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Improved energy supply for non-road electric vehicles by occasional charging station location modelling

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ABSTRACT

Electric mobility has significantly changed perspectives in the mobility sector. Major challenges require the efficient design of systems energy consumption and supply, so that developments focus on battery related improvements such as charging infrastructure integration, recharge process optimisation, battery technology and cost reductions. The concept of occasional recharging is to provide additional usable battery energy to the system without additional disturbance of processes, while using existing process sequences and process interruptions in optimised infrastructure allocations.

Existing models for charging infrastructure allocation to target at maximal demand coverage being determined by vehicles' range demand. Electric supply system integration for occasional battery charging showed the necessity to change the existing demand coverage definition, so that material handling process characteristics include potentials for system adaptions and increased efficiency as alternative demand to be covered. This innovative approach changes the perspective on demand coverage to present a potential within existing processes instead of an additional effort and addresses the shortcomings and recommendations of existing research approaches for an endogenous covering distance, more detailed and precise energy consumption values and the integration of real process information.

Case study investigations showed increased Usable Battery Energy of +40% to +60% and the allocation improvement based on the innovative framework.

1. Introduction

In recent years global energy demand has exceeded its supply and forecasts predict this consumptions to increase for another 50% at least until 2030 [19]. Constantly increasing energy prices and decreasing natural resources have joined this trend and make producing companies require technical solutions for more ecologic and resource saving equipment, procedures and processes [2]:1). Due to this, and fostered by the demand for increased sustainability and system availability, the traditional objectives of industry such as cost, time, quality and operating efficiency have been amended by energy efficiency, system flexibility and adaptability [24]:1).

In reference to sustainable production strategies, companies show more and more willingness to integrate ecologic aspects in production planning and operations. Thus, this new ecological and economical consciousness has made battery electric vehicles (BEV) be the most suitable alternative to internal combustion engine vehicles. Fully electric vehicles do not emit tailpipe pollutants and convert about 59%–62% of the electrical energy from the grid to power at the wheels, while conventional combustion engine vehicles only convert about 17%–21% of the energy stored to power at the wheels [27]. Electric vehicles are used in public transportation as buses and cars which are classified as road electric vehicles (rEV), while material handling related electric vehicles such as forklift trucks or order pickers refer to non-road electric vehicles (nrEV). Non-road electric vehicles can further be differentiated among automated and non-automated alternatives. Non-automated vehicles are controlled and steered by human operators, whereas automated guided vehicles are remotely controlled by a central IT unit [4]. Developments in this area focus on the increase of flexibility in order to catch up with the high degree of flexibility of non-

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automated systems, whereas current industrial implementations are majorly based on material handling function execution on predefined, fixed routes [21].

As forwarding material handling equipment requires energy to process the desired functions of a supply chain [17]:4), energy provision, storage and consumption are crucial factors to system stability, availability and efficiency [29]. In reference to the supply of power to handling systems, recent technology developments allow fast connection and high performance transfer of electric energy, so that several process sequences are subject to conversion from unused non-value adding times [5] to interim, occasional recharging sequences. This new perspective was taken seriously into consideration in the pursued research project on the development of an allocation model for optimised energy supply infrastructure for occasional recharging of nrBEV.

2. Fundamentals

2.1. Requirements of material handling systems

Physical resources need to be planned, implemented and designed specifically adapted to the manufacturing needs in order to efficiently support production operations [6]. One of the physical resources in manufacturing and logistics facilities is the supporting material handling (MH) system, since it helps manufacturing and logistics facilities to improve their productivity, enhance quality of products, and reduce operating cost [16]. By this it constitutes a significant component of supply chains that affect overall operations [15]. Designing a MH system is one step among several steps required throughout the design of manufacturing and logistics facilities [26]. The complexity requires the consideration of all value adding steps including information on all executed handling functions and flow paths [7]; [20], so that designing a MH system is usually treated as a problem in its own right.

The target of modern manufacturing is the production of a high number of products with maximum efficiency at lowest possible cost. High levels of standardisation and efficiency are achieved in line manufacturing which is characterised by high sensitivity to process interruptions and production downtimes, so that high service rates and system availability of all auxiliary and supply processes are required [4]. However, shortened product life cycles have forced manufacturing companies to increase their flexibility and respond times in order to satisfy specific customer requirements [36].

In terms of production flexibility the material handling systems are required to have the capability to enable the manufacturing line to handle work-parts in an effective, programmed way, complying with the following general requirements [18]:

- Dynamic re-routing throughout the system
- Integration of real-time changes in production volume
- Permission of simultaneous assembly of different products
- Coping with unplanned events
- Minimisation of transportation times
- System software and hardware design to integrated object-oriented principles

In reference to the illustrated requirements of line manufacturing and to address these, a central aspect for optimisation in line manufacturing to be considered is equipment availability, which is the proportion of time that a workstation and/or equipment can be used for production. In material handling system design all components that contribute and impact equipment availability need to be considered such as energy required, energy consumption, energy provision and material handling process structures. The process related working time is made up of dead times, waiting times, downtimes, break and idle times that are not available for the central production process, but can be used for other auxiliary functions such as maintenance or battery recharging [24]. For occasional battery recharging, idle times can be evaluated to be usable (positive contribution to the system energy balance) or unusable. Work related dead times, as well as downtimes, are assumed to be necessary for maintenance or short in duration, so that these can not be used for any value adding or recharging activity. Therefore, using idle and break times for occasional recharging in production generates the possibility to decrease non-used operation times, increase the amount of usable energy and by this improve manufacturing efficiency.

2.2. Material handling equipment

Components within material handling applications, based on the usage of battery electric vehicles, generally consist of three major elements: handling equipment, battery and electric vehicle supply equipment (EVSE).

Material handling equipment is essential in order to achieve the required degree of flexibility and adaptability in production related material supply, since the handling equipment has to move between a large variety of points on variable paths. Its design determines the process energy consumption, which has an impact to the energy balance of the material supply system and to process characteristics [22]: 9). Being one of the most important system components, the battery is an electrochemical energy storage device. Its most important function is to store and provide electric energy on demand for the execution of handling functions, so that it is essential for process operations, as well as a central element for all system improvement and optimisation efforts.

Most non-road electric material handling vehicles such as industrial trucks are powered on batteries and practical applications show equipment oversizing in order to ensure a high ratio of equipment availability [17]. In practical applications, process energy availability depends on Usable Battery Energy, so that process execution can only be granted as long as system batteries dispose enough energy to power the electric engines. Usable battery energy is the total energy that can be used within the investigated cycle and contains battery charging and uncharging processes. While 100% of the battery capacity present the nominal battery energy value, usable battery energy considers the losses and the depth of discharge of a battery, so that it refers to the real amount of energy being usable. By this, process related UBE can be increased by recharging processes [30].

The life-time of batteries depends on the realisation of full cycle equivalents, so that charging and discharging patterns of processes need to be considered within energy supply system design. In reference to occasional recharging, process patterns show multiple fragmentary discharging and charging actions with the target to increase Usable Battery Energy over process operations (see Fig. 1).

2.3. Occasional recharging

Occasional recharging addresses the requirements of material handling for increased efficiency but asks itself for a charging station location model for supply system allocation that enables the usage of idle times for additional energy input in optimised locations within existing process sequences. Increased usable battery energy in combination with increased knowledge about processes and process energy consumption allows the adaption and optimisation of all implemented system components.

Technological developments show battery recharge processes with higher transmission performances in order to allow higher