TECHNICAL REQUIREMENTS AND PRACTICAL IMPLEMENTATION OF A DYNAMIC PRICED ELECTRICITY TARIFF

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ABSTRACT

Today most industrial customers use electricity tariffs with static prices and therefore cannot benefit from volatile prices at the short term markets for electrical energy. In this paper the technical requirements to implement such dynamic electricity tariffs are presented. Additionally, a Demand-Response-Interface for the communication between retailer and industrial process is described. The presented concept is implemented and validated in context of a field test with ten different industrial companies of different branches in context of the enclosed project "Happy Power Hour II".

INTRODUCTION

In course of the German "Energiewende", the significance of flexibility in the electricity grids increases [1] [2]. Up to now, the producer side provides the required flexibility, while the consumer side is almost neglected. Due to the simultaneous increase of this trend, the impact and the volatility of the short-term markets like day-ahead auction or continuous-intraday trading at the power exchange EPEXSpot SE increases [3] [4].

Today most industrial customers use electricity tariffs with static prices and cannot benefit from volatile prices of the rising short-term markets. As part of the enclosed research project "Happy Power Hour II", a research consortium led by the University of Wuppertal, demonstrated how flexibility in the industrial environment can already be exploited today. The stated objective was to activate flexibility options for medium-sized industrial companies by means of dynamic electricity tariffs. Hence, the respective companies are able to reduce the energy procurement costs, through reacting on external price signals, from 10.5 % to 35.7 % by day-ahead optimization and additionally from 31.9 % to 73.2 % via the optimization by the continuous intraday [5].

TECHNICAL REQUIREMENTS FOR A DYNAMIC PRICED TARIFF

The main focus of the project was the development of dynamic priced electricity tariffs for medium-sized industries. For a successful implementation of dynamic electricity tariffs in a large number of companies, it is mandatory to design an adaptable system in the direction of companies. It is important to keep the effort of the evaluation of the dynamic price signals low for the companies. Therefore the companies get a concrete electricity price optimized production schedule for each flexible process. These dynamic price optimized production schedules are generated by taking into account process specific constraints. The realization of the previously planned schedules can be controlled by a fully automated system. If the fully automated control of the process is not possible, the companies can control the process through the process operator by themselves.

In the direction of the retailer, which offers the dynamic priced tariffs for a large number of customers, it is mandatory to design a standard workflow. Therefore a high-level automation regarding the communication between retailer and company, the generation of price optimized schedules and the automated trading at the electricity exchange is very significant.

Figure 1 illustrates the different parts of the technical implementation of a dynamic electricity tariff.

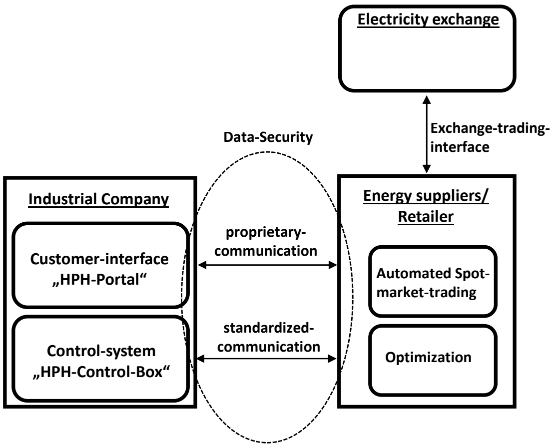

Figure 1: Parts of the technical implementation of a dynamic electricity tariff

Furthermore, data security is an additional technical requirement. Through the introduction of dynamic priced electricity tariffs communication-interfaces emerge, to safely communicate critical data. This applies particularly for the control of an automated system.

Optimization algorithm

The developed optimization algorithm is used to determine an optimal schedule for each process based on the individual restrictions and the spot market price forecast.

The optimization algorithm will be implemented in the control-system of the retailer. Due to the selected tariff-option, it will provide an optimal schedule, which will be transmitted to the control-system or presented at the customer-interface as shown below. Due to the fact that the optimization is not carried out in the control-system with its limited computing power an external solver software could be integrated if necessary.

Due to the fact that a huge variety of industrial processes should be integrated in this Demand-Response-Program the modeling of the scheduling problem has to be as modular as possible. Based on the load model presented in [6], each industrial process is modeled as a sequence of phases which cannot be swapped in time [6]. For each process and each phase a huge amount of parameters is available, such as power limits, required energy, storage limits, minimal and maximal operating times, breaks between phases and many more. The different processes are independent from each other, except the peak power of all processes is limited or the grid fees, which are also based on the peak power, have to be considered.

This universal modeling allows an integration of all suitable process types, such as processes with a storage, like temperature of product storages, as well as processes with different programs, consuming a different amount of energy, which can be switched in time.

For day-ahead scheduling the optimization will be carried out at least one time on the day before delivery using the day-ahead-auction and intraday-auction price forecast. Due to the available forecast horizon of four days, additional optimizations can be carried out the days before if the load shifting of the process needs more planning time. The next step is the integration of the intraday continuous market, which starts after the day-ahead market and allows continuous trades until 5 minutes before delivery. The objective of this rolling horizon optimization is to minimize the costs by shifting the process from expensive to cheaper hours followed by buying the missing energy amount at the intraday continuous market and selling the corresponding energy amounts that have been bought already at the day-ahead market. This optimization is called intraday redispatch and has the advantage that it combines the good predictability of prices at the day ahead market – and with this the safety of not having to buy at extreme prices – with the huger price spreads at the very volatile intraday market [5].

Communication

For the implementation of a dynamic priced electricity tariff two communication-interfaces are placed between the industrial company and the retailer. The first possibility is a retailer-specific customer-interface for the direct communication to the customer and the second one is a standardized Demand-Response-Interface for the direct communication link to the industrial processes.

In context of this paper, the retailer-specific interface is called "HPH-Portal". It is used for the transfer, evaluation and visualization of the price-signals and production schedules to the customer. If it is necessary, the customer has the possibility to edit the process specific restrictions, which are used for the optimization of the schedule like the starting/ending-time or a temperature-limit. The retailer-specific interface can be implemented with a web-interface or by direct coupling to a production-planning tool. Because the interface is retailer-specific there is a variety of further possibilities for additional functionalities and unique selling propositions of each retailer.

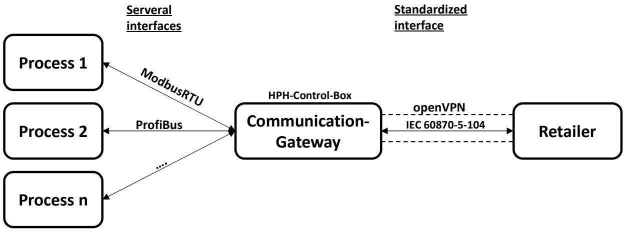

Figure 2: Concept for the communication between technical processes and the retailer

The communication link to the industrial processes is needed to realize and control the previously planned product schedules as it is shown in Figure 2. Each process communicates via a proprietary manufacturer-specific communication-protocol with a process-specific data-model. So it is unavoidable to use a communication-gateway, which supports the manufacturer-specific protocols and can translate it to the developed standard data-model. The objective is the communication of different industrial processes by a standardized interface between the different companies and the retailer.

In context of this paper, the communication-gateway is called "HPH-Control-Box".

Data-Security

The requirements of IT-security for the communication between the technical processes and the retailer is oriented at the communication requirements of control power and is shown in Figure 3 [7].

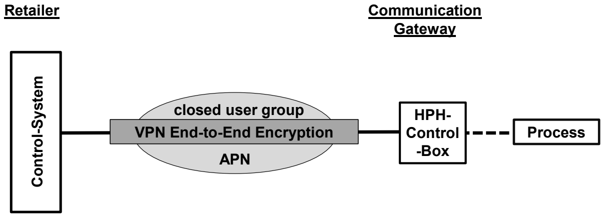

Figure 3: Security concept in accordance to [7]

This means particularly that the HPH-Control-Box is part of a closed user group which is specified in [8]. To discharge these requirements the communication is not realized via the public internet or the companies' internal intranet. Therefore the communication is created via the mobile network, which has access to the retailers network via an own APN (Access Point Name).

Additionally the data-transmission is VPN end-to-end encrypted via OpenVPN. The communication between HPH-Control-Box and the industrial process is not part of the closed user group and the end-to-end encryption.

THE DEMAND-RESPONSE-INTERFACE

The Demand-Response-Interface (DRI), which was developed in the project “Happy Power Hour II”, is hardware independent and based on the communication-protocol IEC 60870-5-104. This protocol is an open standard and is mainly used for controlling electric power grids and other geographically widespread control systems. [9]

The DRI defines the HPH-Control-Box as an IEC 60870-5-104-sub-station and the control-system of the retailer as IEC 60870-5-104-central-station. The communication between central-station and sub-station must always be carried out according to the same standardized scheme. Because of the objective to use one general standardized communication-model it is not possible to communicate additional individual data points.

Data-Model

Table 1 shows the data-model of the DRI for the communication according to IEC 60870-5-104 for one process. This model can be duplicated for additional processes.

Table 1: Communication-Model

Process value	**usage**	**Communication direction**	**Transmission cause**	**Type identification**
Enable-signal	mandatory	Monitoring direction	spontaneous	TK1
Power measurement	mandatory	Monitoring direction	cyclical	TK36
storage	optional	Monitoring direction	cyclical	TK34
temperature	optional	Monitoring direction	cyclical	TK34
schedule	mandatory	Control direction	spontaneous	TK51
schedule-date	mandatory	Control direction	spontaneous	TK51
Ready-To-Receive	mandatory	Monitoring direction	spontaneous	TK1

The naming of the respective data points is listed in the column "Process value". The "usage" column indicates whether a data point is mandatory to be created for each process or if it is optional. The communication direction describes whether a data point is sent in the direction of HPH-Control-Box to retailer (monitoring direction) or retailer to HPH-Control-Box (control direction). The "Transmission cause" column defines the event triggering a transfer. The type identification specifies the data format of the data point specified in IEC 60870-5-104.

The IEC 60870-5-104 specific information “InformationObjectAdress” can be used for the unique identification of each information of the data-model and the “SubstationAdress” can be used for the unique identification of each company.

The “Enable-Signal” is used for the possibility of the process operator to outvote the control-signals of the HPH-Control-Box. Therefore, a switch is located in the near of each industrial process. This switch is used to enable or disable the signals. This information is significant for the retailer to prevent balance energy if a process is disabled temporarily.

The process values “power measurement”, “storage” and “temperature” are used for the real-time measuring of electrical power, any temperatures or any stock level of a storage.

The process values “schedule”, “schedule-date” and “Ready-To-Receive” are used for the schedule transmission. The data-model specifies an application for the schedule transmission of whole-day-schedules, which consist of one setpoint for each quarter of hour for a whole day.

Schedule transmission

In context of this paper, a schedule describes the controllable setpoints for a whole day in a quarter hourly resolution. The setpoints for the particular quarter of hours are transmitted in percent of the installed power and have to be translated from the communication-gateway to a process signal.

The following describes the transmission of a schedule. As soon as the new process schedule is available, the data transfer starts immediately as shown in Figure 4.

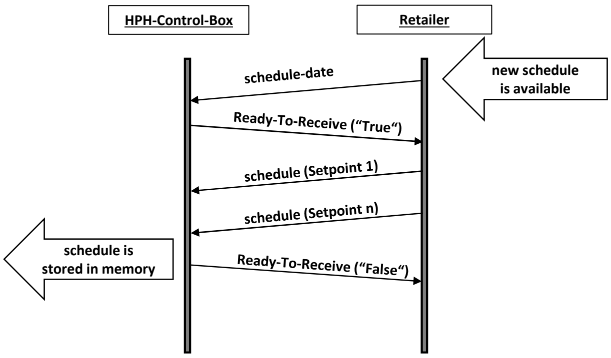

Figure 4: Schedule-transmission

The communication is opened up with the related date (UNIX-timestamp) of the following schedule. This date is used as a unique identifier for the respective schedule. An archive with this unique identifier is created for the day of the schedule in the memory of the sub-station. The archive contains 96 (92 or 100 in case of a time changeover) entries, one for each quarter hour of the day. Each entry of the archive is given the default value of “0”. Subsequently, only setpoint values with a non-zero value are sent from the central-station to the sub-station.

If the sub-station is ready to receive the new schedule, the sub-station confirms the schedule-transmission-request by setting the "Ready-To-Receive" message to "True". Afterwards the central-station starts the transmission of the schedule.

As shown in Table 2 the whole-day-schedule is split in different schedule-elements before the transmission can be started. After the splitting the different schedule-elements are sent sequentially.

The 32-bit command consists of the information of the setpoint (Bit 1-7) and the quarter-hour (Bit 8-14) in the case of use. If the transmitting setpoint value is also valid for the subsequent quarter hours, the information is also contained for how many of the following quarter-hours of the same setpoint is valid (Bit 15-21). Only one bitstring of 32 Bit is transmitted for these quarter-hours. Lastly, the bitstring of 32 Bit includes the information of the number of following schedule elements still the schedule has been transmitted completely (Bit 22-28).

Table 2: bitstring of 32-bit for schedule transmission

Bit	**Usage**	**Value-range**	**Comments**
1-7	Setpoint	0-100%	Only integers
8-14	Quarter of hour for which is the setpoint valid	1-100	Because of time change is the value-range of 1-100
15-21	Number of subsequent quarter of hours for which the same setpoint is valid	1-100	Shall the setpoint exclusively apply for the quarter of hour from bit 8-14 is the value 1
22-28	Number of the following schedule-elements	0-100	Is the actually schedule-element the last one, the value is "0".
29-32	Reserve		

All transferred schedules are stored in the archive on the sub-station. If more than one schedule has been transmitted successfully for the date, the latest schedule is the valid one. All previous schedules for the respective date are rejected and deleted. In the event of a subsequent change in a schedule, the complete daily schedule is always re-transmitted.

After the schedule has been successfully transmitted, the sub-station confirms this by setting the data-point "Ready-To-Receive" to "False".

If the communication between the sub-station and the central-station is interrupted during the transmission of the schedule, the complete schedule is rejected by the sub-station and moved to the archive, the default value of zero is entered for every quarter of an hour. A schedule transmission is considered completed, if the sub-station has set the "Ready-To-Receive" message to "False". As soon as the communication has been reestablished, the schedule transmission is initialized again by the IEC 60870-5-104 central-station.

TARIFF-OPTIONS OF A DYNAMIC PRICED ELECTRICITY TARIFF

The present infrastructure enabled three different tariff-options ("manual", "partially automated" and "fully automated") with different cases for the interaction between HPH-Portal, HPH-Control-Box and retailer.

Tariff-option "manual"

This tariff-option is suitable for industrial processes which cannot be controlled by the HPH-Control-Box automatically. This can be for example a process which is continuous controlled by a process operator like a manual forge hammer.

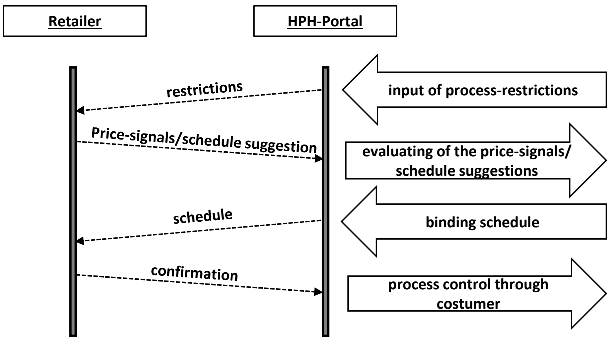

Figure 5: Tariff-option "manual"

The customer has to set the process-constraints into the HPH-Portal for creating the price optimized schedule. The customer receives a suggestion for a suitable schedule for the process and has to evaluate it by himself. Subsequently, the customer has to choose and confirm one of the suggested schedules and the retailer supplies the required energy. After that, the retailer confirms the schedule and the customer has to realize the schedule by himself (see Figure 5).

Tariff-option "partially automated"

This tariff-option is suitable for industrial processes, which have constantly changing process-restrictions like the starting/ ending time or process-duration. By considering these changing constraints, the process is controllable by the HPH-Control-Box (see Figure 6).

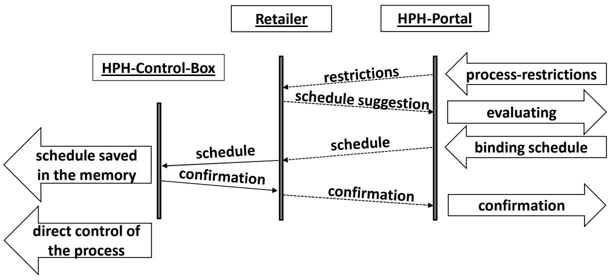

Figure 6: Tariff-option "partially-automated"

This process could be for example a hardening oven with different supported hardening programs. Before the start of the hardening process, the process-operator has to fill the oven with material. Afterwards the HPH-Control-Box starts the hardening process automatically.

Similar to the tariff-option "manual" the customer can set the different process-restrictions into the HPH-Portal and evaluate the schedule suggestions. The decisive difference is, that after the confirming of a biding schedule from the customer, the schedule is transferred directly to the HPH-Control-Box and will be saved there. After the confirmation of the schedule, the customer can be sure, that the planned schedule is realized automatically through the control of the HPH-Control-Box.

Tariff-option “fully automated”

The tariff-option “fully automated” is suitable for industrial processes, which restrictions are changed rarely and therefore can be controlled automatically by the HPH-Control-Box.
This can be for example a heat up process which have to reach a specified temperature at a define time.

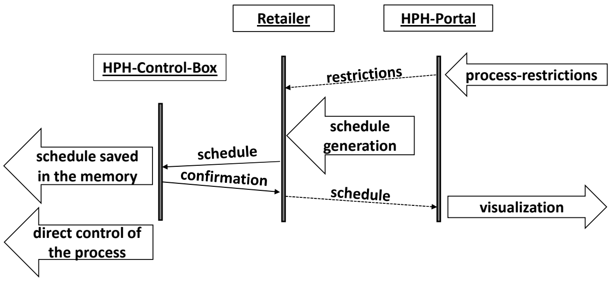

Figure 7: Tariff-option "fully-automated"

In this case, the customer sets the process restrictions once only. Afterwards the optimization and realization of the schedules is carried out automatically through the retailer and the HPH-Control-Box. If required the customer is able to check the schedules with the HPH-Portal (see Figure 7).

CONCLUSION & OUTLOOK

The present paper describes the different technical requirements for the implementation of dynamic electricity tariffs and the possibilities for the interaction of the customer-interface, the automated process control via communication-gateway and the retailer.
All descried concepts are implemented and validated within a field test with ten different industrial companies of different branches in context of the enclosed project “Happy Power Hour II”. Therefore is for example the concept of the HPH-Control-Box implemented on a hardware of the WAGO Kontakttechnik GmbH & Co. KG (see Figure 8).

Figure 8: Developed automatization-system (HPH-Control-Box) for fully control of industrial processes

The advantage of the presented DRI is the security of investment for the customer’s communication-gateway. Due to the usage of a standardized communication-model the customer is not long-term bound to one retailer and can change these without the costs for a new communication link to the industrial processes.
In the future any suitable industrial processes can be equipped with the presented DRI. Hereby a standardized communication can be realized between retailer and industrial process without any investment costs for the communication-gateway.

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