NON-PEER-REVIEWED PAPER

Analytics for energy efficiency concepts and applications

Véronique Boutin
Schneider Electric
37 Quai Paul-Louis Merlin
38050 Grenoble Cedex 9
France
veronique.boution@schneider-electric.com

Rodolphe Héliot
Schneider Electric
37 Quai Paul-Louis Merlin
38050 Grenoble Cedex 9
France
rodolphe.heliot@schneider-electric.com

Keywords

activity patterns, energy model, optimisation, simulation, energy price, multi-energy sources

Abstract

Incredible amounts of data are created, shared and stored every day, but companies are just beginning to harness the potential. The next step will consist of leveraging data to improve the energy efficiency of industry, infrastructure and buildings. With Analytics, a new range of information and knowledge is accessible: data can be transformed into KPIs, benchmarked and used to build patterns and models. This new information can improve action and decision-making for the short-term and rationale for future design & investment strategies, and provide the basis for asset management schemes. This paper explains how Analytics contribute to improving Energy Efficiency in industry. A practical example is given in the field of lift/hoisting machines. We present Schneider Electric's vision of Analytics, relying on 7 features that lay the foundations for efficient design of solutions, and we show how the set of Analytics methods covers the vast diversity of application needs.

Introduction

Energy efficiency is currently driven by energy cost-reduction and is closely linked to operational efficiency. Let's begin with the practical need for efficiency, which all companies face, compelled by global competition, energy & resource constraints, safety and other societal requirements. Machines, equipment and processes have already reached a high level of efficiency in view of the information currently available from physical sensors or human sources. Going further entails the mastery of a level of complexity that surpasses human decision-making capabilities: processing new ranges of information, predicted data, crossing field data with other information sources, computing optimal solutions from a huge array of possibilities – in short, switching from static organizations based on local information systems to real-time adaptive organizations based on prediction, optimization and big data.

Let's take the practical example of mining, an area in which operations are characterized by high variability and uncertainty at all levels of the supply/demand chain. Optimized integrated planning and scheduling calls for synchronized data from multiple sources, both within and outside the operational systems used to manage the traditional supply chain network consisting of mines, process plant, transport network, port and trading desk. Many organizational factors can have an impact on operational plans and schedules: workforce variability, market conditions, maintenance and asset management, accommodation and staff resourcing, and market factors. Human decision-making cannot access all of these parameters and their dynamic changes over time and, as a result, organizations generally operate as functional silos. Now, however, the combination of connected information systems and analytics capabilities makes it possible to optimize planning and scheduling from pit to port.

To make this new step in efficiency happen, it is necessary to enable easy and robust data collection, to provide useful information and create value from the data by analytics technologies and, of course, to manage changes.

Data collection relies on connected devices, pervasive sensors and open communications systems. Specific technologies must be used to consolidate data sets from various heterogeneous sources into a coherent, high-quality set of factual data, deleting erroneous data, managing missing data, providing coherent time-stamping and consistent naming, and adding useful segment-specific information (localization, description, characterization, etc.).

Analytics technologies are used to extract information from data. They have been implemented for some time now to improve marketing and business operations, and are currently being integrated into solutions and products [Davenport 2013]. These techniques relate to data mining, data modelling, simulation and optimization, as well as techniques that enable enriched interaction with users and facilitate human reasoning, such as visual analytics.

These technologies are available. The question is how to make full use of them to improve efficiency and reduce energy consumption and CO_2 emissions. The generic answer is "by providing new information, by enabling better action regarding organization, planning and control and by offering rationale for design and improvement".

In this paper, we show how these generic ideas can be put into operation in concrete applications, with a general overview of the benefits to be gained from analytics, and a detailed example of analytics used to manage multiple energy sources in an advanced elevator system.

Analytics for Energy and Operational Efficiency in Industry

Let's see how analytics can contribute to improving Energy Efficiency in a practical way, according to a 3-step scheme aimed at improving asset performance, production operations and energy procurement.

1) IMPROVE ASSET PERFORMANCE

Asset performance can have a 15 % to 25 % impact on economic results. If assets not properly monitored and managed, energy, raw materials and resources can be wasted, asset lifetime can be reduced, and failures can occur, reducing the availability of production facilities. The assets concerned belong to various typologies: typical cross-segment equipment such as breakers, motors and pumps, segment-specific equipment such as kilns for cement, wells for oil & gas, or even, in some cases, much more complex assets such as networks (in which nodes and lines may be managed differently). For people working in the field, the main concern is how to evaluate the real performance of assets, which may fall short of expectations depending on robustness and effective usage, so as to optimize maintenance operations and find the best balance between maintenance and failure/inefficiency costs, and to rationalize replacement strategy when planning investments.

Intelligence & Analytics provide new potentialities for improving asset performance over the whole life cycle (design, operation & maintenance, replacement), for critical assets and the entire asset portfolio:

- Internal data derived from the asset together with data collected from the asset's "functional environment" are used to produce usage patterns and fault signatures which are monitored for early detection and diagnosis of performance drifts. This is the case, for instance, for HVAC machines in which electrical measurements are combined with air temperature for early detection and real-time diagnosis of problems such as evaporator freezing, refrigerant leakage, condenser fouling or other typical faults.
- Simulation capabilities provide useful tools for *what if* scenarios to evaluate the impacts of faults. Simulation is used, for example, in the field of water distribution networks, in which the impacts of leakage on water loss and energy wastage are currently evaluated using hydraulic models.
- Access to information on the real performance of assets and the capability to calculate the impacts of faults make it possible to optimize maintenance operations and set priorities for replacement.
- In addition, companies are able to produce realistic performance benchmarks by collecting data from connected assets.

2) IMPROVE OPERATIONS

Once individual asset and machine performance is under control, there is still room for improving process efficiency. However, since existing processes have already reached a relatively high level of efficiency, new means for optimization are required. The problem lies in understanding where and how to harness this potential so as to continuously improve the production process while meeting increasing needs for quality, flexibility and safety, given uncertain energy and resource price variations.

Processes vary widely across segments. There are however, common concerns, such as product demand forecasting, upstream or downstream supply chain optimization, production and operation planning, product and service quality, and operating modes for different process steps. All of these areas can be improved by Analytics and the resulting optimization can be highly profitable and implemented without seriously impacting processes, which is a condition for success.

The basic principles are quite simple: provide better real-time information on production or the process in order to improve control in the field, and identify and leverage process flexibilities for greater profit.

- Example of virtual sensors for food & beverage processes: most of the time, complex information is needed for full process control: fermentation level for micro-filtration of beer, crystallization level for ice-cream, humidity for milk powder, etc. Accurate real-time and cost-effective measurement of this information is challenging, but the information may be accessed by collecting and mixing several correlated data items. Analytics create Virtual sensors capable of providing the required information. The basic principle consists of using several low-cost sensors and process parameters to estimate the relevant quantity (product humidity in the case below).
- Analytics to identify and leverage process flexibilities for greater profit: flexibilities can be of several kinds: execution time can be shifted, especially when storage facilities are available, machines or production lines can be assigned to tasks in different ways, operation set-points can be tuned at different levels, etc. Making the most of these flexibilities

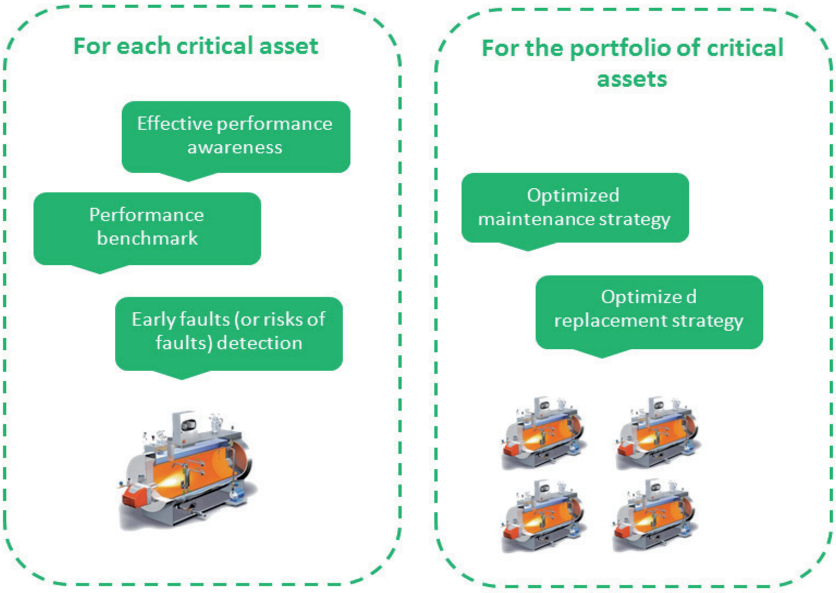

Figure 1. Benefits of Analytics for improving Asset performance.

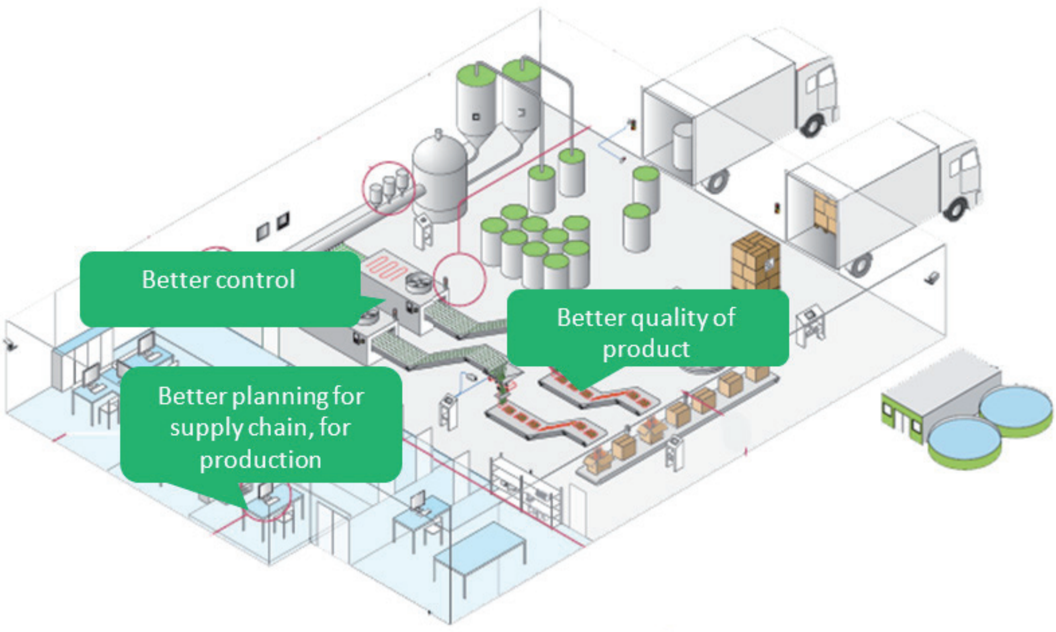

Figure 2. Benefits of Analytics for improving plant operations.

can reduce energy costs since the more energy is used, the lower the rate charged. However, these flexibilities are seldom used as companies are not able to evaluate the potential impacts and profits, or to decide where the optimum lies.

3) REDUCE ENERGY COSTS

The main concern in the field is to minimize energy costs while ensuring the availability of high-quality energy and limiting environmental impacts. Energy procurement is shaped by three major trends: the variability of electricity prices and the new modulation market resulting from demand-side management, emission reduction incentives, and the uncertainty of oil prices in the mid and long term.

There are several means available for improving energy mix and cost:

- Produce energy locally – using renewable facilities or co-generation,
- Recover energy from processes,
- Optimize management of the different energy sources, including storage capabilities, favouring one source over another, deciding on strategy for storing, using or re-selling energy, etc.,
- Make the most of the energy market (variable prices, demand response, emission reduction incentives), matching highest

energy needs with lowest prices, combining smart-grid opportunities with activity management and turning operation flexibilities into energy consumption flexibility offers,

- And, of course, improve energy efficiency to reduce energy demand.

Analytics can play a role in most cases by providing a better understanding of site energy consumption, giving advice for better energy management, and contributing to investment rationale in the field of energy facilities: Energy consumption analysis should be used to understand where, how and why energy is used. This is not easy: energy has to be correlated with process activity, and measured at a sufficiently precise level, which is seldom the case. Data analysis applied to usage and energy data, and in particular disaggregation techniques can be used for in-depth analysis of energy consumption, allocating energy and energy costs to usages and producing energy models that enable energy consumption forecasting.

Note that the emergence of pervasive, low-cost and easy-to-install energy sensors is making energy information more and more accessible, providing much more energy data to feed and enrich energy analysis.

Once energy needs are modelled, it is possible to evaluate various scenarios for energy procurement: Is it worthwhile installing new production or energy storage equipment? What is the optimal sizing, in view of given demand-related assumptions, contextual parameters (such as weather forecasts in the case of solar panels), and cost and CO_2 objectives? Models (of energy needs, energy equipment potential, usages and demand, etc.) associated with simulation and optimization techniques provide tools for decision-making rationale.

An example will be detailed in Part 2 of this paper in the context of a multi-sourcing system for lifts. In this example, an analytics-based tool calculates the optimal design (in terms of costs and CO_2) of sources and batteries, factoring in various criteria such predicted travel and energy tariffs. Of course, when several sources of energy are available, they have to be properly controlled and managed in order to achieve the full potential. The same sort of analytics and models may be used to calculate the best strategy at every moment: should the system buy, store, or directly use energies from the various sources?

Manage Energy prices, energy modulation market and adjust day-to-day operation to energy prices: The energy market and especially the electricity market are becoming more and more dynamic due to new information and connection capabilities. In particular, Demand Response mechanisms are one of the solutions to electrical network problems related to high consumption peaks, the massive introduction of renewables and network instabilities due to aging infrastructure. These mechanisms favour demand flexibility in order to smooth the load demand curve and reduce spare capacity. There are two types of mechanism: variable prices, which influence consumer energy usage profiles statistically, and direct control, which consists of triggering a reduction (on increase) in consumption on the demand side via a signal from the energy utility. Energy modulation is traded in markets, like energy from any production resource. The payment structure includes capacity (resource availability) and actual energy consumption response (decrease or increase).

So far, in the few countries that implement such mechanisms, only energy-intensive industry is concerned. In the future though, flexible consumption on the demand side may expand to many industrial sites, thanks to aggregators which bring together opportunities to subsequently reduce energy demand for short peak periods or, on the other hand, absorb energy surplus in case of high production levels (in particular from renewable sources) during low-demand periods. This introduces new complexity in energy pricing, as well as new opportunities for optimization which can be calculated by analytics.

Let's take the example of water distribution networks: considering the large volume of water storage and pumping capabilities, water networks offer good opportunities for the modulation business. Based on the provisional pumping plan and dynamic energy prices, modulation capability for the next 24 hours is calculated and ranked. Modulations comply with the water pressure owed to customers, the operational rules of the water network (pressure modification limits, water quality, up and down storage limits in water reservoirs, etc.), and reduce the overall energy bill. This is made possible by optimization techniques fed by water demand and energy price forecasts, and coupled with hydraulic simulation.

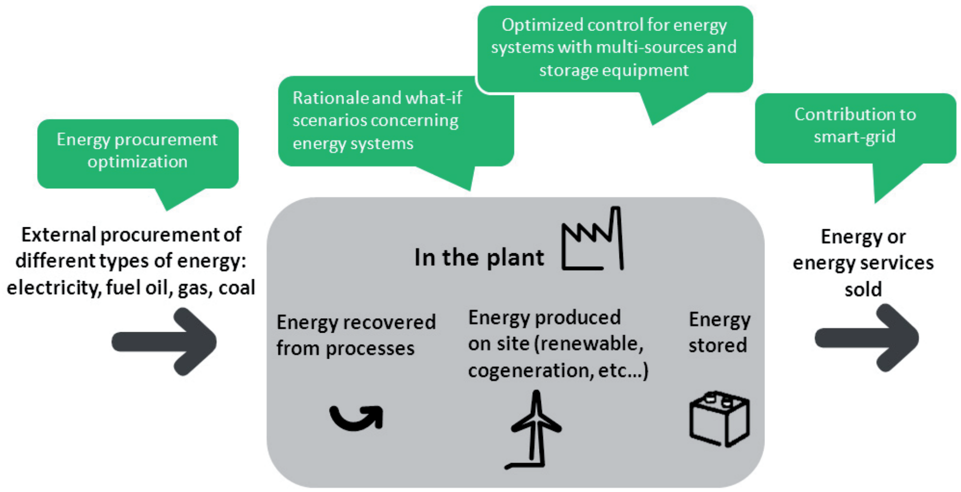

Figure 3. Benefits of Analytics for reducing energy costs.

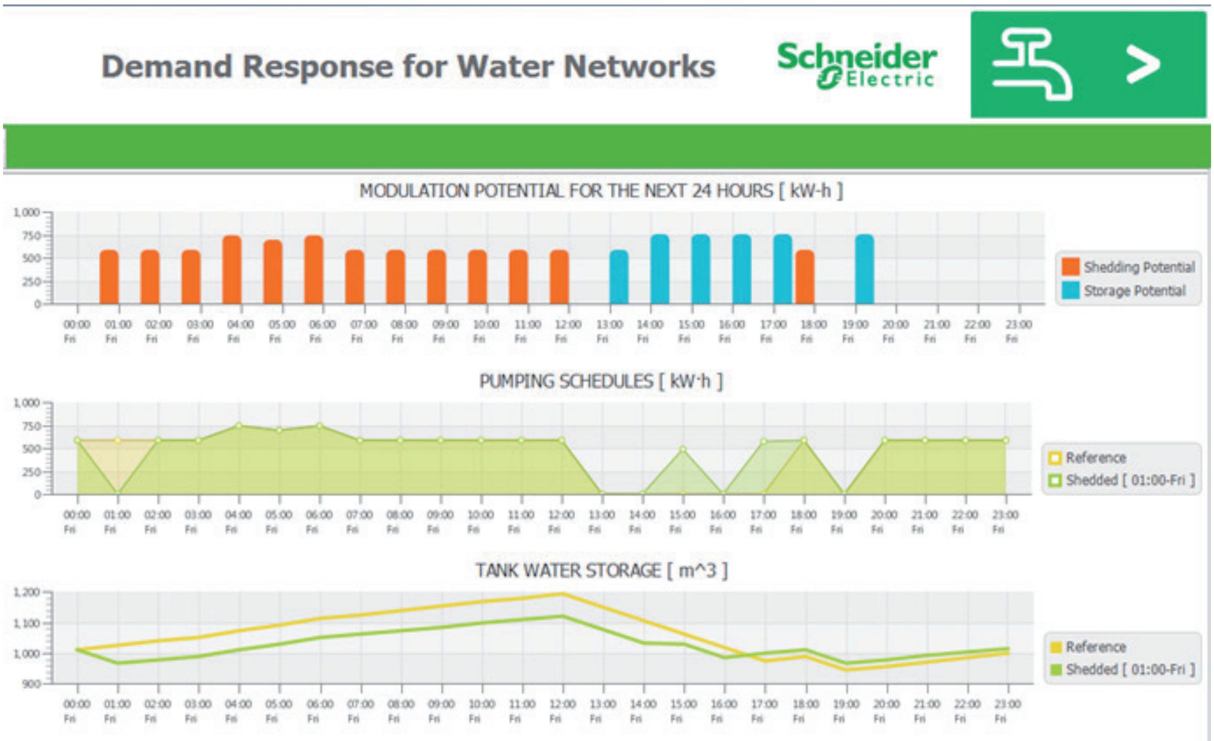

Figure 4. Interface for the water network manager: visualization of modulation capabilities (red for shedding, blue for storage)

An example in detail

1) PROBLEM STATEMENT

There are more than 4.5 million lifts installed in Europe. Urbanization trends and growing awareness of accessibility issues due to an aging population in Europe will foster the need for more of this equipment. Energy consumption of lifts adds up to 3 to 5 % of the overall consumption of a building. Improving the energy performance of lifts is not a marginal goal: electricity consumption in the tertiary sector in Europe is predicted to be 950 TWh by 2020. Elevators and escalators now account for 4 % of total electricity consumption in the tertiary sector, with a trend toward a significant increase of this share. Since potential savings of over 50 % are possible, the impact of lift energy efficiency improvement is in the range of 20–25 TWh[1]. In addition, travel security, especially with energy shortage, is a critical issue that may be solved by an ever-available energy reserve.

Up to now, efforts to improve lifts have focused on the technological aspect of hoisting (hydraulic or traction, geared or gearless traction, etc.). However, other improvement levers are still relatively unexplored, or not yet accessible to a large range of lifts at a reasonable cost. They could improve the energy efficiency of new and existing lifts and the safety of people, making lifts almost autonomous in numerous cases while preserving quality of service with a good technical and economic solution. These levers are based on active energy control:

- Taking into account actual travel needs and travel prediction in order to put equipment in stand-by mode as often as possible, position the car, or set of cars, in the best inter-travel location, and adjust car speed.
- Making the most of energy recovery during deceleration and of local renewable sources, e.g. photovoltaic. This calls for an electricity storage system.

Beyond energy and travel, a new field of improvement is also available at the information level to make technical information on lifts easily accessible from a remote monitoring system for diagnosis or maintenance purposes. Plus, since lifts are the major access point to floors, by observing travels, it is possible to estimate real-time occupancy per floor. This information can be valuable for building management or security purposes, especially in large buildings. Figure 5 summarizes a possible lift system architecture which encompasses all of the analytics-based, advanced functional features described above.

To be noted that this system architecture is enabled by Arrowhead technology. Arrowhead is a cooperative research project financed by both national and European funds (Artemis), and aiming at improving energy management and operational efficiency in various industrial environments with new solutions based on pervasive sensors, embedded software and analytics.

This is the architecture of a system with multiple energy sources, some of them controllable (energy utility), others not (such as local, renewable energy production, etc.), as well as energy recovery and energy storage components. As stated above, this type of architecture provides multiple benefits. However, systems of this sort are not widely deployed today because of various technical challenges:

- Difficulty of evaluating cost-effectiveness of the system.
- Difficulty of making technological choices and properly sizing the system.

1. http://www.e4project.eu/

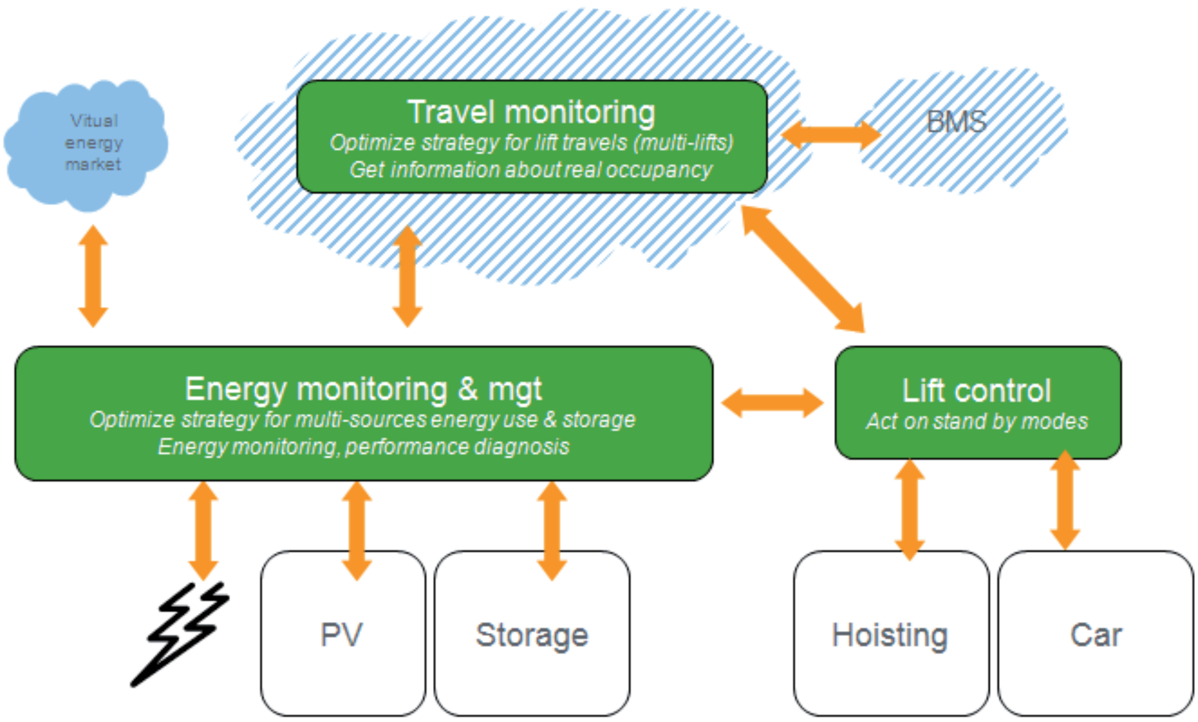

Figure 5. Lift system architecture. The main goal is to optimize energy consumption for given travel requirements. It also allows storage recovery and storage, enabling autonomous use when needed (high energy price, energy shortage, etc.).

- Difficulty of coming up with an optimal control strategy given the complexity of the system.

All of these problems can be solved by optimization. After a brief review of the basics of optimization, we show how it can be used to design the system and evaluate its cost-effectiveness.

2) METHODS

Basics of optimization

Optimization refers to the selection of the best element (with regard to criteria) from a set of available alternatives. In other words, it means finding the minimum of a cost function. The problem is conveyed by the cost function that expresses what is to be minimized. Quite often, the cost function is a trade-off between multiple criteria. It can be a very simple formula in some cases, or it can be complex and result from a detailed simulation. To minimize the function, numerical optimization tools are needed. In many cases, there is no exact analytical solution to the problem, but rather a numerical solution, i.e. a numerical approximation of the problem.

Implementation

First of all, optimization involves two different problems: 1) sizing of the system at the design stage, and 2) real-time control during the operations stage. These problems call for different yet related solutions. Sizing of the equipment (such as an energy storage unit), depends on the control strategy that will later be applied. Similarly, controller decisions will depend on how much storage is available.

Secondly, the data on which the problems rely can be subject to strong variability over time. For example, elevator use patterns are different at night and during the day. Weather strongly influences local renewable electricity production and can only be determined statistically over long periods of time.

To meet all of these needs, it is necessary to consider energy tariffs, forecast use, weather, etc., all of which are relevant for very different timeframes (minutes/hours for use, hours/day for tariff, month for weather, years for the economic equation).

Overall, this means that the problem cannot be solved by a single optimization procedure encompassing all time scales, for which the computational complexity would be far too great to be practically solved. The result is the following multi-layer optimization scheme, shown in Figure 6.

Three optimization procedures, each with its own cost function and numerical solver, have been developed. The design optimizer looks for the best sizing for the equipment (energy storage, recovery) for a given technological choice. It takes into account physical constraints such the maximum weight and volume allowed for each piece of equipment. The optimization criterion is a combination of capital expenditure (CAPEX) and operational expenditure (OPEX).

The second level of optimization looks for the best energy sourcing and storage strategy, for a given technological choice and size, and a given weather and tariff context. The optimization criterion is directly linked to OPEX.

The third level of optimization deals with control, and computes the best controls for storage, controllable and non-controllable production, taking into account forecast short-term energy consumption and recovery, tariffs, and renewable energy production. From a control theory point of view, it manages the various system inputs and, as such, acts as an optimal controller.

As discussed above, this multi-layer optimization scheme can be used in two different use cases (see Figure 6):

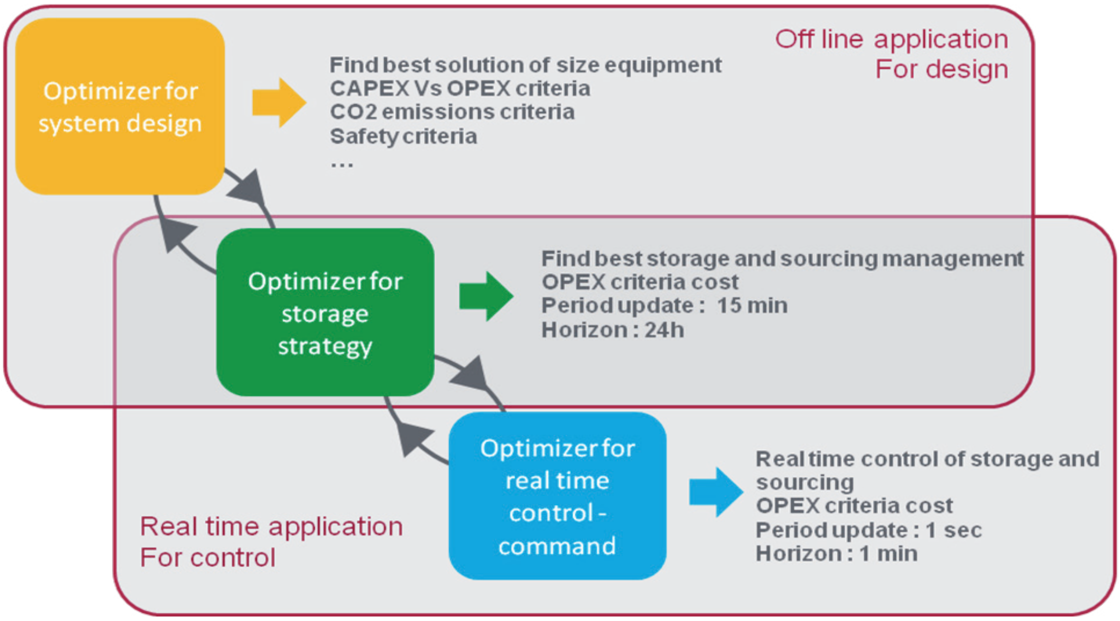

Figure 6. Multi-layer optimization scheme. Different optimization procedures work on different time scales.

- Design stage (offline): optimal sizing of equipment;
- Control stage (online): real-time control of already installed equipment.

We detail below an example of results obtained at the design stage.

3) RESULTS

We computed the optimal configurations for various contexts and usage profiles. Figure 7 shows their payback time, which is generally an important metric for customers. Several storage technologies were explored (lithium-ion, lead-acid), together with size, in addition to PV-panel size. Unsurprisingly, it can be noticed that the solutions explored become truly economically viable for high-usage frequencies. Energy storage becomes useful for such intensive uses as well.

Optimization analytics provided dramatic improvement of elevator energy efficiency by enabling the embodiment of energy recovery, energy storage, and renewable energy production equipment in the system. Other types of analytics can lead to similar results in terms of energy efficiency, as discussed below.

Our vision for Analytics

We have shown in this paper various examples demonstrating the potential of analytics to improve Energy Efficiency. Based on Schneider Electric experience with applications, we propose a classification of analytics according to seven *Analytics features* (see Figure 8).

- Decision support through simulation: the principle is to provide what-if scenarios or simulated information in order to understand the impact of a potential action on a system.
- Context-dependent control: the principle is to control equipment in an adaptive and robust way, ensuring compliance with process goals and constraints while taking into account real-time context evolution.
- Resources and activities planning and scheduling: the principal is to establish optimized planning of activities with respect to criteria such as cost, delay, CO_2, etc., taking into account a set of constraints regarding the process or available resources.
- Condition monitoring, diagnostic, maintenance: the principle is to detect problems or issues as early as possible so as to diagnose causes and manage maintenance.
- Data correlation and prediction: the principle is to reveal patterns and models through statistical learning and clustering, and use them for forecasting.
- Data disaggregation and information discovery: the principle is to discover the characteristics of a system, inferring detailed information from more global information, without prior knowledge.
- Performance evaluation and benchmarking: the principle is to establish various performance indicators and compare them to state of the art and best in class.

Together, these features cover a wide range of application needs. In terms of technologies, they rely on techniques such as simulation, optimization, rules, dynamic systems modelling, statistics, pattern classification, pattern learning, and visual analytics. Most importantly, they can be combined to build complex applications. As previously illustrated, these new applications should drastically improve the operational efficiency, and by thus, the energy efficiency. How to disseminate the analytics for operational efficiency in the industrial world remains an open question. One of the key drivers towards adoption of analytics solutions for energy efficiency is the deployment speed and cost [Rohdin 2006]. Hence, there is a need for building comprehensive libraries of analytics tools and effortless execution frameworks that allow for the implementation of analytics-driven solutions [Bunse 2011]. Beyond technical requirements, the success of dissemination will be conditioned by the ability of

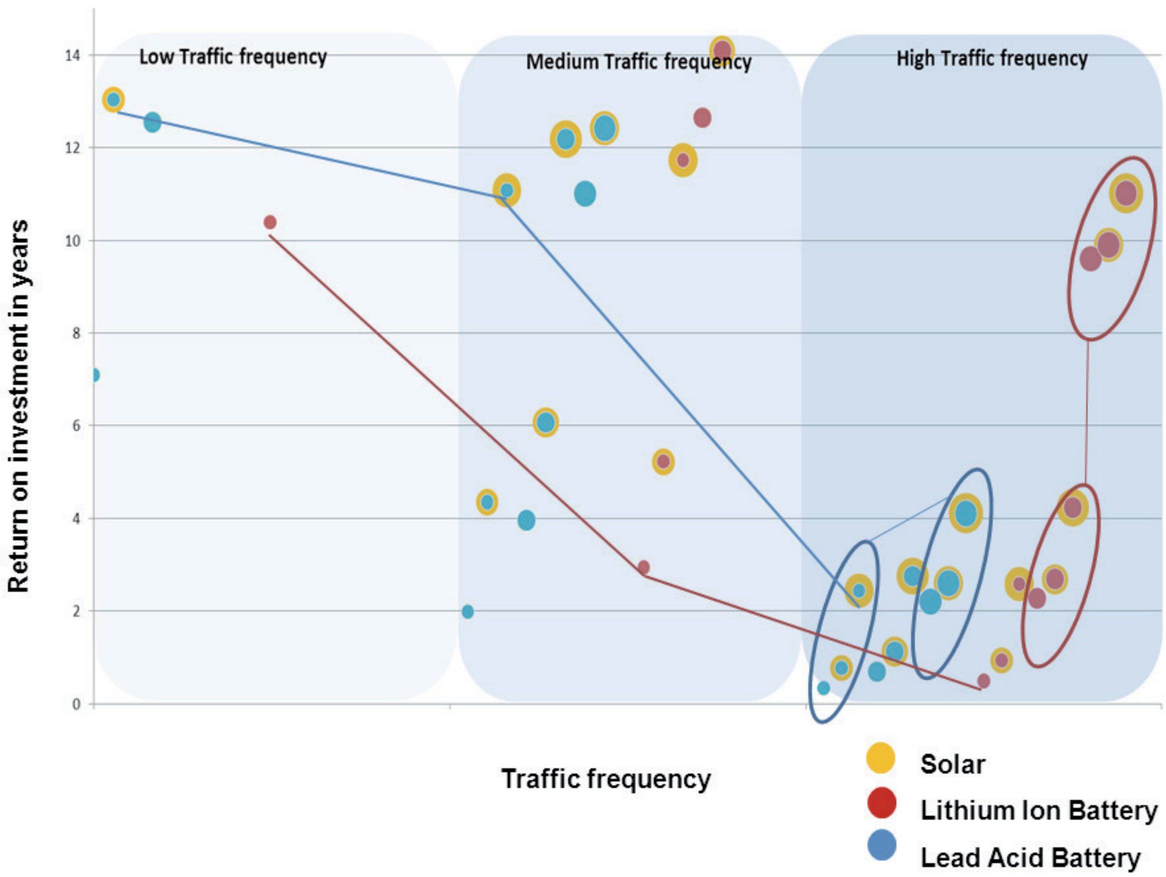

Figure 7. Example of results at design stage. Payback times for various technical configurations and contexts. Dot diameter refers to equipment size.

Figure 8. Seven Analytics features.

analytics players to propose applications tailored to fit applicative needs and taking into account the day to day usage contexts at field, operation, and enterprise levels.

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