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ENERGY MANAGEMENT IN INDUSTRIAL MICROGRID IN MARKET CONDITION

UPRAVLJANJE ENERGIJOM U INDUSTRIJSKIM MIKROMREŽAMA U TRŽIŠNIM UVJETIMA

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Abstract: The paper deals with the problems of Energy Management in industrial plants through the prism of new opportunities created by introducing the electricity market and the new concept of Smart Grid. The Introduction gives an emphasis to the importance of electrical power generation in Industrial environment. In continuation of the article, an overview of the properties of industrial microgrid as a unique entity of the energy in a power system is given. The third chapter shares an overview of the electricity market as an introduction to the analysis of the energy management possibilities in industry. The analysis of the concept of energy management with emphasis on application in industrial environments is presented in the fourth chapter. Special attention is given to Electricity Demand Management and the selection of appropriate strategies for Energy Management in the industrial plants.

Keywords: Load Management, Electricity Market, Industrial Microgrid

Sažetak: U radu je obrađena problematika upravljanja energijom u industrijskim postrojenjima u svjetlu novih prilika nastalih uvođenjem tržišta električne energije, te novog koncepta naprednih mreža. Uvod daje naglasak na važnost električne energije u industrijskoj proizvodnji. U nastavku je dan pregled svojstava industrijske mikromreže kao zasebnog energetskog entiteta u elektroenergetskom sustavu. U trećem poglavlju napravljen je pregled tržišta električnom energijom kao uvod u razmatranje mogućnosti upravljanja energijom u industriji. Raščlamba pojma upravljanja energijom s naglaskom na primjeni u industrijskom okruženju dana je u četvrtom poglavlju. Posebna pozornost u radu je dana upravljanju potražnjom za električnom energijom, te odabiru adekvatne strategije za upravljanje energijom u industrijskom postrojenju.

Ključne riječi: upravljanje energijom, tržište električne energije, industrijske mikro mreže

INTRODUCTION

Planning the use of energy for the industrial needs gains an additional dimension through development of free energy market. It is seen through new opportunities, but also new risks. Energy management can be defined as the group of activities related to procurement, supply from the market, i.e. managing of own generation resources and load management. Supply with electricity (buying at the market or generation in own facilities) for the needs of industrial production has a different framework of implementation in comparison to service sectors. Seen from the viewpoint of energy consumption, industrial environment differs from the public sector mainly in the following:

- large number of different forms of energy,
- demands for quality (reliability of supply)[1],
- added value (energy is raw material with a large added value in relation to the market).

[1] These demands are frequently higher than the level of quality offered by a public supplier.

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When we talking about the added value of energy in industry, the most important concept is the quality of energy. Industrial facilities are often equipped with own systems for generation of useful energy forms due to the fact that the demands for increased quality of energy are sometimes not possible to be satisfied from the grid of the public supply, i.e. distribution grid. Energy needs of a technological process are most frequently heat (cooling or heating) or mechanical work.

Thermal processes are the most frequently used forms to transfer a primary form of energy into mechanical work or electricity. Due to the very nature of thermal engines, only some 20% to 50% of primary energy can be utilised, while the remains are emitted into the environment. If, nonetheless, two different forms of energy (heat, electricity) are simultaneously used from the same process, then we talk about co-generation. Industrial environment is a good example of application of co-generation. In addition to a more efficient utilisation of primary energy source, the industry is a good environment for implementation of the use of energy source in the remains of the industrial production. This utilisation of the available energy, should it be economically justified, yields a significant benefit,

which gains its importance only in market conditions. Development of the market of energy sources brings new challenges and **risks** before the process of planning energy sources in industry. Optimisation of energy resources in industrial environment and managing production up to a certain level can provide for management of the given risks.

1. INDUSTRIAL MICROGRIDS

Independent energy source entities named **industrial microgrids** emerge in industrial environments from the application of advanced methods of networking of electric-power and information-communication technologies (advanced networks, [1]). Basic scheme of (industrial) microgrid is given in Figure 1.

Possible benefits from introduction of industrial microgrids are the following:

- savings due to local generation of heath,
- energy utilisation of leftovers from the process, such as:
  - waste heat from drying processes,
  - heath emerging in exothermic reactions,
  - mechanic energy available for relaxation of compressed medium, as a part of technological process,
  - material leftovers from processes (e.g. gasses rich with hydrogen, being by-product from sugar refinery, dry matter from wood or other herbal matter processing),

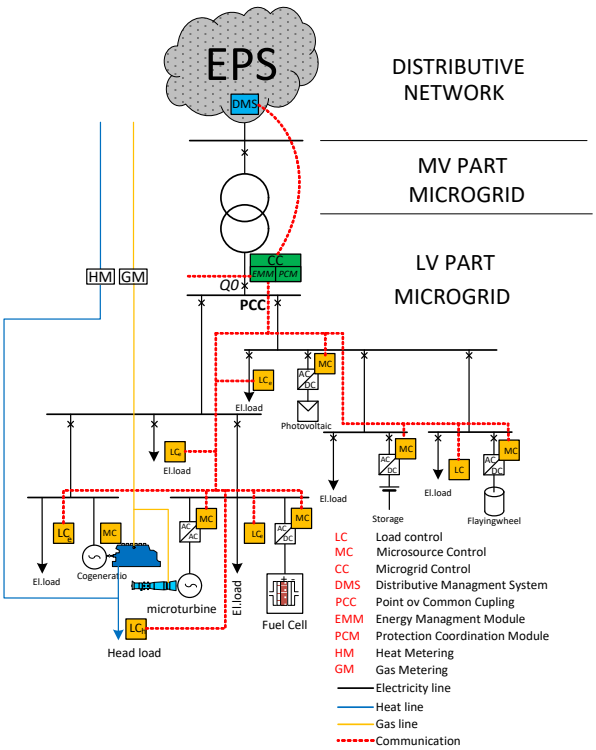


Figure 1: Basic scheme of a microgrid

- savings from non-engagement of labour force,
- savings from avoiding spending of reactive energy,
- possibilities to manage consumption („Demand Side Management“ - DSM)[2],
- decrease of costs of the emission by use of renewable sources and storing of energy.

When creating microgrids, one should primarily have in mind the specificities of an industrial environment, such as [2]:

- facilities are often located in rural areas,
- they are frequently connected to a weak distribution grid,
- they have a large, but predictable energy consumption,
- large demands for availability and quality of supply,
- relatively small number of manageable energy users,

Furthermore, when analysing the possible implementation of the concept of advance networks, the following facts need to be taken into consideration:

- making profit from sale of products or product-related services is a primary mission,
- owners of industrial facilities are not primarily interested in doing business in the energy sector,
- energy supply is subordinated to process technology,
- electricity is only one of the resources used for the needs of production (often the non-dominating one),
- energy in industrial facilities are an integral part of the future product, i.e. energy presents **raw material**,
- industrial facilities are large consumers of labour and reactive energy with low load factor (P_{max}/P_{sr}),
- quality of electricity and safety of supply are the key demands for industrial microgrid,
- system of management of industrial microgrid is subordinated to at least two management systems: system of management of industrial facility and system of management of distribution grid (DMS),
- optimising the architecture and work of an industrial microgrid is a multi-criteria, stochastic problem.

2. ELECTRICITY MARKET - SOME ASPECTS OF KEY IMPORTANCE FOR INDUSTRY

Fundamental premise at the energy market is that the electricity is the good for trading at a specific time. Nonetheless, electricity is an “easily perishable” good which has to be delivered at a precise time, otherwise it loses its value, and, moreover, it creates damages. Maintaining balance between generation (distribution) and consump-

[2] This is one of important components of advanced networks, which is increasingly applicable in industrial environments [3];

tion is important for delivery of this type of goods. Market mechanism are useful because they inherently encourage the flow of capital, decrease of prices and development of competition, which is beyond the obsolete monopolistic mechanisms. Still, market mechanisms are like fire: if they are subjected to adequate control, they bring profit; otherwise they can cause more damage. Market mechanisms cannot ensure physical stability and balance. Technical and regulatory mechanisms have that task.
Observing the electricity market through the prism of trading, the following particularities need to be emphasised:

- trade is done with goods for which origin and quality cannot be determined at the time of trade,
- trade is actually done with the **commitments** to deliver and receive,
- there is no refund, but the financial system of settling the claims is precisely developed,
- time constant of market mechanism is longer than the time constant of a physical system.

Electricity market is made by a few compatible, mutually supporting markets, since the complexity of electricity supply cannot be covered by one market; there are service trade, corrective balancing of markets, long-term energy markets.

As a precondition to introduction of electricity market, traditionally vertically organised companies, as the sole bearers of all activities in generation, transmission, distribution and supply of power, had to separate market from monopolistic activities. We differentiate two platforms for electricity trade in the Republic of Croatia: service of public supply of tariff buyers, and free electricity market (wholesale and retail). Functions of transmission, distribution and supply of tariff buyers are **regulated activities**, while generation, trade and supply of privileged buyers **are market activities**.

Electricity market in the Republic of Croatia was made fully open on the 1st of July 2008, meaning that, since that date, all buyers have the legal right to choose their own electricity provider. Turning point in opening of the market is when the buyers have the right to freely select the supplier to purchase electricity from. Bilateral market model was chosen in the Republic of Croatia. Such a model lies at electricity **supply contracts** (by which the buyers buy electricity from suppliers) and **sale contract** by which the buyers and distributors buy electricity from producers or traders.

In addition to the above contracts, producers and buyers must contract the right to use of grid infrastructure used for the electricity to enter the system or to be taken from it. Grid infrastructure is a natural monopoly and the activity of conduction through distribution system is regulated by a rulebook, while the costs of the use of the grid are publicly known. Since 2015, electricity exchange market was founded in the Republic of Croatia, CROPEX, where the service of anonymous trading is provided between the market members through information system. Trading of electricity is regulated by Market Rules [4] and the Law on Electricity Market [5].

2.1. Participants and types of electricity markets

Participants of the electricity market, i.e. those who trade directly at the wholesale market, are the following: producers, traders, distributors, system operators and electricity exchange market. In addition to the wholesale market, there is retail market with participation of distributors and buyers. The freedom to choose a distributor is the most important (and currently the only) act of participation at the free market. Depending on a distributor and category to which they belong, the majority of buyers does not feel the variation of prices on daily basis. The price paid by the end buyers is defined through the contract in an obvious manner. A two-tariff system is applied in the Republic of Croatia. The overall risk of price change is borne by the distributor. Large buyers can participate at the wholesale market directly, but only if they are registered as distributors.

Due to its characteristics, the overall electricity trade can be divided into two groups: forward market and real time market. **Forward markets** are characterised by trading with time slots for delivery, or takeover in the future. Trading is done with commitments emerging in the future, after the day of purchase. Trading can be long-term, from several days, weeks or months in advance, or just a day in advance. Each day of trading is called the **trading day**, and trade is done with deliveries in certain time intervals (15-minute multiple events) on a precisely defined day (**day of delivery**). There are two ways of trading at the forward markets:

- **Centralised trading** done through a mediating, neutral institution, which facilitates joining of demand and supply. The most frequent form of it is the electricity stock exchange market trading. Members of the stock exchange (market participants) are trading at the market, after they have made a contract with the exchange about the conditions of trade. Sellers bid (sell) amounts of electricity **for which they guarantee** to be supplied to Power Electric System at the given time interval, (e.g. 150,000 kWh in the period from 10:15 to 10:30 on the 31st of May) at a given price. The price of electricity being bided depends on the costs of fuel, facility, maintenance and depreciation. Competitiveness leads to bidding of lower prices coming close to the marginal costs of production. The price at the centralised market is the price calculated as a section of a supply curve (border of acceptable maximum price at which the buyer is pre-

pared to buy a certain amount of energy), and curve of demand (border of acceptable minimum price by which the seller is prepared to sell electricity).

- **Bilateral trading** understands direct entering into sale contract between a seller and a buyer. Trading is done without a mediator and the price presents a business secret. This method is favourable for a long-term and mid-term trading, when large amounts of electricity are being traded (or commitments for supply). Supply of base load is mostly traded using the given market mechanisms.

Real time trading (Spot market) is the closest form of true market of electricity as goods[3]. Delivery follows immediately after the agreement on sale. Having in mind the character of electricity, spot market would be the closest form to the current market. Time constant of the market is limited by the technology of communication. By its nature, real time trading is a corrective market used for balancing between a real demand and planned supply (which have to be precise). Deviations occur due to various reasons. System operator must react to stimulus received from the system (e.g. announcement that a participant will not be able to fulfil the plan, sudden failures) in a way to obtain a certain amount of energy in a short period of time. Therefore, this market is a discriminatory one for those technologies that cannot react promptly (therefore, they are not present at this market). Spot market is characterised by large variations of prices which keep up with the majority of deviations to an extent.

There is no spot market as such in the Republic of Croatia. The system operator (OS) is responsible for balancing and they purchase energy for balancing through contracting of auxiliary services: one buyer (HOPS d.o.o.) and one seller (HEP Proizvodnja d.o.o.). Purchase of auxiliary service is a forward purchase more than real time purchase and cannot be seen as free market because there is not enough of competition present. Namely, the OS contracts the readiness of a producer for secondary or tertiary *P/f* regulation. Should there be a need, the OS to directly send automated or manual order for activation of reserve. Development of competition will lead to organisation of auxiliary services market where it will be possible to implement purchase of balancing energy. Balancing can also be implemented by purchase at specialised, open balancing market based on the same principles as those at the forward market. Such a market is named controlled spot market. Further development of the market can lead to emergence of efficient spot market where the participants of the market will be able to purchase energy they lack for fulfilment of their plans, by which they will avoid payment of large penalties for failed supply.

[3] True market would be the one where an agreement of supply would be made at the time of imbalance emerging, followed by the supply at the same time.

3. ENERGY MANAGEMENT IN THE INDUSTRY

Energy management in the industry is efficient, economical and sustainable use of energy for the purpose of industrial processes. Strategies for energy management in the industry have been developing in parallel with introduction of electricity and other energy source markets and development of Smart Grids. Energy management in the industry equally motivates both supply and consumption (of industrial facility, as a consumer).

From the position of PES, industrial consumers are relatively large individual and concentrated consumers of electricity and their impact to the PES stability is significant. On the other hand, consumption of electricity is a key component in a large number of industrial entities (e.g. production of paper and cellulose [6]). From the position of System Operator, energy management at the place of consumption (managing demand for electricity) provides an additional method for balancing between production and consumption of electricity. Traditional strategy of maintaining balance through **adjusting production to consumption** is expanded by a new paradigm of "adjusting consumption to production" (resulting from the overall evolution of PES). Possibility to impact the profile of consumption without disruption to the targeted effect (profitability from main activity) and making an additional profit in addition to it, is an attractive possibility for users of industrial facilities. Both aspects of the use of electricity in industry justify a rather large importance for implementation of energy management measures.

Having in mind the method of supply (from the public supply system, market purchase or own production), or the way of use, energy management in the industry can be viewed from two aspects: **supply management** (SM) and **demand side management** (DSM).
The link between the two terms can be seen in Figure 2.

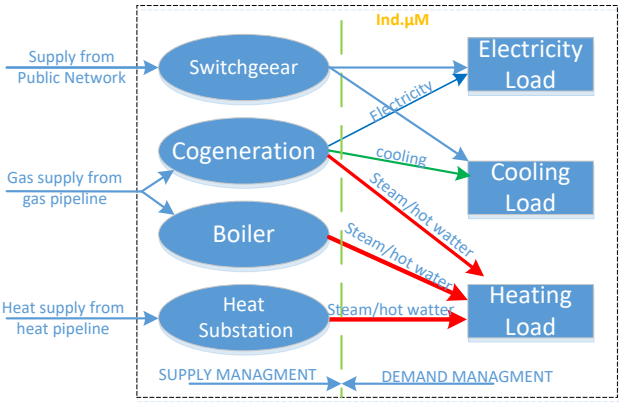


Figure 2: Energy management in industrial microgrid

Briefly: demand side management is related to consumption and supply management is related to production or procurement of energy. The problem of energy management is an optimising problem with stochastic variables

made out of several problems: problem of investment decision-making, problem of optimum size of facility, problem of optimum work strategy.

3.1. Supply management

Supply management understands management of energy procurement processes at the open market, production in own facilities or direct supply from producers. When talking about the industry from the aspect of energy supply, one should always consider multi-vector energy profile of consumption: electricity, thermal energy (in different forms), mechanical energy, cooling energy, etc.
Supply management can also be seen in the context of demand management, but the free market of energy sources opens the new possibilities for its users, so the process of contracting and procurement of energy combined with own production can additionally increase the income, i.e. increase the safety of facilities.
Supply management has two aspects:

- **market supply** understanding participation at the energy market through:
  - selection of suppliers,
  - participation at the market as a buyer,
  - participation at the service market,
- **independent supply** understanding production in own facilities.

Solving a long-term selection of strategy for supply (supplier selection, participation at the energy or service markets), and short-term operational strategy (nomination of load power, engagement of own sources), considering limitation of an industrial facility (order value, deadlines, delays, loss of production) generally presents a multi-criteria, stochastic, optimisation problem. This paper will not deal with supply management in detail.

3.2. Demand management

The term “demand management” has been used in literature for almost 40 years and it presents a group of all measures with the goal to decrease demand for electricity, and by that to decrease the consumption of electricity in the point of use. The term “demand” is equivalent to the power of load of consumers burdening the PES. Decreasing the load, or demand, does not necessarily mean the decrease of the total energy consumption in the given time frame. The literature uses the term “Demand Side Management”, (DSM), i.e. managing the demand at the place of using the electricity. According to [6], DSM includes many activities with the aim to impact and modify the way of using electricity in order to form a satisfactory profile for electricity consumption by the end user. The aim of DSM is to create an appropriate consumption profile to satisfy the needs of the buyer (not to lessen the purpose of use), i.e. to maintain productivity. Similarly, in [7], DSM is defined as a group of mutually linked flexible programmes providing a larger role to the end buyer in moving the demand for electricity in the period of higher load and the overall decrease of electricity consumption. In [8], it is simply stated that DSM includes **everything** that goes on at the side of electricity consumption: from change of traditional bulbs with compact, fluorescent lights up to sophisticated dynamic systems for consumption management.

Somewhat different definition of DSM is given in [9] where the responsibility for DSM is turned to the network operator. Therefore, the reference states that DSM is used only with the aim to decrease energy consumption and improve the overall efficiency in electricity consumption through implementation of different policies and procedures controlling the demand. DSM is usually a task of energy companies towards decrease or total elimination of peak load, which delays installation of new capacities and distribution structures. Usual DSM methods are: combination of high efficiency generation, decrease of peak load, distribution of peak load and operational procedures facilitating efficient electricity consumption.

Until recently, DSM was considered as simple decrease of peak load with users, i.e. levelling of the curve of consumption [6]. Nonetheless, after a while, a wider list of measures was introduced to the term, including overall decrease of consumption. Therefore, it is said that DSM has two key components: **energy efficiency** and **demand response** (DR).

3.3. Measures of energy efficiency

Application of measures in energy efficiency brings the fastest results. Devices and appliances are replaced with same or similar, but more efficient products. Energy consumption is decreased, while effects are the same. Examples from the industry include:

- boilers - better insulation, better maintenance,
- steam systems - better insulation, maintenance, use of condensate return, use of energy from waste heat, better regulation,
- lighting - replacement of traditional lights with fluorescent ones, maintaining high reflectivity of the wails,
- electromotive drive - use of more efficient engines, use of converters of volume and frequency for regulation,
- compressors - use of systems for utilisation of heat, decreasing temperature of input air, maintenance,
- high-efficiency generation of electricity and heat in one single cycle - co-generation,
- compensation of reactive energy.

3.4. Demand response

Demand response is somewhere directly identified with the consumption management systems (or Load Management, LM), as given in [9], emphasising similarities and differences to the mechanism of dynamic response (Dynamic Demand). According to [9], DR is a mechanism used to manage demand for electricity with the final user, as a **response to outer stimulus**, e.g. price of electricity on the market. Unlike DR, reacting only to the stimulus from the network (reaction on the side of user), mechanisms of dynamic response react automatically (based on installed senses or a direct order). According to [10], [11], demand response (DR) can be defined as change of way of using electricity by end users, stepping outside of usual patterns of consumption, as a response to changes in price of electricity over time. Furthermore, DR can also be defined as financial incentives intended to induce reduction in use of electricity during period of high market price, or when the reliability of the system is at jeopardy. DR includes all intended changes in the pattern of electricity use by the end user.

3.5. Examples of DR programme

There are several different DR programmes in practice. Programmes are divided into price- and incentive-based programmes [11]

3.5.1. Tariff programs

Tariff programs are also called models founded on price system ("Price-based Demand Respond", PB-DR). This group of programmes is based on user's conformation of the electricity consumption to trends of retail prices at the electricity market, including:

- **Multi-tariff System** or Time of Use tariff program, TOU). Currently, electricity is almost regularly sold at the retail market through the form of static, multi-tarriff systems. Tariff are unit price of electricity and services paid by retail buyers to the service suppliers in a given time frame. A two-tariff system is common in our region: lower (night) and higher (daily) tariff. Furthermore, in addition to unit price for energy, tariff system contains other items, such as fee for engaged power, reactive power, etc. By use of a multi-tariff system, it is intended to map a time profile of prices at wholesale market to the retail market [10]. Considering the purpose or the possibility for metering of consumption, buyers are offered a range of different sub-choices of a tariff system with additional conditions (models: industry, households, etc.). Adjustment of the profile of buyer consumption, through a long-term planning of consumption, to the profile of default of selected tariff system, is the basis of this DR programme. Tariff prices profile is static and does not often change. This is for the protection of the smallest consumers against market risks. Nonetheless, by strengthening of the market mechanisms impacts, some distributors introduce more than two tariffs in order to, primarily, decrease own risk from variability of prices and, on the other side, to offer more possibilities to the clients. The benefits from a multi-tariff system are specifically visible when combined with re-distribution of peak load [12].
- **Real Time Pricing** (RTP) Application of profile of wholesale prices to the level of retail is a technically complex but unavoidable method of consumption metering of electricity for some buyers in the future. According to this programme, retail prices follow the variability of prices on the wholesale market. RTP is also called dynamic tariffs [13]. In this programme, buyers receive the information on hourly value of price for a day in advance or an hour in advance, to be able to adjust their consumption profile. Many will agree that the application of real tariffs is the most efficient method of DR programme. Users of RTP programme are mostly large consumers who have knowledge and technology to manage consumption in the dynamic conditions. Nonetheless, implementation of this programme understands significant investments into power generation system's infrastructure, including advanced meters [13].
- **Critical Peak Pricing** (CPP) is a combination of static (TOU) and dynamic (RTP) tariff model. Namely, CPP has the same profile as TOU for the major part of the year, except in the days of extremely high price of electricity, when dynamic tariffs are applied as shown in Figure 3 [11].

3.5.2. Incentive programmes

Incentive programmes („Incentive-based Demand Respond"; IB-DR) are also called reliability-based programmes ("Reliability-based DR"). IB-DR are those programmes implemented by network operators with the

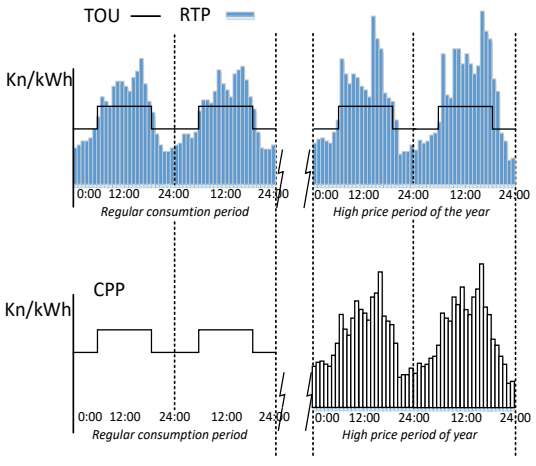


Figure 3: TOU, RTP and CPP programmes of DR

aim to encourage decrease of electricity consumption, offering the buyer with different financial incentives independent from retail prices. This programme involves Contracts where buyer is awarded for implemented measure of consumption decrease, but also penalised if they fail to execute their commitments.

The programme is implemented in cases where decrease of consumption is required because the reliability of supply was put in jeopardy (tertiary regulation of power), or when the price on the market is too high. Some of these methods are described further in text.

- **Direct control** of consumption is a traditional programme of load management organised and implemented by the network operator. For such service the user of the network receives a certain fee for it [10], [11]. In this case, the operator has the possibility and the right to remotely switch off consumption after a short notice. The programme is mostly implemented to avoid too high peak load to in the events which could lead to the collapse of the network. IBDR is almost exclusively contracted with residential consumers. Industry is not a favourable environment, because uncontrolled losses of production are possible.
- **Reduction of Consumption at Demand** Unlike the previous measures, buyers decrease or switch off own consumption on their own. Incentive is integrated in the current tariff as a form of discount or credit, based on user's commitment (promise, agreement) to decrease consumption to the requested value at request (during a network blockage). Non-compliance with the obligations can lead to financial penalisation. This service is also contracted with industrial consumers.
- **Demand Bidding** (bidding by the demand reduction). This programme has a relatively low level of risk because the buyers voluntarily bid their readiness to decrease the consumption on the market, for the next day. If the offer is accepted, the buyer must comply the offered service or risks penalisation [10].
- **Response to emergency demand for decreasing of consumption** is a service similar to decreasing of consumption at demand. It is related to decrease or to switching off the consumption in the event of emergency, for the purpose of preventing network collapse.
- **Economic methods** motivate end user to decrease consumption whenever the price of electricity is high at the spot market [11]. The service is present at both the energy market, and capacities market [10]. Namely, decrease in the power of consumption during a defined future period has a market equivalent to increase of available power of generation capacities. Participants of this programme receive fee for booking of capacities in advance, or penalties for not complying with the commitment.
- **DR Programme of Ancillary Services**. As seen in the previous chapter, the problem of balancing is solved either through the system, or through the market. In systematic approach, the operator contracts ancillary services to ensure stability of the facility. Having in mind that the change of power consumption is faster than the change of power production, and that they have the same effect to maintenance of stability, DR can have a significant role in providing ancillary services (maintaining frequency). Similarly to production facilities providing ancillary service, the ancillary services of DR are charged through booking and for implemented decrease.

3.6. DSM strategy

DSM strategies are measures carried out by the facility user when managing demand. There are three fundamental strategies, or approaches of the user on the outer or inner incentives [10], [14]. **The first strategy** is to decrease consumption during the periods of peak load in the grid, i.e. during high prices of electricity. This strategy means the loss of impact, consciously sacrificing a part of consumption. The literature refers to it as „Peak shedding" [6] or „Load shedding" [15]. The strategy shown in Figure 4 is not very common in the industry, except in cases when the profit from the implemented method yields larger financial effect in comparison to the damages due to loss of production. Reduction of production rarely goes without a reduction of performance, thus the list of priorities defines the order of switching off or decreasing power consumption. Practice knows of purpose-built systems for demand management[4], i.e. consumption power management in two forms: fast and slow. Fast load management (FLM) is used for microgrids when, in the event of a sudden failure or operation start of the outer protection, the microgrid moves into insular mode and it is required to maintain operating function. The second form is slow load

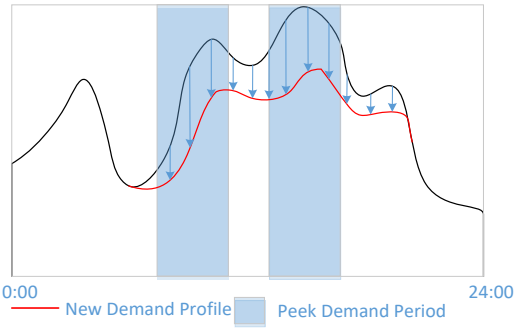


Figure 4: Decreasing peak consumption

[4] It is important to have in mind that the consumption management, in this context, is not the same as regulation of power, which is a direct consequence of technology demands.

management (SLM), used for decrease of peak load. This strategy includes the applied energy efficiency.
Strategy of decreasing peak production can be used without negative impact to the overall effect, in a way that during high tariffs the power of consumption is decreased, and during low tariffs the consumption is increased over the nominal, in order to "compensate" for the missed performance (amount of efficient work). Such change in dynamics frequently understands existing of power storage to store excess of production or to compensate for production.

The second strategy is redistribution of consumption outside of the high tariff period (peak consumption) into the period of low tariff, but without impacting the summary effect, wherever possible. This strategy is specifically discussed and applied in industry only to the part of processes implemented independently one from another, i.e. they are insensitive to the defined time of implementation. The literature refers to it as „Peak shaving [6], or „Load shifting"[7], [15], Figure 5.

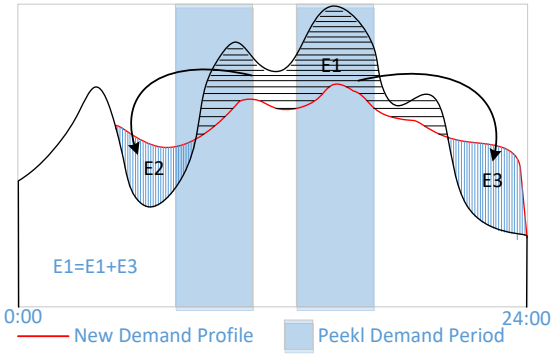


Figure 5: Redistribution of peak consumption

The third strategy is own generation of electricity during the period of high tariffs. This strategy is specifically interesting for industry. Conventional fuel, such as gas or diesel fuel, are used for generation, along with non-conventional fuels, such as sun energy, wind energy, biogas, biomass or waste emerging from the production process [15]. More about this has been explained in the chapter on management of sources. This category surely includes own power generation, such as given in Figure 6.

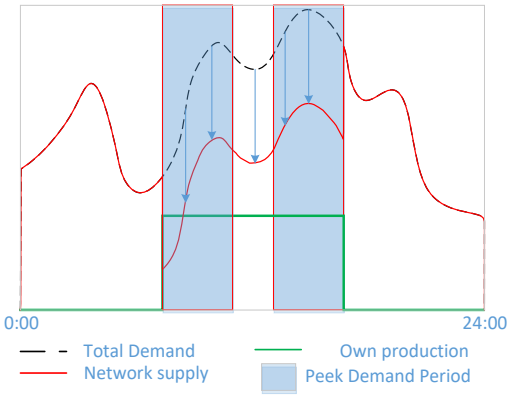


Figure 6: Own power generation.

3.6.1. Selection of strategy for demand management and load management in industry

Under the strategy for demand management we understand a group of measures used by the industrial facility user in order to keep the power of consumption at optimum level. The selection of measures is under the influence of the type of facility in the first place. As given in the previous chapter, there are three primary strategies: decrease the power of consumption, redistribute peak load during the period of lower tariff and own generation. Industrial environment is a process-oriented architecture with co-existence of three technological platforms: process technology (PT), energy technology (ET), and information-communication technology (ICT). Process technology is a commanding technology and defines the purpose and work of all others. Energy technology in an industrial environment is entrusted with supply and/or production, and distribution of energy. Finally, the third element is the information-communication technology, which provides control and management of flows, including goods, materials, services, and energy. Implementation of the analysis for implementation of a certain strategy takes place in five steps, as follows:

The first step is to gather data on energy consumption during production cycles [6]. Quality of analysis depends on density of the collected data. Having in mind that a 15-minute interval is a metering interval for electricity, it is practical to take this interval for other types of energy sources, too. Data on consumption are shown as load curve (LC) or as a load duration curve (LDC). The later one is practical for use because it visibly indicates the situation of maximum load (amplitude and length of duration).

The second step is decomposition of industrial facility into **processes** and **sub-processes**, [6]. Figure 7 shows: the process-based model of industrial facility [16]. Model's components are processes and storages. Each component is characterised by a gradient of material flow $Q(t)$, energy $P(t)$, and time diagram of engagement $\delta(t)$[5].

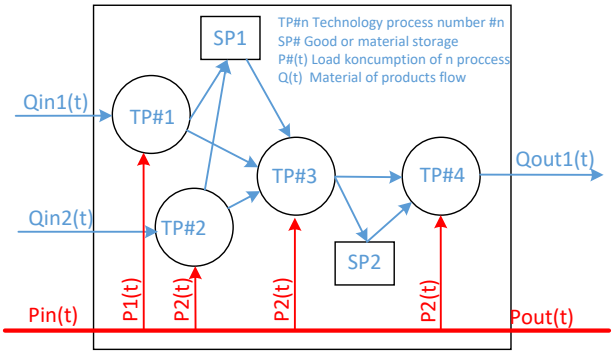


Figure 7: Process model of industrial facility

[5] $\delta(t) = \{0,1\}$. If the facility is not operating, then 0, and if it is operating then 1.

Processes (from the energy source point of view) can be treated as equivalent load with power consumption P(t) and plan of engagement δ(t). Processes, i.e. load, can be classified in several groups [16].

- **Critical processes/devices**, are those that must not be stopped under any circumstances.
- **Related processes** are those that depend one on another in a technological flow. Such processes cannot be separated, and the consumption of energy by one process cannot be decreased without having impact on another process.
- **Processes** with storages are those processes which have storage of semi-finished products inside their boundaries. Well dimensioned storages can provide for transfer of peak consumption or decrease of consumption during the period of high tariff. The storage is used for temporary acceptance of semi-finished products, instead of taking them into the process which is the subject of implementation of demand management measures.
- **Manageable processes/loads** are those whose consumption can be controlled or managed in any way, be it by intensity or time of engagement. Such consumption is subjective to DR measures. Manageability is a feature emerging mostly from the level of equipment of a technological process with technological solutions for management (voltage and frequency converters, switches and contractors for remote switching).
- **Non-manageable processes or loads**, which due to (lack of) equipment with technical solutions or due to technical limitations, cannot be managed (e.g. process of melting of iron in an induction incinerator; decreasing the power of melting or interruption of it, can yield technological losses).
- **Distributable processes or load** are those whose engagement can be moved time-wise during the production cycle, due to technological reasons (day, week, month or quarter).
- **Non-distributable processes** are those whose engagement is in the critical path of the whole process. Moving it in time would cause technological losses.
- A specific category are **storages**. Storages understand elements of the system where it is possible to store thermal energy, cooling energy, electricity or technological medium. Use of storage for the DSM purpose is peak shaving of the load curve improving the load factor H_{sr}/H_{max}.

The third step is classification of processes into one of the groups: batch or continued processes. Batch processes are those where the activity of input of goods, materials, raw materials and energy (and information) takes place separately from the very technological process, i.e. from the activity of discharge of finished product or semi-finished product, waste and energy. Examples of batch processes are those in reactors where reactants are first imputed and then the activation and flow of process starts and at the end process is closed with discharge of the reactor. The process once started cannot be interrupted without larger losses. Melting of iron is an example of batch process. Continuous processes are those where goods, raw materials, other materials and energy continuously enter the process, flowing simultaneously with the process itself, including the output of finalised or semi-finished goods, waste and energy. This paper does not deal with the issue of classifying the type of process, but their impact to the measures of DR.

Classification of processes into the first and second categories is not unambiguous. A decision on classification can be made by examining the form of the load duration curve, as shown in Figure 8. The curve of load duration has a visible change (fall) of power in a relatively large part of the time interval for batch processes. This means that there are those periods of large (duration of batch process) and small consumption (filling or emptying of batch). On the other hand, continuous process through the major part of the operation has a relatively large load factor H_{sr}/H_{max}.

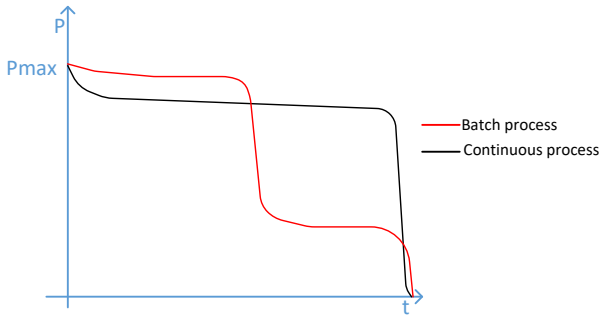


Figure 8: General difference between the curves of load duration for charge and continued processes

In relation to that, the general rule says:

- Bath processes are suitable for application of the measure of redistribution of peak production („Peak shifting“);
- Continuous processes are suitable for application of the consumption decrease process or any other method (energy efficiency, own generation).

The fourth step is the analysis of processes and limitations. This step sees a more detailed analysis of the possibilities to apply DR and DSM measures, with limitations [6].

For Bath processes:

- Analysis of time schedule of load: what are the hours with full load, decreased load or of situations with no load. The analysis should be carried out by statistical processing (calculation of mean value and standard deviation).

- Furthermore, the analysis moves into finding out what are the limitations for sub-processes and the process as a whole. Are the processes distributable or not? In the event of non-distributable processes, redistribution of load is not possible. The measure of energy efficiency (decreasing consumption with the same effects) must be applied.
- In doing the analysis, one has to keep in mind the features of (sub)processes, such as of minimum and maximum standstill time, or operation; gradient of starting, or stopping of process.
- The most important limitation is that the total technological effect must remain the same.

For continuous processes:

- Similarly to batch processes - if the process has a time-based linked to a certain part of the time cycles, it is not possible to change the method of decreasing peak consumption. Measures of improving energy efficiency are applied as a solution.

The fifth step is determination the potentials of DSM. The DSM potential can be qualitatively expressed by the following: decreasing demand of an energy subject (industrial facility); (1) and/or decreasing the costs for the consumed electricity; (2).

$$\Delta P_{\max} = \max_i \left(\sum_j \overline{P_j} \delta_j(t_i) \right) - \max_i \left(\sum_j \overline{P_j} \delta_j^*(t_i) \right) \quad (1)$$

$$\Delta T = \left[\sum_j \left(\sum_i \overline{P_j} \delta_j(t_i) c(t_i) \right) - \sum_j \left(\sum_i \overline{P_j} \delta_j^*(t_i) c(t_i) \right) \right] \Delta t \quad (2)$$

where:

$i, j,$ count-down of time intervals and count-down of processes (group of energy users subjected, as a group, to a certain DSM strategy);

$\overline{P}_j$ mean power of a process;

$\delta_j(t_i)$ Function of time engagement of a process j prior to a DSM strategy application. Function values are 0 or 1,

$\delta^*_j(t_i)$ Function of time engagement of a process after to a DSM strategy application. Function values are between 0 and 1, in order to qualify the effect of decreased consumption („Load shedding”);

$c(t_i)$ Price of energy source (electricity) during the observed period ti;

Δt Duration of a metering interval (15 minutes or 1 hour);

Decrease of engaged power on daily basis has immediate effect to the system, but also on the consumption of the user. Depending on the type of supply contract, method of metering and eventually selected DR programme, decrease of engaged power on the level of metering interval has a financial (incentive) effect to the final user too.

4. CONCLUSION

Energy management is of joint interest for both the system operator and user. Industrial environment is of specific interest because the level of consumption and different engaged useful energy forms provide not only for load management, but also energy supply. Energy supply understands any form of engaging production resources for the needs of the final user. Due to the position and importance of energy in industrial environment, as well as the added value brought into the subjected product, energy supply management is not possible without the interaction with the process management. Furthermore, the ICT provides such a quality of interfaces towards outer systems (market in which a given industry is active, energy market, superior management systems) that it is not possible to exclude them when considering advanced business environments. According to the model of an advanced network („Smart Grid“), it is possible to implement integration of process, energy and information technology into a unique, advanced, networked system which can secure optimum use of property and production resources, maintain interaction towards outer systems and environment.

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