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Production energy optimization using low dynamic programming, a decision support tool for sustainable manufacturing

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ABSTRACT

The presented study investigates the application of a Model Predictive Controller, equipped with linear-programming based optimizer, with application to energy management in production environments. The study focuses on an automotive OEM assembly plant that consumes fossil fuel (natural and landfill gas) in addition to electricity drawn from the grid. This manuscript details the optimization structure under two different cost functions; specifically, cost-savings and energy efficiency. The predicted results are in agreement with the current plant consumption and demonstrate the conflicting nature of the two cost models proposed; thusly, highlighting the importance of objective decision making tools, driven by specific performance criteria, in managing the energy and the overall sustainability of production environments. Additionally, the study discusses the role of the co-generation process efficiency on the overall plant energy consumption.

1. Introduction

Energy management and efficiency in production lines and manufacturing environments, which is estimated to be around 38% of the world's energy consumption IEA (2008), is gaining more importance, not only because it is a quality neutral way to reduce production cost but also because of its role in ensuring the facility compliance with environmental regulations and best practices. Numerically, in 1999 the automotive industry spent around $3.6 billion to cover production energy costs, Galitsky & Worrell (2003). Additionally, the effect of the carbon emissions (product of energy consumed) can add to the energy cost if a carbon-tax policy is enforced.

Even though, most Original Equipment Manufacturers OEMs employ a centralized energy system to manage and monitor their energy inputs and conversions; such centers have limited control over the actual energy expenditures and losses within each production cells, Omar (2011). This is due to the fact that energy in-house generation (through co-generation) and distribution is still based on a push system, depicted in Fig. 1. Moreover, the current benchmarking and auditing tools applied for the automotive industry is still limited in scope (i.e. only assembly activities) and may not include even the body panels forming energy, which is estimated (by the Automotive Parts Manufacturers' Association APMA, 2000) at around 19% of the total plant energy. Such auditing tools include the Energy Performance Indicator EPI, and the Long-Term Energy Forecasting LIEF. Other plant level tools include an analytical tool from the Swedish Environmental Institute IVL, termed the Environmental Priority Strategy EPS, the EPS established a set of Environmental Load Units or ELU's for each kg of material used in building the automobile, Ryding (1994). Omar (2011) proposed a complete energy audit for the automobile manufacturing, when Aluminum intensive vehicles are produced relative to current steel bodies. The aforementioned discussion reveals that energy consumption in production environments is not only coupled to emissions but also to the material input, which highlights another important sustainability aspect of energy consumption. More discussion on lightweight material selection and its impact on production energy is found in Mayyas et al. (2012a,b,c, 2013). Furthermore, from the processing technology point of view, the discussion in Zeng et al. (2009) addresses energy saving potentials in the automotive production specific to energy intensive processes mainly the paint curing activities.

Furthermore, in the automotive industry, the OEMs' energy management centers still rely on a fixed strategy, which is typically tuned to reduce the input energy-cost not the total energy consumption, which in some instances can be conflicting objectives,

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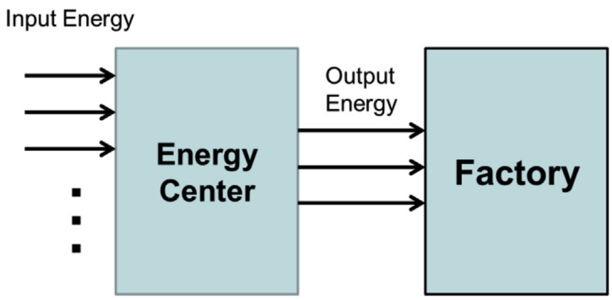

Fig. 1. Block diagram of a traditional energy management system of OEMs.

Rohdin and Thollander (2006). Furthermore, these practices of energy management in production are not adaptive to short run changes of operations; working shifts, production schedule, non-production periods, etc., so the planning for cost-savings is done on annual basis and based on fixed aggregate plans, which reduces the plan overall effectiveness in achieving its cost-saving goals. Even though, some studies developed Sustainability Process Index SPI in industrial settings, Pindea and Tan (2006); these indices are not readily applicable to process-level energy management. This fact further exposes the need to develop a systematic methodology for decision making, or decision making support, as it relates to process-level energy control, which can best be achieved through structured understanding, via modeling, of current energy expenditures and their trends.

Simulation based models have been used to better estimate the energy consumption within factories Heilala et al. (2008); Herrmann and Thiede (2009); Rahimifard et al. (2010). Simulation enables a more adaptive (intelligent) energy management strategy that not only predicts the future energy consumption using real time feedback but also can optimize the energy distribution and conversions within the plant accordingly. Fig. 2 presents such proposed strategy that is the research topic of this manuscript, which displays the energy center input energy (i.e. natural gas, landfill gas, and electricity from the grid) and output (as mixed electricity [generated and purchased] and natural gas as pass-through, and the compressed air and hot and cold water. The factory is presented as the energy sink, with the simulator to provide the demand side, taking into considerations the production changes and conditions (number of units, working hours, air tempering, etc.). The optimizer seeks to satisfy the demand side, using scenarios i.e. different energy mix and conversions strategies (how much landfill gas to be used in boilers to generate electricity, which chillers (absorption or centrifugal) should be used to generate cold water). Thusly, this study proposes a new optimization scheme to support the decision making process as it relates to industrial energy-management applications; the study proposes a feedback loop structure to help energy/production planners make decisions using different objectives and under different constraints, thus descriptive and prescriptive (normative) scenarios can be applied.

2. Current research status

The research in energy management, optimization and decision-making for manufacturing systems is not yet as well established as in other fields; such as the energy management and control in hybrid vehicles, and in residential and commercial buildings' Heating Ventilation and Air Conditioning HVAC schemes, where more complicated control strategies and decision support tools and understanding already exist and are being applied, Christina and Ernst (2008), Kong (2005), Ippolito at al (2001), Ma (2010), and Vahidi (2004). This limitation can be related to two main reasons; firstly the lack of a generalized model, which can accurately estimate the energy performance of the different variations of manufacturing systems and processes. Even though several statistical models as in Brahma (2000) have been developed to estimate production energy consumption, still its accuracy is limiting its applicability. Secondly, there is a lack of internationally accepted Key Performance Indicators KPIs to govern the energy assessment efforts in production, Henri and Journeault (2008). Other reasoning can be related to the fact that most factories rely on a single energy type that is Electric power drawn from the main grid, which can typically portray a less complicated perspective on their energy management issues. However, current study focuses on large-scale automotive OEM assembly-facilities that consume multiple energy resources namely; fossil fuel (natural gas and landfill gas) and Electricity, at the same time it employs several in-house energy generation and conversion steps, which further complicate its energy management computations and the decision making process (the right mix of energy to acquire, and the best conversion processes and technologies to be used).

For systems other than manufacturing, their energy management is based on a centralized Energy Management System or EMS

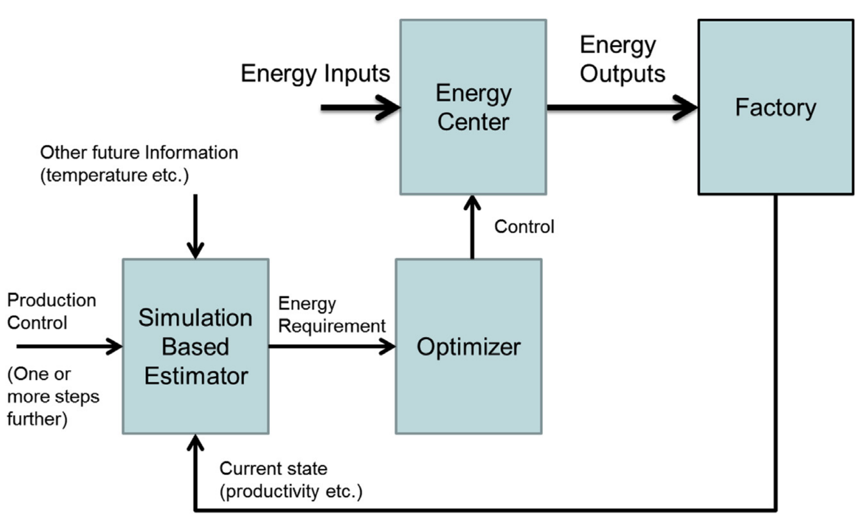

Fig. 2. The proposed energy management system.