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Procedure for generating a basis for PPC systems to schedule the production considering energy demand and available renewable energy

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Abstract

Production planning and controlling (PPC) plays an important role in modern production enterprises. Current production management systems consider resources such as material, labour and production capacity and their respective costs, but neglect the role of energy and possibilities for cost savings. To develop sustainable production (in terms of economic and environmental aspects), the system must be extended; energy aspects, such as energy demand and available renewable energy, must be included in planning and monitoring the production. The paper presents a procedure for generating a basis for PPC systems to schedule the production related to energy demands and available renewable energy, for evaluating the planning errors and for indicating problems in the production based on the energy plan.

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Keywords: Production Planning and Control System; PPC; Energy planning; Renewable Energy; Direct consumption of renewable energies

1. Introduction

A production facility serves to transform raw materials into products, usually with the goal of achieving a designated output (in terms of quantity and quality) at minimum costs (see Figure 1, Part A). With the aid of planning systems, raw-material inputs, outputs of products, by-products and waste are planned related to a determined output of products (including services).

In general, current production management systems consider resources such as material, labour and production capacity at its respective costs, but neglect the role of energy (electrical and thermal energy) and its possibilities for cost savings. Though energy management systems have been pushed in the last years by legislation and financial incentives [1], the integration into operational production management is pending. To develop sustainable production (in terms of economic and environmental aspects), the **managed system must be extended; energy aspects must be included in the planning** (see Figure 1, Part B). In times of climate change, because of high greenhouse gas (GHG) concentration, increasing consumption of energy and rising energy costs (despite declining prices in the energy market), it is necessary to look at the production factor energy with respect to **sourcing** and **consumption**.

Production companies need to consider not only the costs of energy but its sustainable generation as well. Therefore, even for smaller production companies, energy sourcing is becoming more complex because of increasing sourcing criteria. Next to the energy prices of different energy forms, taxes and levies apply (depending on a country's legislation), investment costs and sustainability criteria must be considered when energy sourcing decisions are made. What is the best option for sourcing energy: sourcing from an energy provider and/or (partial) self-generation by own renewable energy (RE) sources? For companies wishing to self-supply, the design of their energy plants is important (see [2] for more information on this). In the case of (partial) self-supply, the fluctuating nature of energy is an issue to be handled. In which way and to what extent are energy forecasting and energy demand planning necessary?

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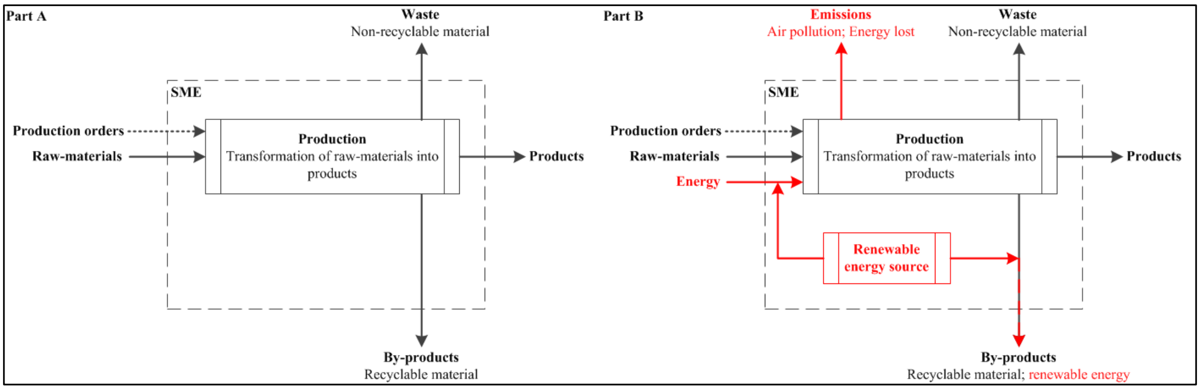

Fig. 1: Transformation of raw-materials into products without (Part A) and with (Part B) consideration of energy consumption

While operational production planning is already a complex task, the following questions need to be answered for the integration of energy aspects: Which aspects of energy planning need to be considered? And how does it change traditional production planning and controlling (PPC)? For production companies, energy consumption can be split into two categories: First, in basic demand to achieve operational capability; second, in production-related energy demand (see Figure 2) to transform material (input) into products (output). For the latter, energy planning in the sense of scheduling the daily energy demand respectively its causation, the production, is vital. When the energy demand is known, e.g. in the form of a 24 h day-ahead plan, it can be matched to the availability of self-generated RE to optimize costs and minimize environmental impacts, e.g. GHG emissions. Under this aspect, the PPC system should balance the daily energy demand and energy supply from RE sources and grid. For this, demand planning data, supply forecasting and planning data, including estimated error and balancing possibilities on both sides, need to be available. For the supply side, energy availability from fluctuating RE sources such as wind and sun need to be forecasted, while non-fluctuating RE such as geothermal or biomass can be planned.

An enterprise can benefit from using self-generated RE energies, as mentioned, to reduce energy costs and avoid GHG emissions by avoiding regular energies (fossil fuels). The drawback is, for maximizing the effect, additional know-how and planning capability are needed: energy planning needs to be done and must be joined with production planning. Though this is a drawback, the prerequisite for energy planning, energy monitoring, can be used as a benefit, e.g. with continuous monitoring of planned energy versus actual energy demand, the status of the machines can be monitored. Deviation signals can indicate problems, and counteractions can be taken immediately.

The paper presents a four-step procedure for generating a basis for PPC to schedule the production related to energy demands and available RE. The presented prototypic procedure is based on the following assumptions:

- The stability of the grid for energy supply in times of low RE production is guaranteed.
- The design of thermal and electrical RE sources is fixed, and the RE generation is only related to weather conditions.
- The absolute input and output of required material and energy related to the daily production program (production orders) is fixed.
- The enterprise is able to install and operate RE generation plants and manage its own energy demand (for more information, see [3])

After this introduction, a short overview is given of related work. Section 3 presents first, the methodology used to develop the procedure; and second, a detailed description of each step of the procedure is given. Section 4 contains the conclusion and future work, followed by the references.

2. Related Work

The scheduling of energy demands and RE production is the topic of several papers (for an overview, see [4]). In general, these papers investigate how energy planning can be used to achieve significant benefits on the market [5, 6] and/or minimize environmental impacts [7, 8]. Previous studies have analysed the deviation of expected and actual energy demand under the objectives of meeting production requirements while minimizing the overall operating and environmental costs through producing. The papers have also been focused on evaluating the deviations of forecast RE generation and take this into account to optimize the energy planning [7, 9–11]. The review [12] presents an overview of existing research about smart grid technologies and applications of the smart grid. The growth of networking through the smart grid in households and industry offers new opportunities for monitoring the distributed energy generation and energy demands by utilizing historical energy generation and consumption data. The basis for this monitoring and a key function of the smart grid is the accurate energy demand and RE generation forecast.

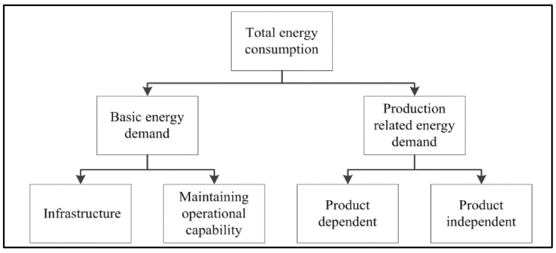

Fig. 2: Separation of the total energy demand

The current literature states that accurate energy demand forecasts and RE generation forecast play an important role for optimizing the energy supply. Nevertheless, current investigations neglect to describe how energy demand and RE forecast data are provided and prepared to schedule the energy supply of an enterprises. To uses the schedule as a threshold to indicate problems in production and track the status of the machines has also not been researched in the past.

3. Four-step procedure for generating a basis for PPC to schedule the production related to energy aspects

The four-step procedure has been developed based on previous work of the three research projects: e-PPS [13], REN ProV [14], and PREMdeK [15]. Each project was carried with partners in industry. The results of the projects were discussed and evaluated by the industry partners; in the case of the REN ProV project, it was even implemented in an on-going production, and in the PREmdeK case, it was verified by a discrete-event simulation using empiric data. The results of the three research projects were analysed accompanied by a literature search on current publications to put in the proposed four-step procedure. The procedure is yet in a prototypic state. Though the single steps are tested, the full procedure is not.

The procedure contains the following steps:

1. Guideline for correlating energy demands and productions orders in a PPC system for 24 h energy day-ahead planning (investigated in e-PPS). [16]
2. Guideline for generating energy forecast data for fluctuating RE to use in PPC systems (investigated in REN ProV). [17]
3. Methods for evaluating energy planning uncertainties and energy forecasting errors to define alert thresholds for monitoring deviation of planned energy demands and actual consumption (investigated in PREmdeK and in literature, e.g. [11]).
4. Procedure for developing and using energy plans. [10]

3.1. Guideline for correlating energy demand and productions orders in a PPC system

The basis for developing a 24h energy day-ahead plan is a well-functioning PPC system where generated work lists are followed to a great extent. Product work plans (routings) include next to regular information, e.g. single work steps, set up time and run time, the required energy for each work step on the preferred resource and, if applicable, alternative resources.

Work plans exist for the whole production program. For each step, the specific energy demand (see Figure 3) must be determined and recorded in the PPC system as a new resource. These specific energy demands can be categorized in basic energy demand and production-related energy demand (see Figure 2).

The basic energy demand can be separated into two sub points: infrastructure and maintaining operation capacity. Infrastructure includes energy demands, e.g. lighting and air conditioning systems. These energy demands are related to the season of the year. For 24 h energy planning, the relation to the season must be noted in the form of seasonal energy demand profiles. The energy demand for maintaining the operation capacity is, e.g. the demand to hold a machine in standby mode, in idle mode and the demand to start or stop a machine (see machine status startup/shutdown in Figure 3). Usually, these basic energy demand data are not part of the PPC system and must be implemented as new resources in the system. The production-related energy demand can be split into product dependent and product independent.

The product-dependent energy demands are related to one specific product which is consumed by one specific machine (see machine status running in Figure 3). For example, when a production step for a product can be run on two or more machines, the energy demand should be measured for each machine. Both specific energy demands must be recorded in the PPC system and appointed to the machines. Product-independent energy demands are always the same, e.g. transportation via conveyor system between two machines and production steps which are required for more than one product. These energy demands are not part of traditional PPC systems and must be implemented as new resources in the system. For measuring the energy demands per work step, it is very important to observe the right start and end time of each production step to get correct specific energy demands. A cause of incorrect start and/or end times could be that the times for loading and/or unloading the machine in idle mode have not been considered though belonging to the work step.

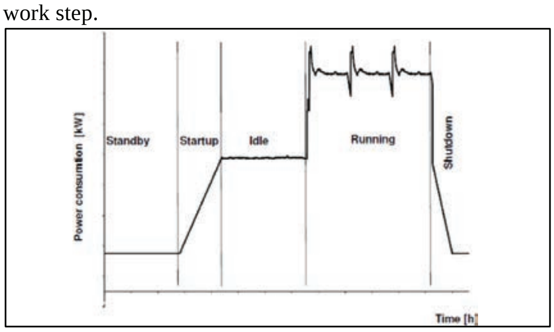

Fig. 3: Overview of possible machine status related to energy demand [17]

The measurements must also be made with an acceptable frequency to avoid mistakes. Frequencies that are too low can lead to lower specific energy demands because short high-load peaks are not recorded. After measuring the energy demand profiles and recording them for each production step in the PPC system, it is possible to generate 24 h energy demand plans in relation to the production plan for the next day.

3.2. Guideline for forecasting the RE production in a PPC system

The calculation of RE production related to machine design and weather data for specific time intervals is usually not part of a PPC system. For this calculation, an external tool is required. An example of an external tool is the simulation software PREmdeK version 2.0 (www.hs-emden-leer.de/premdek.html) [15]. PREmdeK simulates a local energy system consisting of a photovoltaic system, wind plant and solar heat. Based on weather data for wind speed, wind direction, air temperature, air pressure, and solar irradiation, the simulation calculates the RE power related to weather conditions and machine design of the RE sources in 15-minute intervals and a given timeframe.

The required forecast weather data for the calculation can be requested from weather services like:

- Deutscher Wetterdienst (www.dwd.de)
- Meteonorm (www.meteonorm.com)
- Meteogroup (www.meteogroup.de)
- UKMet Office (www.metoffice.gov.uk).

After simulating the expected RE power, the data can be imported into the PPC system. Similar to the energy demands, the RE power must be implemented as a new resource in the PPC system before it can be used for the energy planning.

3.3. Evaluation of uncertainties in planning the energy demand, and forecasting the RE production

Several expected and unexcepted errors can lead to a deviation between planned and actual profiles. Expected errors are, e.g. measuring inaccuracy of the energy and prediction accuracy of the weather. Unexpected errors could be, e.g. unplanned machine breakdowns and rush orders for the production. To track the status of machines to indicate problems in the production, the acceptable deviation between planned demand and actual energy demand must be known. To determine the acceptable deviation and define a threshold for the deviation, a statistical analysis of historical data must be done.

Table 1. Evaluation of the results for RMSE

	Meaning of the deviation
RMSE = 0	No deviation between planned/measured profile (optimal result, but not realistic)
RMSE > 0	RMSE should be as low as possible
RMSE >> 0	High deviation indicates problems in the production

For the analysis, historical data about production plans and specific energy demands should be available. Historical weather forecast data and the actual weather data can be requested from weather agencies (see Section 3.2). The following equations give a collection of methods to define thresholds to indicate problems with the planning system and to evaluate the accuracy of forecasted RE power.

The **root mean squared error (RMSE)** in Equation 1, is the average deviation between the planned/forecast data (θ_1) and the actual data (θ_2), being N the total number of pairs (θ_1/θ_2) records. The unit of the RMSE is the same as the unit of the used data. [11]

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(\theta_1 - \theta_2)^2\right]^{1/2} \quad (1)$$

The RMSE can be used as a threshold to indicate problems in the production. To evaluate the results for RMSE, the rules in Table 1 can be used.

The **mean absolute error (MAE)** is a quantity used to measure how close planned profiles are to measured profiles and to can be used to determine trends (see Table 2) [11]. The mean absolute error is given by Equation 2.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\theta_1 - \theta_2 \quad (2)$$

3.4. Procedure for developing and using energy plans

Figure 4 shows a process sheet about the procedure to develop a 24 h energy plan and use the plan in production. The process sheet is separated into two parts: Part A considers the procedure for energy planning (one-day-ahead); Part B uses the energy plan in the production (production day). The procedure should be implemented in the ERP system from the enterprises. The first test of a similar procedure was tested in the e-PSS project.

Before energy planning can be started, the production schedule must be created following certain optimization criteria like (A1): delivery date, machine work load, cycle time, etc. In case RE sources are used for energy supply, the required weather data must be requested from the weather agency (A2-3). Based on the weather data, an energy forecast needs to be calculated with external tools, e.g. PREmdeK simulation and imported to the PPC system (A4-5). Now, the PPC system plans the expected energy demand for the next day and balances the demand with the RE generation (A4). Three cases are possible when using RE sources and energy from the grid for the energy supply (see Figure 5). Case 1, the produced RE, is lower than the energy demand from the production enterprise.

Table 2. Evaluation of the results for MAE

	Meaning of the deviation
MAE = 0	No deviation between forecast and measured profile (optimal result, but not realistic)
MAE > 0	Positive MAE means the forecast profiles are on average higher than the measured data
MAE < 0	Negative MAE means the forecast profiles are on average lower than the measured data

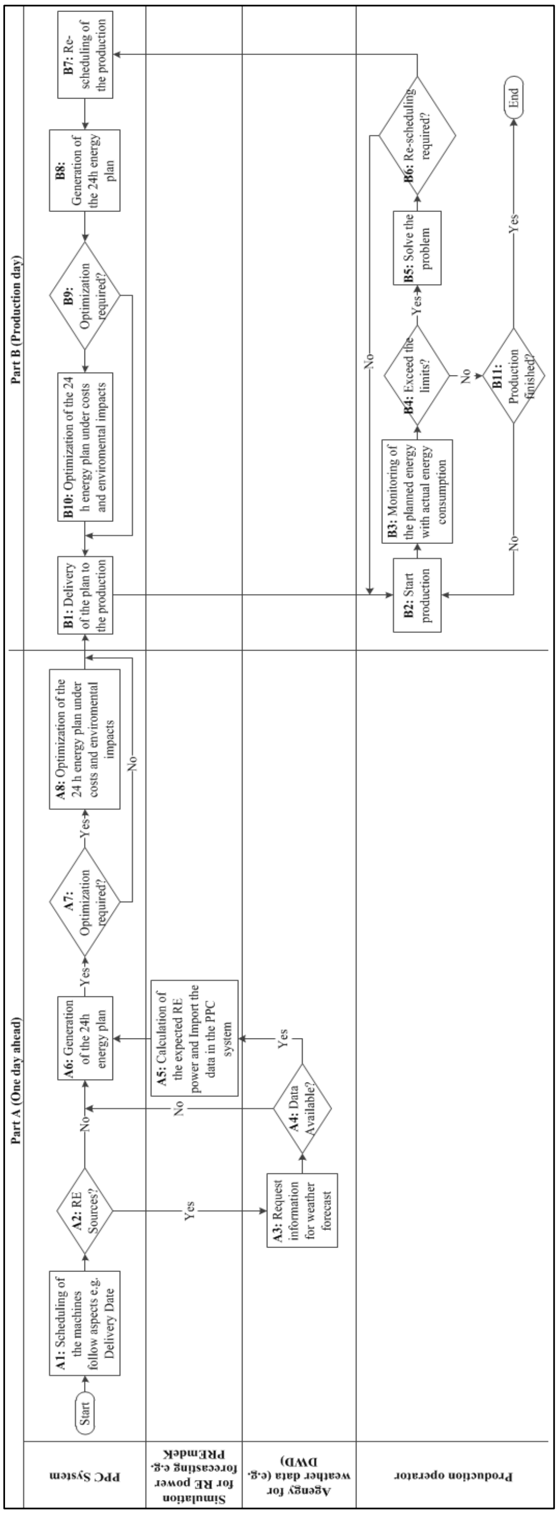

Fig. 4: Process sheet about the procedure to develop a 24 h energy plan and using the plan in the production

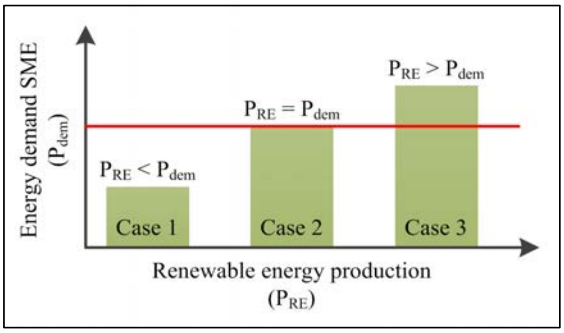

Fig. 5: Possible cases by using RE sources for the energy supply of a production enterprise

In this case, energy from the grid is required to meet the energy demand, causing higher energy costs and negative environmental impacts compared to own RE. In Case 2, the produced RE meets the energy demand of the production enterprise, causing costs only for operating the RE source, but without emissions. In Case 3, the produced RE is higher than energy demand. As in Case 2, the energy demand is covered by the RE source. The enterprise has several options to handle the overproduced RE. The RE could be injected into the grid and the enterprise benefits from the feed-in tariffs. Another option is to temporarily save the RE in storages for later consumption. Depending on investment costs for storage and cases, the best option needs to determined. Current feed-in tariffs in Germany (12 cents/kWh) are lower than possible cost savings (20 cent/kWh) by self-consuming the RE. Under this aspect, the PPC system should try optimize the daily energy demand and energy supply by RE sources and grid, like in Case 2 (A7-8). One optimization possibility is load shifting. In this case, production loads are shifted in times with expected RE availability. To shift a production step, the following possibilities must be applicable:

- Scheduling of the production step in times of higher RE generation than energy demands (Case 3, Figure 5)
- Interruption of the production step with continuation at a later time (intermediate stop)
- Using a machine with lower energy demand (only possible if machines can execute the same production step and the machine is available)
- Start of machines, which have high energy demands in the startup phase, to times of RE availability and hold in idle mode until it is used

These possibilities are usually applied in job-shop and semi-flow organized production. Further information about classification of manufacturing systems and their suitability for load-shifting are presented in the article [3].

After the optimization, the production plan is given to the responsible production operator (B1), and the production can start (B2). With continuous monitoring of planned energy versus actual energy demand, the operator tracks the status of the machines (B3). If the actual energy consumption differs from planned demands, and thresholds are exceeded, this could indicate problems at the affected machines (B4-5). In this case the problem leads to longer shutdowns of the machines, a rescheduling is recommended, considering the new situation in the production (B6-10). If no limit exceeds and all production orders have been processed (B11), the production day is finished.

4. Conclusion and future work

The paper presents necessary steps to introduce energy planning into PPC. The basis for energy planning is a running PPC system to schedule the production. The PPC system must contain all required production steps, which are necessary for producing desired outputs. Additional to material consumption and machine time, the energy data must be available. For energy planning, it is required to extend the system with new resources, e.g. those needed for infrastructure and for maintaining operational capacity including RE sources. Another requirement is that machine failures are addressed adequately. If processes run too early or too late, this could lead to lower cost savings and negative environmental impacts. To early-track machine failures in the production, the paper introduces a status monitoring method with the aid of energy planning. It should also be ensured that changes in the production scheduling because of rush orders or machine breakdowns correlate with the energy demand.

In future work, the procedure needs to be evaluated. For this approach, several analyses and improvements must be done: One is the testing, evaluating and improving of the energy forecasting module of our Simulation PREmdeK. The energy forecast by wind power and photovoltaic is done based on regional forecasting data already provided by the German weather service (DWD). Based on the results from the analysis, the deviation of forecast and actual RE generation related to the machine design of the RE source can be determined. Another analysis should be done to determine the deviation of planned to actual energy demand in the production. The results could be used as thresholds to indicate problems in the production and to determine the benefits in terms of cost and environmental impacts of energy planning with RE. For this, suitable companies need to be found.

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