An IT-architecture to support energy efficiency and the usage of flexible loads at a container terminal

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Abstract

This paper presents a component-based software architecture that enables a container terminal to optimize their energy demand and the flexibility of this demand. This flexibility is gained from using energy-intensive battery-powered Automated Guided Vehicles (AGVs) for container transport within the terminal. While Demand Response strategies are known and already applied in some industrial branches, it is not yet common in the logistics domain due to highly dynamical and time-critical processes. In order to forecast the energy demand for the terminal and to be able to optimize it while having constantly changing logistic processes, the architecture includes modules to process a simulation based forecast of the power demand, optimize the demand by changing battery charging plans and to control the execution of the optimizations.

1. Introduction

In order to take part in new possibilities of the liberalised energy market and because of the growing influence of renewable energies, customers can adapt their energy consumption in regard to the variable price of their energy supply or they can adapt their consumption patterns in regard to the availability of renewable energies. They can even help to stabilize the grid by offering control reserve energy. New consumer behaviours are expected to emerge when E-Mobility is growing from only a few vehicles to a mass market. Software is needed to support the customer in optimizing their energy demand by reacting to different price or availability signals transmitted by the energy supplier.

In integrating flexible loads of the customer side, especially loads of large industrial and business enterprises, a high potential for supporting grid stability is seen. But not only from a grid point of view, but also from the sales perspective and from the customer side the possibility for new concepts is given. Using the terms “Demand Response” and “Demand Side Integration” the possibilities for influencing customer loads are discussed for quite some time and the first commercial contractors have entered the market to not only focus on large industries but also support small and medium enterprises to benefit from the liberalized power market. Pooling of different customers with flexible loads to one virtual customer (“virtual power plant”).

When E-Mobility is established flexible loads arise and can be used in industrial or commercial enterprises which are not a common part of the power market or known for their flexible energy demand. This is for example the case in a sea-side container terminal that is using automated

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guided vehicles (AGVs). At the Container Terminal Altenwerder (CTA) in Hamburg several AGVs are now equipped with battery-powered engines. The batteries introduce flexibility to parts of the power demand because the battery charging can be shifted in time. Since daily business at the terminal is very variable, a forecast of the terminals utilization and the respective energy demand is needed to determine potentials for load shifting and to use it effectively. A software system supports the use of the gained load shifting potential and supports the power demand forecast. The components of this software are described in the following chapters.

First, this paper provides a short introduction to the terms “Demand Response” and “Energy Demand Forecast” at container terminals, before the software architecture to support the energy demand forecast, the use of the flexibility in the power demand and the control of the power consumption at the terminal is introduced. The paper closes with a summary of the current implementation status and an outlook on future integration plans.

2. Demand Response and Energy Demand Forecast in a Container Terminal

Demand Side Management is defined as “[…] activities which involve actions on the demand- or customer-side of the electric meter, either directly caused or indirectly stimulated by the utility.” [1]. To be able to react in a flexible way to outside stimuli one needs a deep knowledge of the energy consumption patterns at the customer side. In an industrial enterprise with continuous and recurrent production cycles the energy demand can be forecasted with rather simple methods [2].

Optimization of the power demand can, besides others, include the following goals at the customer side:

- Load shifting and peak clipping
- Confirmation of the forecast to the supplier
- Offering balance energy
- Offering operating reserve

While the topics load shifting and peak clipping are not really new to applications of energy management, often described in the context of Demand Response [3], the other points are fairly new to the market, at least in Germany, and standards and processes for these use cases are still under development and are referred to in the context of Demand Side Integration [4]. Especially the communication from the consumer to the supplier lacks in standardized implementations. Some standards like IEC 61970/61968 might be a basis, but architectures for using it are rarely implemented [5]. Energy-related studies indicate that there is an overall potential for Demand Response and Demand Side Management of 60 GW in the European Union [6] and 8,5 GW in Germany [7].

While the studies also name some industry divisions with the highest potential, the division of logistics is never mentioned [7][8][9][10]. One reason for this might be that logistic processes are highly dynamical. For example, in a container terminal they are depending on the number of ships and containers to be handled. These numbers vary from day to day and do not follow any pattern. The energy demand is therefore highly dynamical as well. Also the potential for load shifting or other optimization goals seem rather low since the processes are not flexible in their time. This changes when E-Mobility is introduced. If battery-powered vehicles are used at a logistic enterprise the logistic processes are in parts decoupled from the corresponding energy consumption. At CTA, for example, ten AGVs are equipped with two battery systems; one is always used directly in the AGV, while the other one is charging in the battery-charging station. Since it takes less time for charging one battery system than the duration of AGVs operating time with a fully-charged battery system, flexibility is introduced to the power consumption of the battery-charging station.

3. An software architecture to support the use of flexible loads

Software to support Demand Side Management in a container terminal has to be aware of the logistic processes of the terminal. The battery usage in general and therefore the time of a battery exchange request of an AGV are highly dependent on the time points of ship arrivals and the number of containers to be handled. If the power consumptions of the AGVs as well as the entire terminal are known, the charging operations can be controlled in such a manner that the overall energy demand is affected in an optimized way. Battery exchange times and battery charging can be shifted in order to do so. Respective operating systems have to be informed of the change to their default behavior, the execution of the planned optimization has to be supervised and adaptation strategies in case of deviations must be applicable.

The proposed architecture is built up of the following three modules:

- The Logistics Simulation module
- The Energy Demand Optimization module
- The Energy Controller module

These three modules and their sub-components will be described in the following chapters.

3.1. The Logistics Simulation module

The Logistics Simulation module is responsible to forecast the container transport request which have to be dealt with the AGVs and the power demand of the entire terminal. The module includes components for the storage area, transport area and the quay area (“shipping”). The shipping component simulates the arrival and departure of the ships based on the list of sailings. In order to unload the container from the vessel a specific number of quay cranes is assigned to each ship. This number depends on the number of containers and the planned retention time of the respective ship at the terminal. The transport module simulates the AGVs, which transport the containers from the quay cranes to the storage/stacking area and also the other way around. They use a fixed layout of possible routes but find their way through the routes dynamically. AGVs without a current transport order drive to parking positions and wait for the next order. If a battery system of a battery-powered AGV drops below a certain charging level, the AGV drives to the battery-exchange station to switch the empty battery-system. The discharged battery system is automatically removed from vehicle and stored for charging. A charged battery system is entered into the AGV that is continuing operations after the exchange. The time point of a battery change is logged to have a starting point for load optimization later on. The Storage is divided into 26 yard stacking depots and one depot for refrigerated containers.

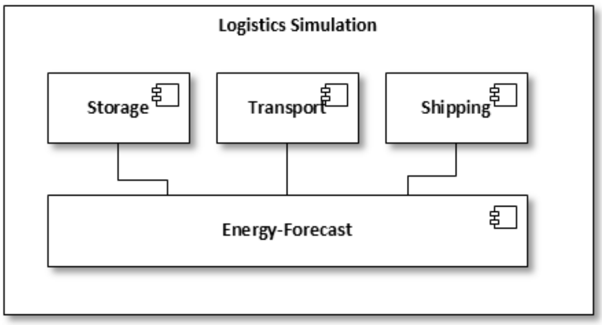

Figure 1: Components of the Logistics Simulation

While simulation of logistic processes in a container terminal is not really new (a literature review can be found in [11], for example), the focus has never been on the power demand. During a simulation run the power consumption is recorded for every involved actor, each having an individual energy usage model. For example, the lighting of the terminal has static power consumption depending on the time of sunrise and sundown, while the quay cranes have an energy consumption based on their current task like lifting a container, putting down a container or moving a container. From the power consumption of each consumer in the simulation an overall power consumption of the terminal can be calculated. A power demand forecast can be generated by starting the simulation the day before the processes are actually executed.

3.2. The Energy Demand Optimization module

The total energy consumption and the time points of battery exchanges from the simulation are input parameters for the Energy Demand Optimization module. Additionally, it uses processed price or priority signals from the Energy Controller module. Depending on the optimization goal the Energy Demand Optimization module optimizes two parameters:

- the charging of the battery: optimizing means to charge the battery in time slices when the energy price is low or when possible benefits are high
- change the time point of a battery exchange: in some cases it might even be useful to call an AGV to the exchange station earlier than waiting for the charging level to drop below the limit for a battery exchange

The module can use different strategies to optimize the demand regarding the use cases mentioned in the previous chapter. One rather simple strategy can be to charge the batteries at times when the spot price is low. Another strategy could be to charge the batteries primarily in times when the power generation from renewable energies is high. The optimization has to be done after the simulation, since the exit times of the batteries from the charging station are only known during runtime of the simulation and not a priori.

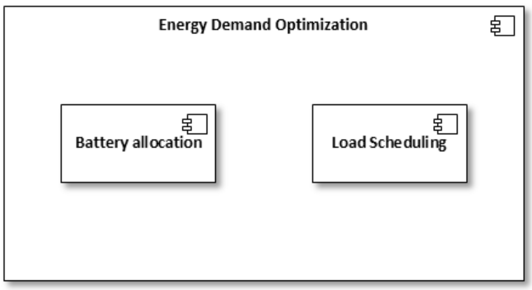

Figure 2: Components of the Energy Demand Optimization module

The result of the energy demand optimization is an operating schedule for the battery-powered AGVs and charging schedules for the batteries while they are stored in the charging station. It is important that the optimized operating and charging schedules have no impact on the logistic processes that have to be handled. One constraint is that the departure time of a ship must not be influenced. It has to be able to depart at the same time as it would do without any optimization. To check this constraint the simulation is executed a second time with the same sailing list as before but with the optimized schedules for the battery exchange and the charging of the batteries.

3.3. The Energy Controller module

The Energy Controller module is responsible for communication with external applications like the terminal ERP-system for ship arrival and departure plans (the so called sailing list), the AGV and Battery Management System for controlling the execution of the optimization and the external price signals. From the energy service provider it receives next day's energy prices and prices for control reserve energy services. These are passed on to the Energy Demand Optimization so it can optimize the energy demand regarding these price signals. It is also possible to send a forecasted energy load curve to the energy service provider so that he can use it for his very own forecasting purposes. The unit controller is responsible to pass the calculated plan on to the Battery Management System (BMS) and the AGV Management System so that they are able to execute the battery changes and the battery charging according to the plan.

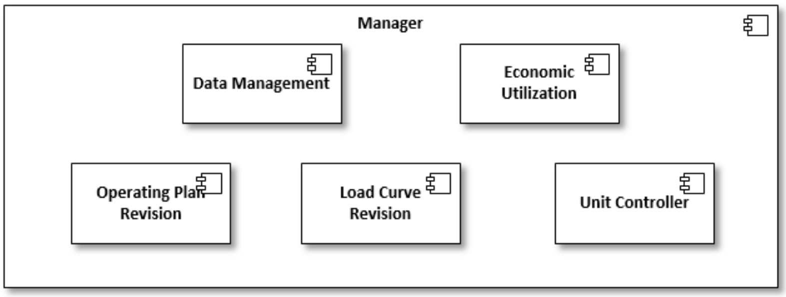

Figure 3: Components of the Manager module

The most challenging part of the Energy Controller is to observe the execution of the plan and to react to changes that affect the planning. Two components are responsible for this: the Load Curve Revision and the Operation Plan Revision. The first component is in contact with the energy management system where the currently metered data of the terminal is available. The metered data is constantly compared to the forecasted load curve. If the forecast is deviating from the current consumption, the plan might not be valid anymore. The same occurs when the Operation Plan Revision, which is contact with the AGV and the Battery Management System, recognizes that there are deviations between real world execution and the planning. Different strategies can be applied if a plan deviation is observed. The plan can be adapted to the new situation or the plan can be discarded. In the second case a defined default behavior of the AGV and the Battery Management System is required, which is used as back-up. This is also the behavior during the first run of the simulation before the optimization.

Figure 1 shows the single components of the architecture as well as the interfaces to the external systems.

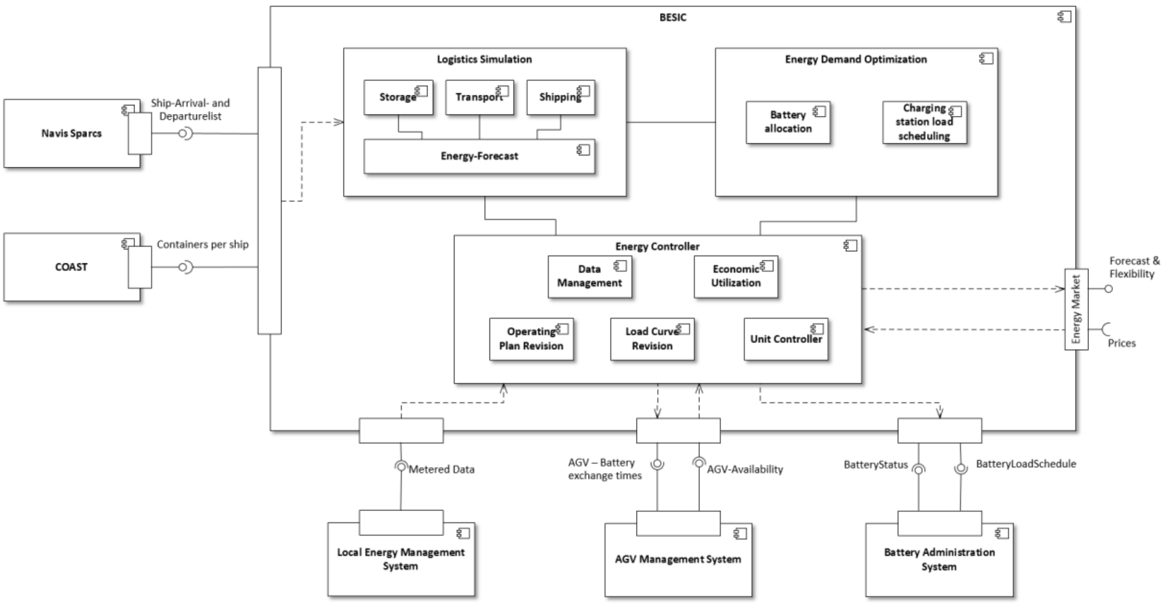

Figure 4: Overall system structure with external components and interface

3.4. Process flow of the application

The process usually starts the day before the actual logistic processes take place. At this time the ship arrival and departure list is quite reliable, energy prices for the day ahead spot market are known and the supplier has enough time to adapt to the forecast.

First all input data is gathered. Needed is the ship arrival and departure list including the number of containers to be handled per ship. This data is input for the simulation. Price signals, RTP-Prices or prices for control reserve energy offers are needed for the later optimization.

If the input data is available, the simulation is started. Result of the simulation is a forecast of the energy consumption for all consumer groups (including the battery charging station) as well as the overall energy consumption of the terminal. Additionally, the times of the battery entries and exits to the charging station are known. All this data is passed on to the Energy Demand Optimization module where the demand is shifted to provide an optimal energy supply. Optimization can include different entry and exit times of the batteries to the charging station. To verify that all logistic processes work with the different changing times as well as without, the simulation is executed one more time with the changed parameters. If the plan cannot be verified because the logistic processes are interfered the optimization is started one more time with a different goal or it is discarded and the initial timetable of battery exchanges from the first simulation run is used. The last option means that no optimization has occurred. A valid plan is passed to the AGV and the Battery Management System.

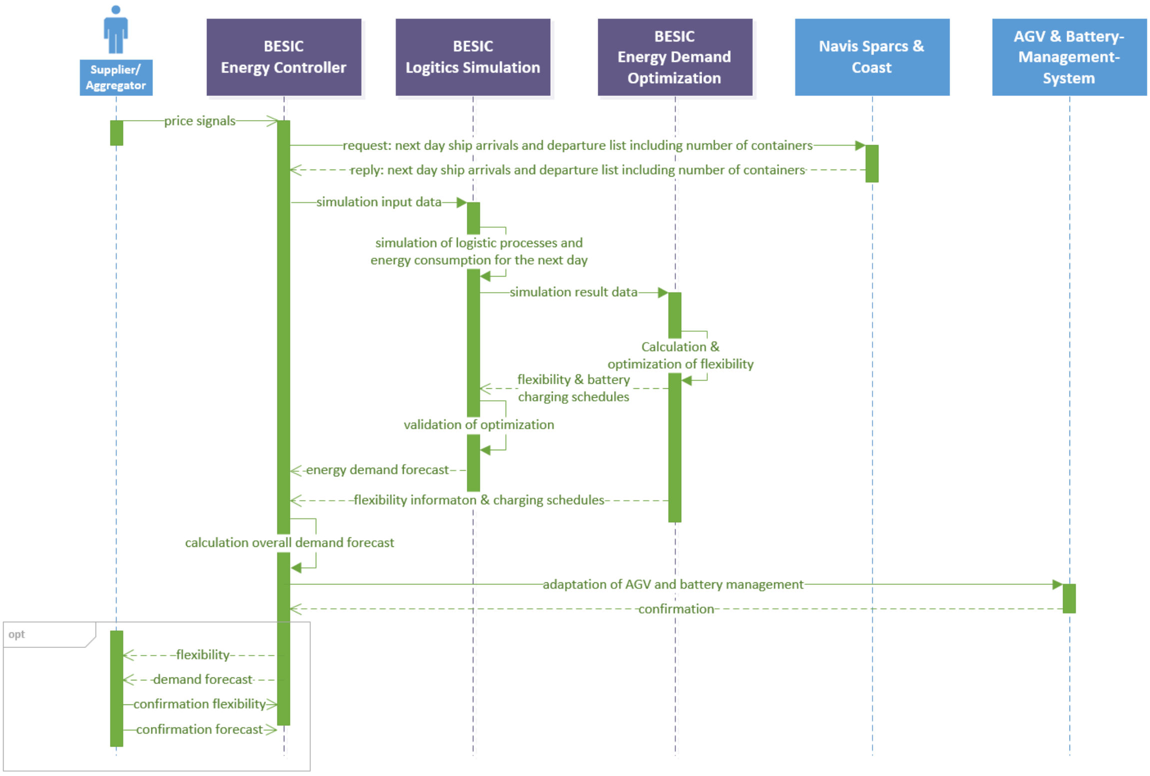

Figure 5: Sequence diagram with the information flow during the forecast and optimization process

At the time the forecasted logistic processes are actually taking place, the execution of the battery switching and the charging schedules is surveyed constantly. If a deviation of real world processes is recognized the planning is discarded and default behavior for AGVs and battery charging takes place. This way interference of the energy demand planning with changed logistic processes is avoided. Reasons for a deviation might be a delay of ship's arrival or the delay in processes due to weather conditions.

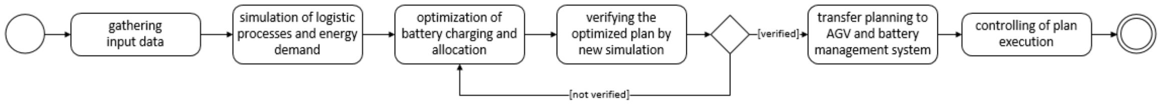

Figure 6: Steps of the software including control

3.5. Integration of the architecture into an energy management system

Since CTA has not implemented a complete energy management system (EMS) yet, the architecture is designed to be able work as stand-alone application with respective interfaces. At the time when an energy management system is fully installed at CTA, which is planned to be done soon, the architecture will be integrated into this system. Energy control and surveillance features can be executed and controlled by the energy management system itself. The EMS continuously meters the power consumption of all consumers at the terminal. One main function of the energy management system will be, besides collecting meter data, the avoidance of new power peaks during terminal operations. Besides the battery charging station, other switchable consumers, e.g. lighting or air conditioning, will be switched off when a new power peak is approaching within a 15 minute time range in order to avoid this peak. Parts of the Energy Control module could be executed directly from the energy management system since the metered data and some control functions will be available there. The Logistics Simulation and the Energy Demand Optimization module are not expected to be part of the energy management system, so further interfaces will be developed to integrate the simulation and the optimization as smooth as possible.

4. Current implementation and outlook

The Logistics Simulation module is fully implemented and in parts validated. First results of the energy demand forecast showed a need for modification of the energy consumption from some consumer groups. While the forecasted load curve relates to the load curve metered in real operations it was generally too low. Modifications have been applied to the static consumers of the terminal like lighting and offices. Additionally the hinterland connection was reworked to have a more realistic consumption pattern.

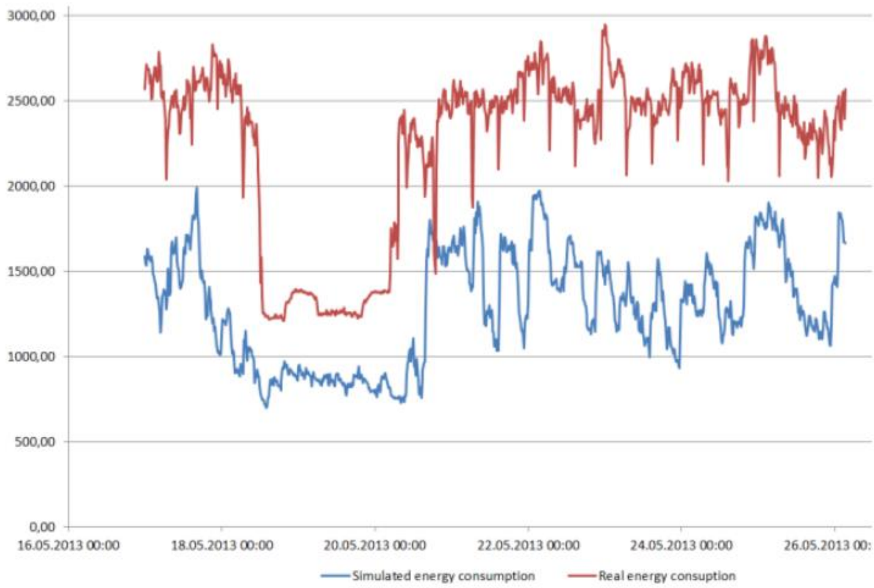

Figure 7: Simulated and real energy consumption before modification

The Energy Demand Optimization module is currently implemented. First optimized battery charging schedules have been calculated and could be verified by the simulation. A user interface for manual adaptations is available. Further optimization strategies still have to be implemented and tested. The Energy Controller module is not yet fully implement. A module to receive price signals from the stock exchange and from the control reserve energy platform is in place. A reading interface to the AGV management system will be available soon. The needed data is provided by the AGV and Battery Management System as XML-log data and just has to be read out. For the controlling of a Battery Management System the concept has been worked out in detail. The load curve revision and the operating revision still have to be implemented. Additionally, an overall application interface that assembles all the different modules and controls the process flow is currently developed. Future work is the direct integration into an energy management system. This has not yet accomplished since an energy management system is not yet in place at CTA.

Further research will be conducted to include strategies for integration of renewable energy generation. E.g., CTA is thinking of installing a wind turbine within the terminal. To use the generated power of this station would have the highest preference during optimization. Further parameters like wind prognosis data would have to be integrated.

Another research topic is the adaptation of generated plans and schedules to a changed real world situation. As described in chapter 3.4, a deviation from the forecasted processes to the execution in the real world leads to a cancellation of the charging schedules and to a return to default behaviour. Possibilities to adapt generated schedules in regard to unplanned events will help to have a higher probability that the energy consumption will follow an optimized planning.

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