Towards the Energy Efficient Future Factory

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***Abstract*—Up to now, most factories and their processes were designed and constructed with the cost as the most important economic factor. However due to the increased changes in energy sector, the energy optimization should be another key indicator for cross layer optimization. In order to achieve this optimization, energy has to be measured locally and almost in real time, while manufacturing control activities should also be aware of the energy consumed. Furthermore higher-residing decision support systems and enterprise services, will take also into consideration the overall energy consumption, for each process and optimize globally and locally. These goals are assisted with the increasing automation within the factories that can provide better visibility and efficiency of the shop floor.**

I. Motivation

The business world shares common goals towards cost effectiveness, energy efficiency and sustainability. As we witness the last years, the energy sector has started undergoing dramatic changes that will have an eminent effect on businesses and economy. Manufacturing is one of the key industries in the European domain directly contributing more than 22% on GDP, with an estimation in 2004 that 70% of jobs in Europe depend directly/indirectly on manufacturing [1]. Energy hungry industries and logistic domain, can benefit from energy efficient approaches with the aim to be more cost effective and sustain the economic growth while in parallel optimizing the vast amounts of energy consumed.

Approximately one third of global energy demand and CO_2 emissions is attributable to manufacturing [2]. Information and Communication Technologies (ICT) can help not only achieving better awareness on the real carbon footprint of the industry but also reduce it. As factories are important consumers of energy, they need to react and adapt quickly to business trends imposed by increases in energy prices. There is need to analyze on-site the management of energy within the factory, with the goal to optimize it. Targets for energy savings can be set by indexing the results of this analysis to production levels and by defining dynamic optimization strategies.

Conventional energy management methods at factory level are characterized by a number of limitations, as plant states are isolated and cannot be fully understood since there is no infrastructure for holistic mapping to business and continuous measurement of energy consumption. This lack of insight prevents energy efficient decision taking in real-time. Energy awareness and optimization of the factory can be enhanced significantly by on-line monitoring of energy consumption information and by including energy optimization in the control loops. Internet technologies applied in modern factories can help us achieve these goals.

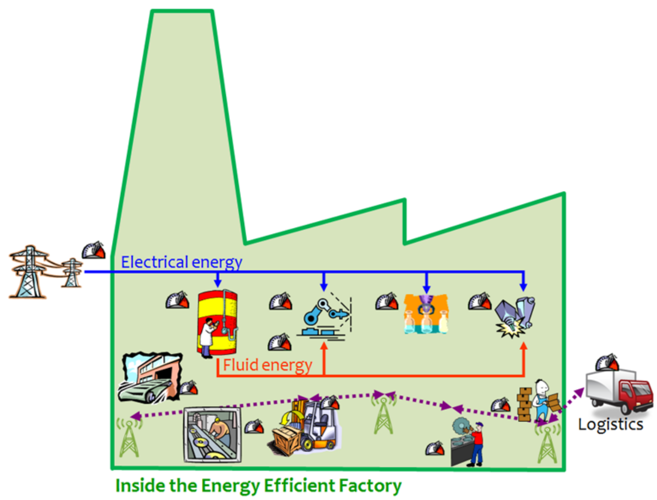

Fig. 1. The energy efficient future factory

II. Raising Energy Awareness

We propose to pave our way towards Energy Efficient Factory of the Future (EEFF) in the mid-term by continuously obtaining energy-related rich information from any location of interest at the factory floor and combining it with enterprise-wide information for global factory optimization. The vision inside the energy efficient factory is illustrated in Figure 1. We need to monitor the major energy consumption sources e.g. the electrical, fluid but later also thermal and compressed air. We need to be in position of correlating the information and create processes that are energy aware and strive for better energy usage.

Networked Embedded devices can offer real business benefits [3] with respect to monitoring and asset management, and in this case they can be used in conjunction with intelligent metering strategies to continuously monitor data, regardless of the physical location of its providers, and subsequently convert it into business relevant information. The delivered information will be further elaborated & visualized to offer: energy efficient automatic maintenance schedules (at production sites),

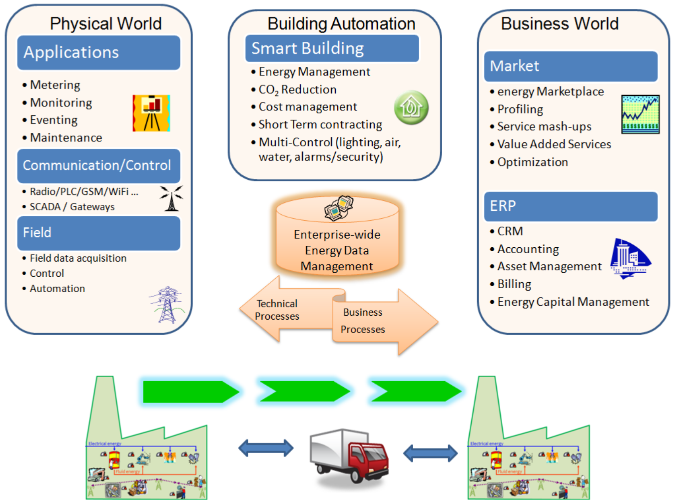

Fig. 2. Cross-Enterprise Energy Efficiency

energy efficient runtime planning of product/supplies routes (for continuous track & trace systems), and optimal sequencing and balancing of manufacturing shop floors.

Energy awareness will be introduced at the factory level via networked embedded technologies for automatic discovery of devices e.g. sensors/RFID readers/computers/mobile devices/PLCs etc. and on-device and in-network data processing. The unnecessary overload of centralized software applications processing the data will be avoided by extending traditional monitoring techniques with the ability to evaluate raw data, extract business relevant information at source, and offer it as a (web) service. Wireless and indoor Geo-location technologies will assist in obtaining the necessary asset spatial information.

As depicted in Figure 2 energy efficiency goes beyond simple monitoring and standalone decision-making processes at local level. Collaboration among different domains must be in place and this includes the physical world e.g. within the factory, the business world e.g. enterprise systems and goes also in the direction of building automation where e.g. the factory is hosted. Data gathered in all layers need to be correlated and commonly evaluated in order to lead to energy efficient strategies that take a holistic view on how energy efficiency can be achieved. This should also include cross-enterprise issues e.g. the logistics for transporting the product and materials prior to, within and after their processing. Of course the whole approach needs to be further complemented in cooperation with external entities such as as smart electricity grid and the increasing integration of alternative energy resources [4].

Energy efficiency will be brought to the factory level by including dynamic asset and service management. The criteria for optimizing processes, production and logistics will cover not only cost, but also energy-related indexes. The optimization loops will cover all factory levels, from the automation system to the ERP, ensuring multidisciplinary coordination and control. In this way it will be possible to have business decisions taken in full knowledge of the energy consumption situation at factory floor ("closed loop" approach). Web services for embedded devices (including low power wireless) and automatic discovery of resources will be used to guarantee reconfigurability and cross-layer integration from device level up to ERP.

Traditional techniques for organization and visualization of the collected information from the factory floor involve custom-made interfaces. The information is organized and displayed graphically so that human personnel can interpret it meaningfully. However, to understand the state of the process it is required for the personnel to have good knowledge of the plant (processes, factory layout, etc.) in addition to experience in factory automation. The application of statistical analysis to make data based decisions (e.g. SixSigma) has been shown to result in 40-60% productivity improvements in real case studies [5].

However, this type of approach has negative outcomes if applied blindly. These disadvantages can be tackled by automatically organizing and evaluating information devices e.g. sensors to produce business relevant Key Performance Indicators (KPIs). These indicators will subsequently be used for automatic intuitive strategy creation, business decision making and visualization.

The continuous tracking & tracing of material flow through all process steps has been shown to result in improved profitability, reduced material loss (a decrease from 2.5% to 0.75%) and improved equipment utilization [5]. Real time asset monitoring systems can help in detecting abnormal plant behavior resulting in increased energy consumption. Vice Versa, increased energy consumption might be an indicator of a malfunction which can be tackled early enough (preventive maintenance).

Top down change management through a single ERP instance has been shown to result in an 80% reduction in response time per transaction while the number of transactions grew 450%. The corporate IT budget for manufacturing operations has increased from 3% (2001) to 19% (2007) [5]. This illustrates the need for integrated IT architectures to support new multidisciplinary coordination and control principles for large scale production / track and trace systems.

Enterprise Resource Planning (ERP) systems are extensively used today to plan and schedule the use of resources in manufacturing operations. The planning and scheduling process is mostly "open loop": strategies are modified periodically and dispatched to the plant for execution. Most feedback from the factory is only given in case of significant disruptive problems. This is because of the mismatch between the protocols and data formats used at enterprise and factory levels (many factories still resort to using shared files to integrate MES and ERP systems). An additional problem is the increasing amount of information that the ERP has to handle as it gets more integrated with the shop floor; thus better data evaluation and quality should be done at the device level and business relevant information should be communicated to the ERP via an event based infrastructure. This integration can be

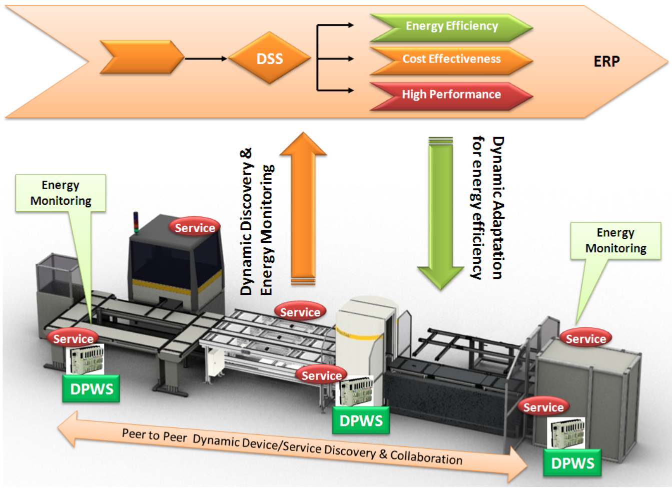

Fig. 3. Energy Aware Business Processes and dynamic shop-floor adaptation

addressed by utilizing cross-layer SOA and Web Services as unifying technology. Data quality can be addressed through definition/selection of Key Performance Indicators.

III. Cross-layer SOA for Energy Efficiency

In the recent years we have witnessed the SOA concepts starting to be successfully applied to the shop floor [6]. Especially with the devices being able to offer their functionality as a service, SOA platforms can easily integrate them. As an example the SOCRADES project has developed a platform that strongly couples the Enterprise systems with the shop-floor [7], [8] via the usage of web service enabled devices. This platform taps to the future event based shop-floor infrastructure, and can be used as a basic block where energy-efficient services can be build upon. Enterprise applications are now able to connect directly if needed to devices, without the use of proprietary drivers, while non web-service enabled devices can still be attached and their functionality wrapped by gateways or at middleware layer. Peer to peer communication among the devices will push SOA concepts further down at the device layer, and the of usage of semantics in web services [9] will create new opportunities for functionality discovery and collaboration.

Web services are suitable and capable of running natively on embedded devices, providing an interoperability layer and easy coupling with other components in highly heterogeneous shop-floors. Device Profile for Web Services (DPWS [10]) and OPC UA [11] are emerging technologies for realizing web service enabled controllers and devices. Several projects such as SIRENA (www.sirena-itea.org), SODA (www.soda-itea.org) and SOCRADES (www.socrades.eu) provide a platform to develop a DPWS stack targeting the industrial automation devices on the shop floor [12]. DPWS is an effort to bring a web services on the embedded world taking into consideration its constrained resources. Several implementation of it exist in Java and C (www.ws4d.org, www.soa4d.org), while Microsoft has also included a DPWS implementation (WSDAPI) by default in Windows Vista and Windows Embedded CE.

As depicted in Figure 3, the production line is continuously monitored with respect to its energy consumption. The machines themselves are able to monitor in real-time the energy consumed, and by using a stack like DPWS offer the results of the measurement as a web service. Other services offered by the machines include also monitoring and controlling of their functionality (e.g. start, stop, mode change to low-power/stand-by etc). Such services are discovered not only by the nearby devices but also by the Enterprise System, which subscribes to them and gets all the events e.g. status and energy consumption of the machine. This is for instance possible via the WS-Discovery and WS-Eventing standards supported.

In the Enterprise level, a Decision Support System (DSS) considers all business constraints in conjunction with the real-time feedback received from the shop-floor. Based on timely data, decisions can be dynamically made that fit the best that specific time. In our case the DSS can decide upon production requirements to follow different approaches such as an energy-efficient process, a high-performance one (without respect to energy) or a cost-effective one (again irrespective of consumed energy). Of course the long term goal is to have a high-performance cost-effective energy-efficient process, but in the meantime such possibilities that affect the end-product quality, price and its quantities produced are expected to exist. Once a decision is taken by the DSS (which may collaborate with other DSSs in the shop-floor), this needs to be enforced, which is now possible since the ERP can directly access device functionality.

Existing approaches will provide new capabilities once their functionality is correlated with energy monitoring. As an example, preventive maintenance can be enhanced. Monitoring of energy consumption that exceeds the usual levels might be an indication of a machine fault. Furthermore optimized production planning will schedule energy intensive tasks in a way to avoid peak load or when “cheap” energy coming from local alternative energy resources is available. Similarly, production activities with high cooling requirements will not be scheduled on hottest day hours, or when the room will be cooled as a side-effect of another process. Such optimizations are only possible if global view is available for synergies to be developed.

IV. Dynamic Energy Product Labeling

As result of being able to map the energy needed at each step, optimizations can be applied for the realization of more efficient from the energy perspective processes. Furthermore we know exactly how much energy was consumed for a specific product to be made and can certify that for a specific product. This can be captured in the energy labeling of a product such as the one depicted in Figure 4, where the exact amount of energy spent to produce it is named as well as the one consumed for the transportation of it. This will empower the consumer to select the product based on its carbon footprint.

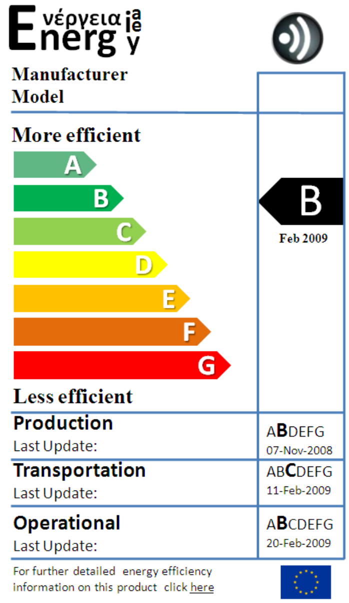

Fig. 4. Dynamic Energy Labeling

Although this is partially done today e.g. footwear and shoe companies, this is only based on estimations, is static, does not include logistics energy spent and stops when the product leaves the factory. However once the product leaves the manufacturer site, more energy is spent until it reaches its point of sale (POS). Dynamic labeling that can be updated by authorized parties can help maintaining an accurate and real view on the total amount of energy consumed for the specific product. As such, the selection of products and tools will not be done merely based on their quality and productivity, but also their energy efficiency. We expect that in the short-term ISO standards for assessing energy efficiency will be available for more industry-wide transparency.

V. Research Directions

A. General Issues

We need to investigate towards several directions in order to make factories more energy efficient. General issues to be solved include:

- An interoperable infrastructure that allows us to on-line monitor energy consumption down to discrete device level
- Concrete models for energy consumption prediction at each layer e.g. device level, location, process level etc
- Enterprise services that evaluate and assist in optimizing plans and processes dynamically based on their energy usage e.g. at production, at supply chain, etc
- Applicability of Market driven mechanisms and close collaboration with energy providers for optimal energy usage / Integration of the distributed alternative energy resources
- Support for software management for large scale infrastructures e.g. remote monitoring, remote diagnostics, predictive maintenance etc
- Paradigm shift towards exploiting micro-factories, for energy optimization, will lead also towards stronger ICT requirements for coupling and cooperation of modules.

B. Architectural Issues

An Architecture for effective integration of versatile SOA-ready devices with the Enterprise services needs to be created. Real time interactions of all developed systems with Enterprise Services. This calls for:

- Cross-domain dynamic discovery of devices and services at Enterprise level
- Seamless integration of data/information discovered with Enterprise Applications
- Advanced interoperability to allow for improved collaboration of services at all layers (device/net/enterprise)
- Design methodologies to include real-time interaction with embedded devices at shop-floor.
- Advanced data management at all layers from Enterprise Resource Planning (ERP) level to device level resulting from increased data/info volume
- Enterprise level management of large numbers of heterogeneous devices
- Design and develop a set of techniques (methodologies and tools) for designing and executing context aware solutions based on the integration and composition of different services provided at enterprise (e.g. ERPs) and factory levels (e.g. embedded devices).
- Extension of existing business processes to consider energy consumption
- Strategies for creating intra-/inter- Enterprise energy efficient business processes
- Modeling, validation and verification of business processes composed on SOA
- Flexible evolution and execution of business processes considering runtime dynamic service inputs
- Complex KPIs / algorithms for holistic enterprise optimization
- Business model adaptation based on energy related KPIs
- Simulations that can optimize plant's functionality at engineering phase and without the need of running in real life.

VI. Discussion

To be able to gather the necessary data, an advanced metering [13] framework has to be in place. This should be done in real-time and be integrated with enterprise systems. As devices in the near future will provide their functionality as a service (most probably a web service), we will not only be able to turn the device on or off as it is done today, but take advantage of its different power mode states, which are now available and controlled via the services the machine exposes. Future machines are expected to auto-manage their state and fall into a low energy consumption state if no tasks are executed or while waiting for the next task.

As shown in Figure 2, having energy efficiency at device level is not enough. Orchestration at the process level in production lines is needed, and this includes IT systems and associated processes e.g. goods transferring /logistics. Energy Efficient Asset Management combined with route optimization will lead to inventory reduction for Production-to-Order systems.

As now we are able to explicitly monitor and map energy consumption to specific business processes in a detailed manner, new key performance indicators can be created that are energy-aware. When new processes are modeled, we can also calculate the expected energy consumption. Furthermore optimization strategies can be applied at business level as well at device level to make them more energy consumption optimized.

Energy consumption is instrumented and observed, and the decision-making elements of the system (such as enterprise software) can utilize energy consumption as an optimization parameter in real-time and closed-loop fashion. The focus is not only in sensing, but also in embedded data processing so that we can obtain digested information from the factory floor

Efficient information aggregation strategies should enable the optimization of the energy consumption of a factory. Specifically, the acquisition, processing, aggregation and combination of data produced by multiple sources such as field devices and heterogeneous sensor-nodes deployed to monitor machines. "In-network" processing of events to optimize data transfers over networks, avoid bottlenecks introduced by central aggregation strategies, and increase the quality of the collected data need to be effectively tackled.

Key performance indicators to create overall views of production floors and their detailed energy consumption need to be created. Existing strategies for balancing production will need to be extended by specifically considering energy efficiency aspects. Analysis of KPIs and historical data will allow the evaluation of energy consumption optimization strategies. These strategies will include control algorithms, which act in order to minimize the difference between given goal KPIs and actual measured KPIs and even take predictions into account.

VII. Conclusion

A paradigm shift is envisioned from "Maximum gain from minimum capital" towards "Maximum value from a minimum of spent resources" [2]. As shown, initial steps towards energy efficient factories can be partially realized today, however significant research needs to be done in order to address more holistically the efficiency capabilities within the factory, correlate effects and provide enterprise wide and cross-enterprise efficiency as the vision depicted in Figure 2 shows.

Energy efficiency in the manufacturing domain goes beyond simple stand-alone approaches e.g. peak load avoidance, single process / machine optimization etc, and should be seen in a more holistic form, where local vs. global optimizations are supported by an Information and Communication Technologies based Infrastructure that dynamically adapts to conditions and business plans/goals.

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