GCSM 11th Global Conference on Sustainable Manufacturing
2013 23rd - 25th September Berlin - Germany

5.2 Requirements on the engineering of advanced standby strategies in automobile production

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Abstract

A key challenge in manufacturing industry within the next years is to reduce and optimize energy consumption of production systems without affecting productivity. To adress this problem, different approaches are discussed, such as smart grids, or utilization of more energy-efficient machine components. A new approach on shop floor level is to optimize production control strategies, to power down inactive machine components during non productive phases. To fully exploit this potential, it is necessary to integrate the planning of the required control systems into all phases of the engineering process. This paper presents a concept for the integrated engineering of these new applications by evaluating planning tools, methods and data models regarding their suitability to implement the concept of advanced power down and restart concepts. In conclusion, requirements on these tools, methods and data models are defined, to empower them for optimal support of the future engineering process.

Keywords:

Engineering Process, Standby Control, Energy Efficiency, Engineering Data Models

1 INTRODUCTION

1.1 Challenges

A current challenge in manufacturing industry is to increase energy productivity without adverse effects on output, availability and operational robustness. It is a strategic objective ever more recognized in industrial production to systematically save energy related cost and to generate competitive advantage by rationalized use of energy and reduced CO2 emissions. [1]

Aside from the energy oriented planning of products, processes and resources at the early stage, significant potential is attributed to energy oriented production planning and scheduling in the operative stage. Here, efficiency gains may be harvested by ‘energy-sensitive control of material flows, machines and peripheral systems’ in production systems. [2] As one aspect of this, the reduction of energy demand during nonproductive phases in production represents a promising approach. [3] While significant potentials have, among others, been identified in the fields of machine tools and body in white [4], [5] the problem of efficiently engineering dynamic operative manufacturing system control systems has not been sufficiently solved, especially when taking into account later implementation in industrial control systems.

Digital support for the design and implementation of control strategies and of control systems for an energy oriented production therefore remains open to discsussion. In current established practice, control system engineering does not sufficiently consider energy efficiency as a planning objective. To address this deficit, this paper presents a new approach for designing, optimizing and implementing production control strategies by integrating digital design and validation of these strategies into engineering.

1.2 Vision

To ensure a sustainable success of energy management, planning and control must be linked. Practicable concepts for the integration of digital methods are required, in order to evaluate and optimize energy efficiency of production systems. This must firstly integrate digital models, methods and tools for control system design and operation, in order to realize energy optimized production planning and scheduling and production control. Secondly, it must integrate a concept for energy oriented control system engineering.

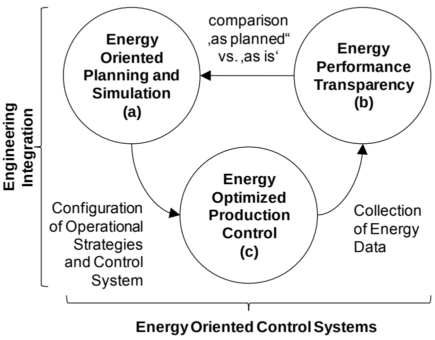

Figure 1: Integrated Key Applications.

This leads to a demand for three integrated key applications for energy oriented production control systems, as shown in Figure 1. First, planning and simulation applications integrating energy efficiency aspects must analyze the production systems in question to identify and validate improvement opportunities. Second, transparency with regard to both energy and production performance must be facilitated by intuitive access to the collected energy data, e. g. by innovative visualization methods. Third, energy optimized production control systems must implement efficient control strategies on different automation levels.

G. Seliger (Ed.), Proceedings of the 11th Global Conference on Sustainable Manufacturing - Innovative Solutions
ISBN 978-3-7983-2609-5 © Universitätsverlag der TU Berlin 2013

2 ENGINEERING OF ENERGY OPTIMIZED CONTROL STRATEGIES

2.1 Advanced Standby Strategies for Automated Control of Energy Saving Modes

During idle phases or during interruptions of production flow, a temporary transfer of machines, machine components or even entire manufacturing line sections into an Energy Saving Mode (ESM) of operation may tap economic potential. This may be implemented in different ways, e. g. as a temporary machine shut down during scheduled breaks, as a slowed mode of operation during phases of low utilization, or as power down procedures into ‘standby’ or ‘sleep’ modes during unplanned disruptions. For powering down a machine or device, multiple energy levels may be feasible. [6]

Similar as with consumer devices, ESM for industrial use represents a machine state where components required for quick power up and restart into production mode stay active, while nonrequired components are temporarily switched off and disconnected from the supply networks. During the resulting energy reduced machine state, certain restrictions on operative responsiveness and availability, e. g. powering up within a certain time, may apply. The duration of the energy reduced state and the transitional state may be called Energy Saving Phase (ESP). Figure 2 shows the principle of this behavior for a machine that consumes electrical power.

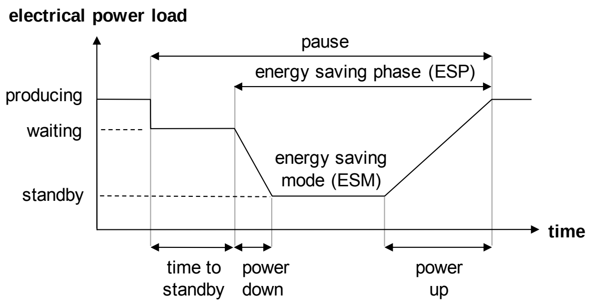

Figure 2: Electrical Power Load during Switching into ESM.

To put machines into ESM requires control mechanisms, composed of both hardware components (physical control systems, able to control the energetic behavior of machine components) and a processing logic (based on a decision strategy). Such an Energy Saving Control (ESC) may be located on different automation levels, either in a software application (e. g. on ERP or MES levels) or in industrial control systems software (e. g. on PLC or PAC levels), or as a combination thereof. Implementation of the necessary software algorithms may be built on existing automation systems hardware by integrating new protocols, such as PROFIenergy. [5] The required logic, formulated in an Energy Saving Strategy (ESS), must be the output of energy oriented engineering. These strategies may be labelled ‘advanced’ if able to process additional information from the production process and its ambient conditions in an anticipatory way, so as to adaptively react to dynamic energy demand and to accordingly control the ESM. Such advanced ESS can take into account e. g. material flow information on line level, thereby dynamically identifying situations advantageous for power down during low utilization conditions or failure situations, as shown in [6]. Since these strategies may be installed on different factory levels, several automation levels must be addressed. As shown in [8], various ‘energy control loops’ can be implemented to control the energy flow in production autonomously, requiring new information flows and communication mechanisms. This represents a future challenge for the implementation of industrial automation systems, able to realize those energy optimized control strategies. Obstacles to efficient information sharing and reuse in the field of Sustainable Manufacturing have been stated: Lacking standards for information representation, lacking interoperability among engineering applications, and lacking consistency across information modeling approaches. [9] It follows that requirements to innovate the engineering processes and to accommodate effective ESS design and implementation need to be identified. [9] Generic requirements should therefore be known and formulated, in order to adapt traditional engineering processes.

2.2 Involved Engineering Steps

To implement an ESC for ESS all engineering phases within the engineering processes of the digital factory [10] have to be adapted to the new requirements. Energy efficiency has to be integrated into plant design, into the mechanical and electrical construction steps, the programming, the plant manufacturing and assembly, the virtual and real commissioning phases as well as the ramp up stage (Figure 3). First basic decisions for an energy optimized plant layout thereby can be taken in the design phases. Afterwards, in the successive realization phases, results from the design phase may be built on to implement new control concepts like ESCs.

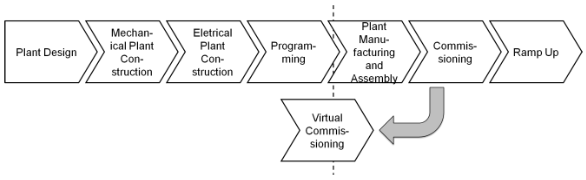

Figure 3: Engineering Steps according to [10].

2.3 Relevant Engineering Information

In [11] the concept of ‘planning objects’ is introduced. According to this, one single information object may be used to combine all relevant information to a real existing object. This can take place along the entire planning and realization process. Different levels of automated production systems can thus be modelled by aggregation of lower level objects into higher level objects.

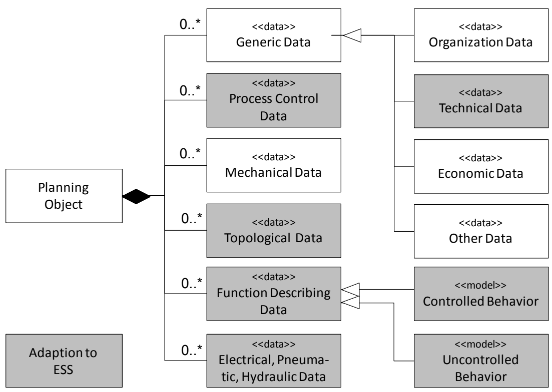

Figure 4: Information Model for ESS.

The main advantage of this concept is to provide a specific view on a planning object for each engineering task. This view only includes the relevant models and corresponding information. For the future task of designing ESS, a new engineering view therefore must be provided. Different data views that belong to a planning object must be adapted and extended, as shown in Figure 4. Thus, a distinct new ESS view can be defined. To integrate all necessary information for the design of ESS into the concept, at least five informational entities must be included in the different data blocks of a planning object. These are:

1. The physical manufacturing area involved, defining the machines and components affected by power down or shut down, must be enclosed in the view.
2. The conditions for power down and power up, such as logical conditions or time conditions, should be specified both on line level (i. e., for interconnected machines) and on machine level (i. e., for machine components).
3. The required shut down sequences, both on line level (e. g. for sequential machine shut down, resulting from informational interaction between machines and/or transport and handling systems) and on machine component level (i. e., the specific power down sequence), must be included.
4. The transition times for the transfer into and out of ESM.
5. Boundary conditions, such as technical restrictions for the maximum allowed frequency of ESM per hour in order to limit component wear out, or even conditions when ESM should be omitted, might also be included in the view.

As this list is noncomprehensive, this view may be complemented with further information when necessary.

2.4 Relation of ESS information and engineering steps

Figure 5 shows this allocation of the previously stated informational entities to the relevant planning phases. For the application of control systems implementing ESS, the specific information (a) has to be processed in different engineering steps (b). For example the ESS relevant topology data are used in all phases from plant design to plant manufacturing and assembly. In contrast to this, the functional description data are only used in later stages of the process.

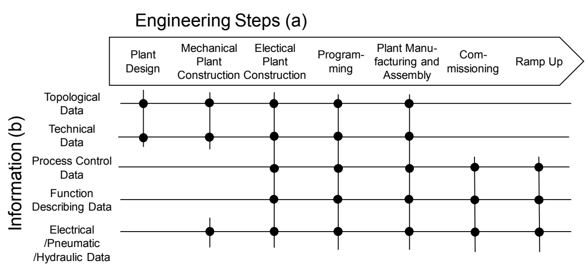

Figure 5: Information Flow between Engineering Steps.

3 GENERAL REQUIREMENTS

3.1 BWM Classification

Within the planning process of automation systems, each engineer needs different auxiliary means to execute his specific engineering tasks. In [12] these resources are classified into three categories, called ‘BMW’ classification:

- B (german: ‚Beschreibungsmittel‘) – Data models provide means of formal description.
- M (german: ‚Methoden‘) – Methods.
- W (german: ‘Werkzeuge’) – Tools.

The first category includes both engineering models and data models. These models shall be able to contain all relevant information needed to execute an engineering method. This might be information regarding a single object, a relation between objects or the formalized behavior. The second category includes methods that describe, in a systematic fashion, necessary activities to obtain valid results in the corresponding engineering step. The third category contains tools supporting method execution. These must offer specific functions to the engineer that can be used to implement the methods.

All of these categories have to fulfill certain general requirements to support the objective of implementing ESS. A collection of these new requirements is presented in the following subsections.

3.2 Data Models

Requirements on engineering data models can be subdivided into two subgroups, the first related to static information models and the second to the description of the dynamic behavior of the energy optimized system.

Requirements relevant to static models are:

- Informational descriptions of energetic machine states that are coherent with nonenergetic operational states.
- Attributes to system states and transitions that relate to energy use.
- An energy view extension, assuring that energy demand and consumption can be derived from the model.
    - Extensions for data handling and information management, including metadata management.
    - Known energy consumption behavior, such as energy profiles.
    - Restrictions, such as limits for the frequency of occurrence of ESM.
    - Models to maintain relevant energy related data over the production system lifecycle, so that informational entities can be connected over time and over successive engineering and implementation steps.
- Model parameters for dynamic analysis and experimentation.
    - Requirements regarding energy use, e. g. admissible values for peak load.

Requirements relevant to dynamic behavior are:

- Adapted dynamic behavioral descriptions of machines and components to include the energetic behavior, such as models to describe the switching and operating behavior of energy optimized automation systems as described in [13].
- Interaction and conflict resolution rules between energy efficiency objectives and other efficiency targets.
- Formalized description of ESS, e.g. concerning the implementation as a reactive, a prospective or a combined logic. [7]
- Interaction models for the communication of energy related information inside the production system.

3.3 Methods

In the category of methods, the following general requirements can be stated:

- Procedures to facilitate model building for energy calculation, including approaches to adopt and reuse existing models for energy analysis so that no new models must be build from scratch (or only if the anticipated gain of knowledge justifies the effort).

- Ability to analyze energy efficiency at different levels of abstraction and granularity. [9]
- Efficient ways to prepare input data for use in dynamic models, and procedures for efficient experiment design and execution and for result documentation. This includes the ability to transform input information into computation-friendly forms for analysis and optimization. [9]
- Quantified uncertainty analyses must become part of the verification and validation procedures. [9] This requires suitable validation and risk measurement indicators for scenario evaluation.
- Intuitive ways to support the quick evaluation of generated results and output data, such as innovative visualizations.
- Ability to couple modelling methods with a suitable portfolio of optimization methods and algorithms.
- Integration of requirements from control systems design and automation standards.
- Ability to implement the control as a central or autonomous control on a certain automation level.

3.4 Tools

In the category of tools, a number of requirements can be formulated:

- Interoperability of systems needed for energy efficiency assessment and aggregation of suitable metrics. [9]
- Support for energy views, integrating energetic parameters and models for energetic behavior.
- Efficient storage and exchange of relevant information. [9]
- Functions to combine static energy information and dynamic energy behavior models.
- Functions to calculate aggregate and specific energy demand and consumption from the models.
- Integration of or coupling with suitable optimization algorithms.
- Appropriate human machine interfaces.

3.5 Adapted Business Processes

Additional to the requirements on the models, methods and tools, the business processes have to be adopted for an economic and verified implementation of ESS. Following challenges regarding the process should be considered:

- Descriptions for operative procedures, e. g. adapted planning processes.
- New factory acceptance processes.
- New testing methods for ESS and ESC implementation during ramp up.
- New operating strategies.
- Adopted development and implementation milestones, including new decision and checking points and quality gates.
- Adapted description standards for energy aspects.
- Adapted specification sheets and functional specification.
- Adapted parameters for purchasing departments.

Though this list of changes in the business processes, just as the engineering information stated above, is noncomprehensive, it illustrates the complexety of nontechnical restrictions that must be considered in the introduction of ESS into planning processes.

4 APPLICATION CASE: STANDBY STRATEGIES IN AUTOMOBILE PRODUCTION

Subsequently, an exemplary approach for the stated principles and procedures will be presented. The underlying assumption is that the design of ESS can be supported by digital models. These can be used to analyse the potential, to optimize the decisional logic and finally also to implement the operational control logic in industrial automation systems. Support in different fields of activity is required, such as material flow analysis and energy flow analysis, combined optimization of both, and in implementing the strategies into control systems. Figure 6 provides an overview over these fields in the form of a method matrix. Envisioned result of this approach is the generation and formal description of premises for power down and restart concepts. This provides the basis to program and implement ESCs.

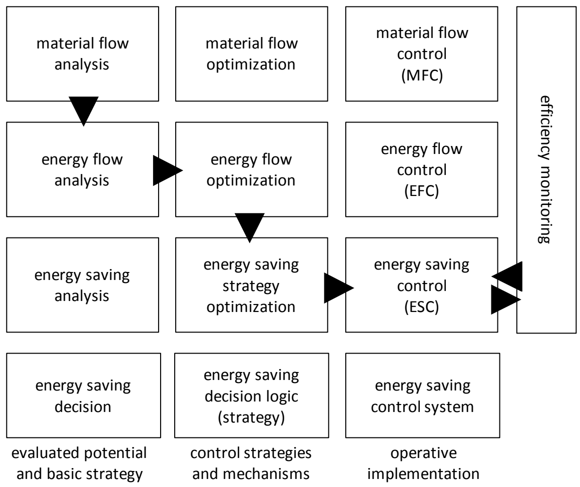

Figure 6: Method Matrix for ESC.

4.1 Production System Model Building

Discrete Event Simulation (DES) is an established method of the Digital Factory [10]. It represents dynamic processes of a system within an experimental model [14] and may typically be used to analyze material flows. Taking the view of ‘dynamic processes’ as interconnected material and energy flows, these simulation models may be augmented by energy flows to help calculate and analyse the energy consumption of complex production systems.

A widely followed approach in industry is to use standard libraries for digital model building to reduce modelling cost. Providing energy modules as part of these libraries allows to significantly reduce the modelling effort and to increase the reuse of existing simulation models. Implementation of this approach has been demonstrated on established simulation tools to assure conformity with existing processes of automobile manufacturing. [15] An example of this is the adoption of the modeling and simulation tool ‘Plant Simulation’ (an established standard tool for material flow simulation with major German automobile manufacturers and suppliers) to the analysis of energy consumption, as shown in pilot studies in component manufacturing and body in white manufacturing. [7], [15], [16], [17]

4.2 Production System Analysis

The first question of analysis amounts to a quantification of non value adding energy consumption and of the resulting saving potential for implementing ESM. To start with, ESM is only viewed on machine level and component behavior inside the machine is not considered. Following this approach, ESS are simulated based on the overall material flow in the system on manufacturing line level. [7] To implement this, the model objects representing machines are put into ESM and the material flow is stopped in certain predefined situations, i. e., when defined conditions are met. These conditions must be specified in the model. In this manner, selected control strategies that are most feasible for operation can be deduced from the model in the course of experiments.

Results of this analysis are:

- Occurrances of ESM at each simulated machine in the manufacturing system with given simulation premises. This can, for example, be used to show that defined standby frequency limits are not exceeded.
- Quantified energy saving potentials for the simulated machines with given production premises, e. g. product mix, setup time, tact time, failure scenarios, based on a given standby configuration. The latter may include the definition of allocated machines, of transition times, of material flow conditions, the dependencies between components, machines, transport and handling systems and control systems, as well as the specified power loads in different energy levels.
- Improved understanding of the effects of different standby parameters, such as transition times, and of specific energy consumption in ESM, both on the overall energy consumption and on the production output.
- The interacting effects of the different strategies applied, and a more complete understanding of the energy reducing effects of the strategies, and on their effects on output, on the utilization of machines and conveyor systems and similar performance measures.

Still, material-flow-oriented control strategies can be analyzed even without coupling the simulation model with a physical control.

4.3 Optimization

Innovation oriented production systems must ensure optimum productivity while considering various restrictions in the planning and execution of production processes. [18] With regard to energy saving production systems, the purpose of optimization therefore must be to identify optimal technical design structures and operating points for the engineering and implementation of ESS.

A typical overall optimization issue is to assure that the execution of machine ESM does not affect operational productivity and output requirements are met, while reducing product-specific energy consumption. Further aspects may be integrated into analysis, such as disturbance reactions or dynamic failure behavior resulting from recurring power down and power up transitions. In connection with the achieved energy reduction, the particular standby parameters (see 2.3) under the above mentioned restrictions can therefore be subjected to optimization. The respective potential can be located in different areas, as described below.

Economic Feasibility of ESS

Overall, the feasible energy saving potential over the production system lifecycle must be made transparent and confronted with the predicted cost for design and implementation of the required control systems in the engineering process. To the degree that ROI is anticipated, up front costs into necessary hardware and software systems can thus be justified. For this, invest into necessary hardware components must be known.

Technical Feasibility of ESS

Achievable energy savings must be balanced against known and suspected technical and operational risk. This comprises risk to system and process reliability, e. g. incurred by instable machine behaviour due to new complex control systems interactions. Another risk is the additional machine wear that is caused by frequently powering down and successively starting up the production hardware and control systems. Further, risk to productivity results from nontimely start up procedures, from increasing sensitivity to failures and from the resulting need for additional maintenance. Though hard to predict, the evaluation of these critical issues within the context of saving energy provides a promising field for optimization.

Specific ESS Configuration

As listed in 2.3, various configuration parameters, e. g. transition times or power down sequence, determine the specific characteristics of the standby behaviour of a machine. The identification of favorable parameter values may be optimized and balanced against the anticipated engineering effort that is necessary for developing and implementing components with the required behaviour.

Finally, machine based strategies may be evaluated against material flow oriented strategies as well as in combination of both, as [7] has shown,

Standby Application and Scaling of ESS Deployment

This issue concerns the question a) which machines respectively production areas should be subjected to ESM in general and to what degree they can contribute to overall energy savings, b) which strategies should be applied to which machine and c) on a technical level, the configuration of an optimum number of specific ESM and energy levels per machine.

A further question may be addressed by determining suitable manufacturing conditions under which ESS may favourably operate, with the prospect of implementing dynamic concepts where the validity of the ESS changes over time, i. e. the ESS acts only during specific periods.

Another approach is to minimize power down and shut down occurances respectively due to technical insecurities, in favor of slowed operation. In this context, rules for allocation of these strategies, their temporary disablement or even for dynamic switching between different strategies may be tested for optimality regarding the above mentioned targets. This can include the question where actual automated control is necessary and where maybe human interaction procedures can sufficiently assure energy reduced machine modes, as during shift breaks or scheduled pauses.

4.4 Transfer to Field Control Concept

In a final step, the results of the optimization phase have to be transferred from ESS to field control concepts. Here, several challenges have to be solved:

- The engineering data exchange towards PLC programming has to be supported.
- ESS have to be implemented into control programs afield.
- The specific field communications between the ESC and the different single devices that can be switched into ESM on different energy levels have to be designed.
- ESS have to be implemented such that after switching between different ESM or energy levels, all single devices as well as the entire line or plant still works correctly.
- This part of the engineering process has to be optimized for future projects.

For these challenges prototypical implementations currently exist. The data format AutomationML is used to organize the data exchange. Implementation according to the PROFIenergy specification is a means to realize the field control system and the communication between the devices. For validation new energy specific simulation models have to be implemented in tools of virtual commissioning. Further, a common approach must define libraries for engineering process optimization and reuse of project results.

5 SUMMARY AND OUTLOOK

Significant potential may be attributed to energy optimized control of production systems. Advanced control mechanisms may be used to implement intelligent strategies for powering down and restart machines and components during nonproductive times. The logical decisions taken by the operative control systems to perform this kind of behavior on shop floor level must be formulated in strategies to facilitate the predictive analysis and optimization as well as the efficient implementation of energy optimized control. This leads to a demand for the validation of these control strategies in early planning stages and for the support by digital models, methods and tools. Integrated concepts are needed to innovate the engineering process accordingly. This paper has stated a view on the general requirements that should be fulfilled to arrive at this objective. Concluding, in an exemplary pass through the consecutive steps of production system model building and analysis, optimization and, finally, transfer into the field automation concept, selected challenges are stated that govern the current practical engineering process.

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