service provision, and material delivery. Each of the standards is the result of thorough research by scientists with extensive experience, set to optimally meet the needs of manufacturers, retailers, customers, trade associations, users, or regulators. Several standards can be classified into several groups:

- quality management standards for more efficient operation and reduction of product failures.
- environmental management standards that help reduce environmental impact, reduce the amount of waste generated and promote sustainable development;
- health and safety standards that help reduce accidents at work;
- energy management standards to reduce energy consumption;
- food safety standards that help prevent food contamination and
- IT security standards that help protect sensitive information [7].

### 2.1. Energy management standard - ISO 50001

As a result of all the knowledge about the importance of electrical energy and its "smart" management, the ISO 50001 standard was created, which is based on the model of management systems adopted and implemented by organizations around the world. The standard can make a positive contribution to organizations of all kinds in the near future while at the same time supporting long-term efforts to improve energy technology. ISO 50001, Energy Management Systems - Requirements with guidance for use (ISO 50001) is an international standard developed by the International Organization for Standardization (ISO) at the request of the United Nations Industrial Development Organization (UNIDO). This standard provides organizations with requirements for Energy Management Systems (EMS). This facilitates integrating energy management into their overall efforts to improve quality and environmental management. This standard is of particular importance to organizations around the world because it is based on good management practices in manufacturing, business, and service institutions to meet stakeholder requirements, prevent risks and achieve strategic approaches to value creation, energy efficiency, and sustainable development. An energy management system helps organizations to better manage energy consumption, which brings improved productivity as a result. This includes developing and implementing energy policy, setting achievable energy use targets, devising action plans to achieve them, and measuring progress. This may include the implementation of new energy-efficient technologies, reducing energy waste, or improving ongoing processes to reduce energy costs. ISO 50001 recognized organizations as a framework for developing an efficient energy management system. Like other ISO management system standards, it follows a *"Plan-Do-Check-Act"* improvement process. *The Plan-Do-Check-Act* (PDCA) is an iterative, four-step approach to continuously improve processes, products, or services and solve problems [8]. This includes systematic testing of possible solutions, evaluation of results, and implementation of those that are shown to work. Figure 3 illustrates the PDCA approach [9].

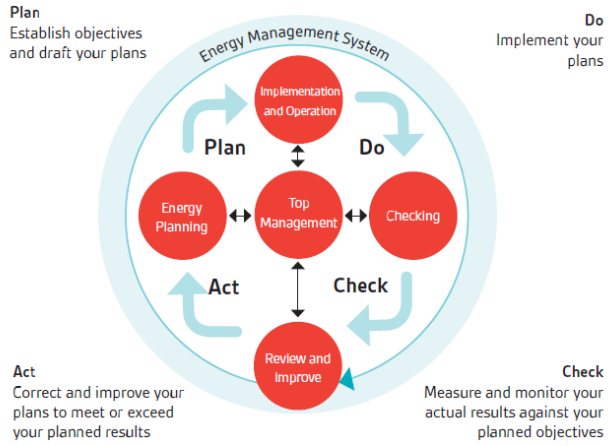



Figure 3: Illustration of the PDCA approach

ISO 50001 provides a set of requirements that enable organizations to:

- develop their policy for more efficient use of energy;
- set targets in line with that policy;
- collect data to better understand and make decisions about energy use;
- measure and analyse the obtained results;
- determine the degree of policy effectiveness and
- continuously improve energy management.

ISO 50001 is designed to help an organization improve its energy performance through better utilization of its energy resources. Improved energy performance can quickly provide benefits to an organization by maximizing energy use and related assets, reducing both costs and consumption. The advantage of this standard is that it brings many benefits to both small and large organizations, both from the public and private sectors involved in the production and provision of services in all regions of the world. It establishes a solid energy management framework for industrial plants, commercial, institutional, and government facilities, and entire organizations. It is characterized by wide applicability in national economic sectors. There are many benefits of applying this standard - reducing environmental impact, improving concreteness and reputation, reducing costs... It is estimated that this standard can affect more than 60% of energy needs worldwide, given that this percentage is part of energy at the global level used in the commercial and industrial sectors [10].

## 3. PRODUCTION PROCESS OPTIMIZATION

The following is a concrete example of optimizing the production process by modifying the production schedule of individual intermediate products, respecting all the requirements. In this way, the company will significantly reduce the costs incurred due to the use of electrical energy and contribute to the relief of the power system during peak load, since then the price is the highest.

Since the essence of the ISO 50001 standard is based on the PDCA approach, the following example shows how to achieve optimal plans that are the basis for all further actions that need to be taken for the purpose of accreditation and re-accreditation for the said ISO standard.

### 3.1. Problem description

We consider a production process consisting of two phases, or two machines ($S_1$ and $S_2$) where each machine can produce three different intermediates $s_{11}$, $s_{12}$ i $s_{13}$ or that is $s_{21}$, $s_{22}$ and $s_{23}$. One machine can produce only one intermediate product at a time. Also, with each machine, the production speed of individual intermediate products can be regulated in a certain range, which directly affects the total energy consumed. The optimization period consists of $N$ time steps. At the end of the $k$-th step, the number of intermediates must be at least $s_{i,j}(k) \geq \bar{s}_{i,j}(k)$, $i=\{1,2\}, j=\{1,2,3\}$, $k=\{1,2,\ldots,N\}$, where $\bar{s}_{i,j}(k)$ represents the required amount of intermediate $j$ produced by the machine $i$ at the end of the $k$-th step of the optimization process.

#### 3.1.1. Dynamic model of the production process

The amount of product at the output of individual machines can be described by the following dynamic model:

$$\begin{bmatrix} x_{11}(k+1) \\ x_{12}(k+1) \\ x_{13}(k+1) \end{bmatrix} = \begin{bmatrix} x_{11}(k) \\ x_{12}(k) \\ x_{13}(k) \end{bmatrix} + \begin{bmatrix} v_{11} \cdot w_{11}(k) \\ v_{12} \cdot w_{12}(k) \\ v_{13} \cdot w_{13}(k) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} x_{21}(k+1) \\ x_{22}(k+1) \\ x_{23}(k+1) \end{bmatrix} = \begin{bmatrix} x_{21}(k) \\ x_{22}(k) \\ x_{23}(k) \end{bmatrix} + \begin{bmatrix} v_{11} \cdot w_{11}(k) \\ v_{12} \cdot w_{12}(k) \\ v_{13} \cdot w_{13}(k) \end{bmatrix} \quad (2)$$

where $v_{1,j}$ and $v_{2,j}$ are standardized speeds of individual machines, and $w_{1,j}$ and $w_{2,j}$ are logical variables (values 0 or 1) that determine which intermediate product is produced at some point. Relevant variables in the optimization process are $v_{1,j}$ and $v_{2,j}$ and $w_{1,j}$ and $w_{2,j}$.

#### 3.1.2. Limitations of the production process

As the fact is that the machine can only produce one intermediate product at a time, the following limitation obviously applies:

$$w_{11}(k) + w_{12}(k) + w_{13}(k) = 1 \quad (3)$$

$$w_{21}(k) + w_{22}(k) + w_{23}(k) = 1 \quad (4)$$

Standardized production speeds of individual intermediate products may vary between the minimum and maximum value:

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$$\underline{v}_{1,j} \le v_{1,j}(k) \le \bar{v}_{1,j} \tag{5}$$

$$\underline{v}_{2,j} \le v_{2,j}(k) \le \bar{v}_{2,j} \tag{6}$$

Standardized production speeds of individual intermediate products may vary between the minimum and maximum value:

$$m_1 \le x_{1,j}(k) \le M_1 \ , m_1 = 0; \tag{7}$$

$$m_2 \le x_{2,j}(k) \le M_2 \ , m_2 = 0;$$

$$j = \{1,2,3\} _ k = \{1,2,...,N\} \tag{8}$$

It will be assumed that the energy consumed depends on the speed of the machines $f_1(v_{1,j})$ and $f_2(v_{2,j})$ which depends on the machine itself and can be, for example, square, linear or some other shape. Finally, it will be assumed that the price of energy during the day is not constant, but its value is predetermined on an hourly basis as $c(k)$; $k=\{1,2,\ldots,N\}$.

### 3.1.3. Optimization problem

The goal of the optimization process is to find the sequence of machine speeds $v_{1,j}$ and $v_{2,j}$ and logical variables $w_{1,j}$ and $w_{2,j}$, which determine which intermediate product is produced at some point while satisfying all the above limitations of the production process and at the end of the optimization process to produce the required amount of intermediate product while consuming a minimum amount of electrical energy or achieving the most economically efficient production.

$$\min_{v_{i,j},w_{i,j}} f_1(v_{1,j}) + f_2(v_{2,j}) \tag{9}$$

The schematic diagram of the optimization procedure is shown in Figure 4.

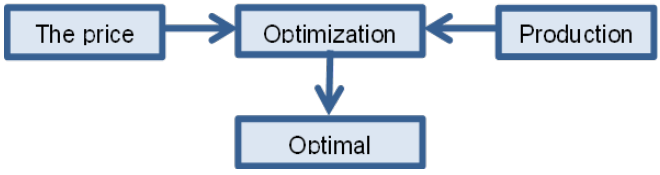



Figure 4: Schematic diagram of the optimisation procedure

### 3.2. Simulation of the optimization process - an example

For the described example of the production process, a numerical simulation and optimization will be performed in the *Matlab software environment* using *Yalmip* optimization modelling language.

The optimization was performed with the following parameters of minimum and maximum normalized machine speeds:

$$\underline{v}_{1,j} = 0, \bar{v}_{1,j} = 10, \underline{v}_{1,j} = 0, \bar{v}_{1,j} = 4; j = \{1,2,3\}$$

The normalized speeds of the machines represent the number of intermediates produced per one step of the optimization period, which, further, directly affects the actual speed of rotation of the machines. Furthermore, the requirements for the quantities of intermediates are defined for the end of the optimisation period (24h) and for half of the period (12h).

$$x_1(24) = [5 \quad 5.5 \quad 6]^T, x_2(24) = [2.5 \quad 3 \quad 3.5]^T$$

$$x_1(12) = [3 \quad 3.2 \quad 4]^T, x_2(12) = [1.5 \quad 1.7 \quad 2]^T$$

The minimum and maximum number of intermediate products after any step of the optimization period are:

$$m_1 = 0, M_1 = 10$$

$$m_2 = 0, M_2 = 4$$

Table I shows the standardized electrical energy prices through the optimization period:

Table I: Normalized electrical energy prices through the optimization period

| Step | Price | Step | Price |
|---|---|---|---|
| 1 | 1 | 13 | 1.2 |
| 2 | 1 | 14 | 1 |
| 3 | 1 | 15 | 1 |
| 4 | 1 | 16 | 1 |
| 5 | 0.8 | 17 | 1 |
| 6 | 0.8 | 18 | 0.5 |
| 7 | 0.8 | 19 | 0.5 |
| 8 | 0.8 | 20 | 1 |
| 9 | 0.8 | 21 | 1 |
| 10 | 1.2 | 22 | 1 |
| 11 | 1.2 | 23 | 1 |
| 12 | 1.2 | 24 | 1 |

Thus, the matrix $c$ describing the price of electrical energy is defined as follows:

$$c = [1 \ 1 \ 1 \ 1 \ 0.8 \ 0.8 \ 0.8 \ 0.8 \ 0.8 \ 1.2 \ 1.2 \ 1.2 \ 1.2 \ 1 \ 1 \ 1 \ 1 \ 0.5 \ 0.5 \ 1 \ 1 \ 1 \ 1 \ 1]$$

The criterion function is defined as:

$$f(v_1, v_2, w_1, w_2) = \sum_{i=1}^{23} \left(c(i)v_1(i) + (i)v_2(i)\right) + \alpha \sum_{i=1}^{23} \left(w_1(i) - w(i-1)\right) \tag{10}$$

where is $\alpha = 0.6$. Another member in the criterion function was introduced to minimize the number of intermediate product changes during the optimization period.

### 3.2.1. Simulation results

Figure 5 and Figure 6 show the changes in the amount of intermediate products $x_1$ and $x_2$ at the end of each step of the optimization period. The dashed lines show the required amount of each intermediate in the middle and end of the optimization process, while the solid line describes the change in quantity. All quantity requirements have been fully met and that the production process has been optimized without reducing efficiency and endangering end customers.

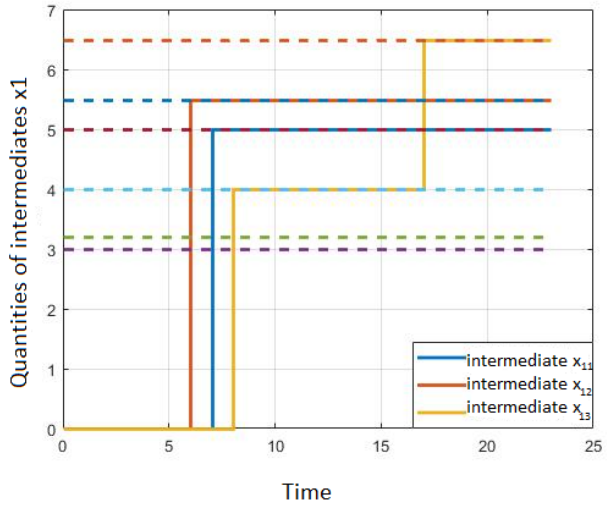



Figure 5: Quantities of intermediates $x_1$

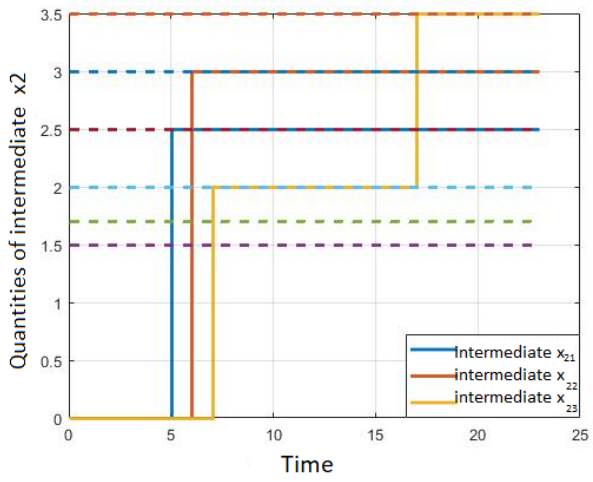



Figure 6: Quantities of intermediates $x_2$

Figure 7 shows the machine speeds $S_1$ also $S_2$ during the optimization period. Comparing the speeds of the machines with the quantities of intermediates at the end of each step shown in Figure 5 and Figure 6, a clear connection between them is visible - the speed of the machine during the step determines the number of intermediates produced at the end of the same step. So, in the sixth step, the standardized speed of the machine is equal to 6, which means that at the end of the sixth step, the amount of one of the intermediates will be equal to the number six, which is true. The standard speed of machines directly determines the actual speed of rotation of machines on which the current power of the machine or the amount of electrical energy consumed depends. What has also been achieved with this production plan is that each machine runs in two longer intervals instead of several shorter intervals. This fact brings additional savings due to higher power consumption when starting the machine, but also saves the time required to change the mode of operation of the machines.

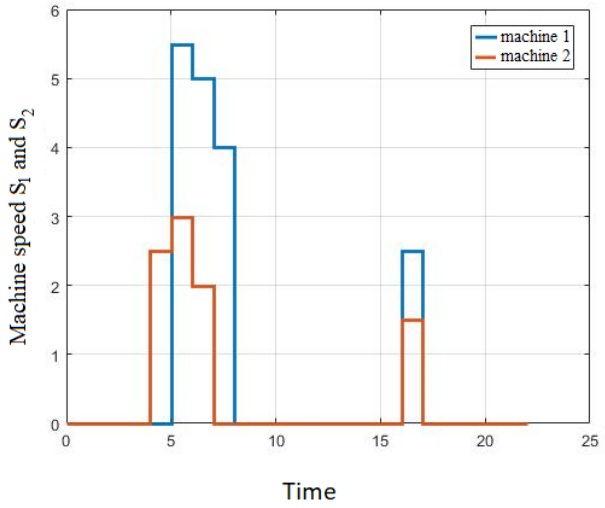



Figure 7: Machine speed $S_1$ and $S_2$

Figure 8 and Figure 9 show the fact that the restrictions given by expressions (3) and (4) are met, as well as the requirement for a minimum transition from one to another mode of operation, that is the method of production characteristic of each intermediate product.

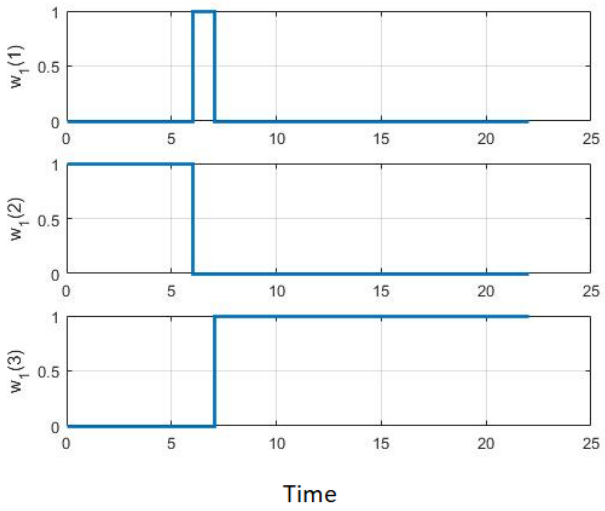



Figure 8: Plan of production of intermediate products on the machine $S_1$

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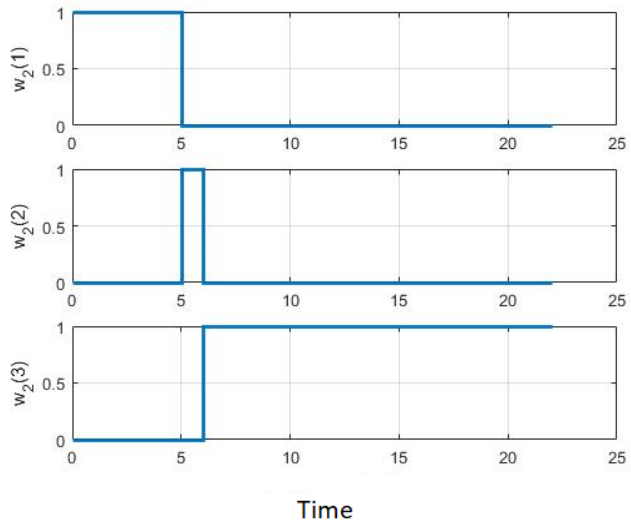



Figure 9: Machine intermediate production plan $S_2$

### 3.2.2. Optimization process with additional limitations

Since the model of the production process and production plant described above is extremely simple, an additional limitation is added regarding the difference in the number of intermediate products between successive steps of the optimization process. A requirement is introduced that the difference in the amount of intermediate at the end of successive steps of the optimization period must be equal to 0.5 and 1 and 0 in case the machine did not produce this intermediate as it describes the real possibilities of most machines. So, it can be written:

$$\left(x_{1,j}(k+1)-x_{1,j}(k)=1\right)\vee\left(x_{1,j}(k+1)-x_{1,j}(k)=0.5\right)$$
$$\vee \qquad (11)$$
$$\left(x_{1,j}(k+1)-x_{1,j}(k)=0\right), j=\{1,2,3\}_k=\{1,2,...,N\}$$

The results of the optimization process with an additional limitation are presented below. Figure 10 and Figure 11 show the fact that the requirement of permissible differences in the number of intermediate products of individual machines has been met. Between every two consecutive steps the difference, if any, is equal to 1 or 0.5.

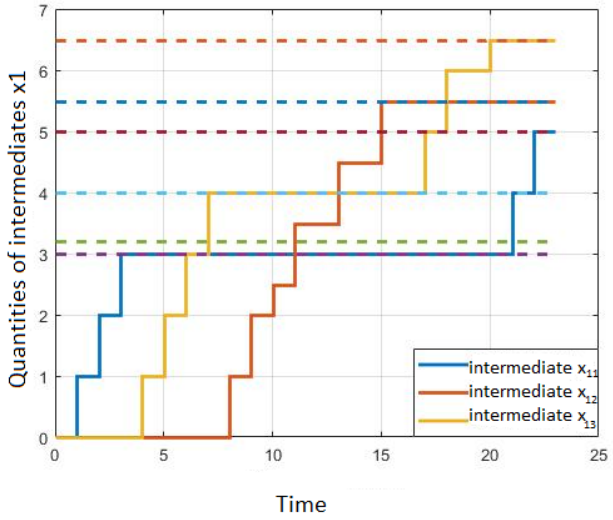



Figure 10: Quantities of intermediates $x_1$

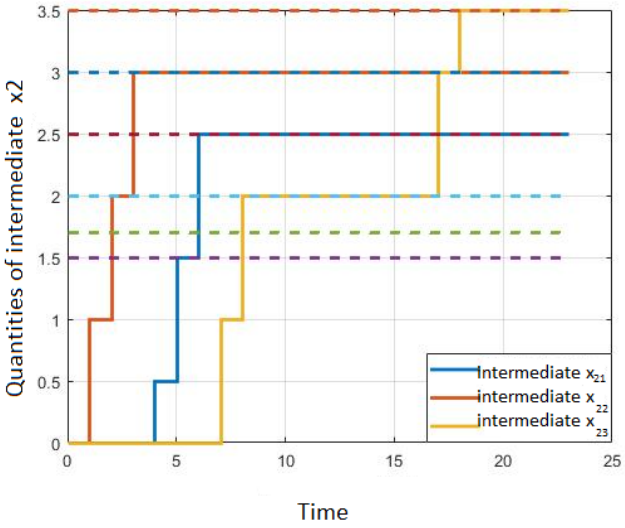



Figure 11: Quantities of intermediates $x_2$

Figure 12 shows the standardized speeds of the machines, which, of course, are always equal to 0, 0.5 and 1.

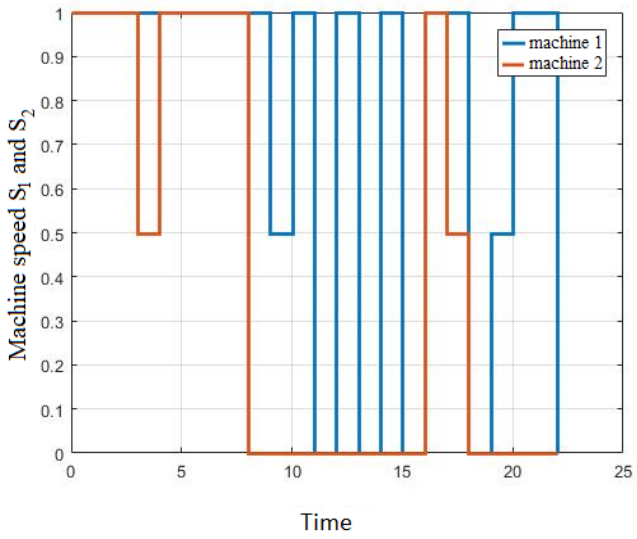



Figure 12: Machine speed $S_1$ and $S_2$

As in the previous case, the requirements regarding the fact that each of the machines can produce only one intermediate product at a time were met, as shown on Figure 13 and Figure 14.

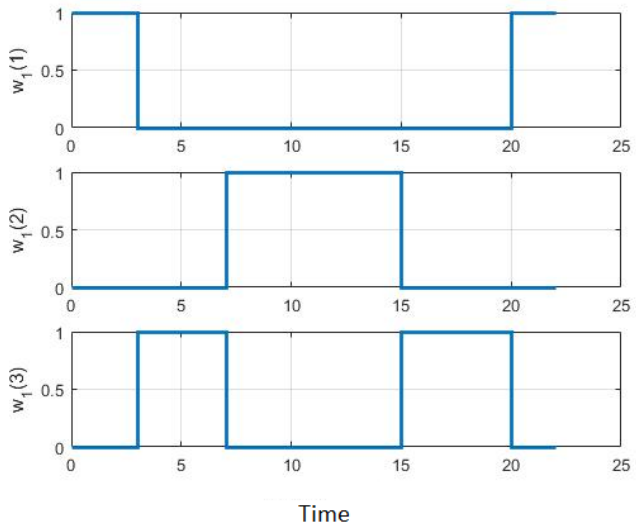



Figure 13: Machine intermediate production plan $S_1$

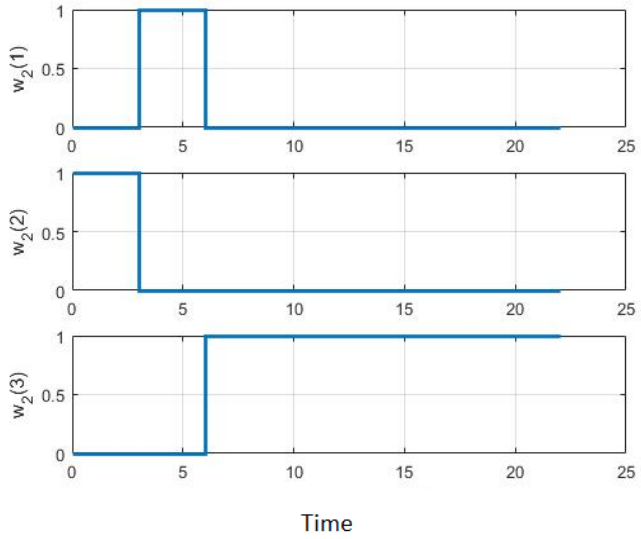



Figure 14: Plan of production of intermediate products on the machine $S_2$

It is evident that by slightly upgrading and complicating the models and limitations of the production process, results are obtained that seem much closer to reality and the opportunities that would occur in a production facility. This is a simple demonstration of how a quality knowledge of the opportunities in the production plant very quickly and easily leads to the creation of a model that can and should serve as a basis for planning and implementation of production and general operations of the company.

### 3.3. Applying the production model in practice

The following model of the production process shown through *Matlab* at any organization can achieve significant savings. It is a basis that can be upgraded according to the needs of the organization to best describe the appropriate processes specific to individual factories. One of the possible problems of this mode of operation is that, if all or most factories located close to each other start to apply this model of production, they lead to "shifting" the period of maximum electrical energy consumption to those parts of the day that were previously characterized by lowest consumption. Thus, the previous periods of lower electrical energy prices would become the opposite and factories would incur higher costs than was the case before the application of the shown mode of operation and production. This potential problem is elaborated on and described in the paper *Flow Shop Scheduling for Energy Efficient Manufacturing* by Hao Zhang. The foundation of everyone, including this solution, is reflected in quality communication. Communication and good cooperation between electrical energy suppliers and factories as consumers can be mutually beneficial. At the end of each time interval of a predetermined length, the supplier would inform the consumer about the situation in the electrical energy market and the current price. In this way, the company could "postpone" its consumption to periods when there will be less electrical energy consumption and achieve savings and contribute to the relief of the power system in times of greatest demand. This model of interaction is characteristic of *smart* grids, which will become a reality in the near future. Another form of communication is the exchange of information with nearby companies. By sharing constantly updated information on electrical energy use, they avoid the risk of the already mentioned "shift" of the peak demand period and the consequent increase in expenditure.

## 4. CONCLUSION

Planning and "smart" energy management is the basis for the successful and rapid development of companies in the industrial sector. By applying the ISO 50001 standard, the possibility of great savings due to the use of electrical energy is realized, the harmful impact on the environment is reduced and it facilitates easier management of the power system.

The presented simplified production model provides a quality understanding of the optimization problem that almost all companies face and is the basis for further improvement and complexity in accordance with the specifications of each of the production facilities. It represents the first and basic phase of the PDCA approach, and that is planning.

After implementing the plan and achieving the set goals, the organization has the opportunity to invest the saved financial resources in expanding the business area, purchasing new equipment that has a higher level of energy efficiency, increasing employee salaries, or using them in any other way that it believes will contribute to the progress and even greater success.

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