Optimal Energy and Emissions Management During Energy Transition

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Introduction

The energy landscape is evolving. Energy costs are fluctuating widely and global concern to reduce Greenhouse Gas (GHG) emissions grow stronger. Traditional energy sources, such as coal, have relatively declined in importance, while supplies from natural gas and renewables were consistently growing in recent years because of cost reduction. Additionally, the COVID-19 pandemic impacted consumption patterns, resulting in drastic price volatilities for oil and petroleum derived products, although recently recovered to previous days levels. Adding to the complexity of this environment, hourly or sub-hourly changes of power market prices are becoming very common around the world.

Manufacturers are aware of energy's role in overall costs and emissions. As a result, they put significant effort to achieve a better management of their energy systems. For large-scale process plants, energy normally accounts for 50% of operating expenses (that is, excluding the feedstock). Consequently, an energy use reduction of 10% can often improve margins by 5%. As companies seek to boost profits and reduce emissions, energy optimization is naturally one of the first places to look.

When companies can manage energy provision and consumption in real-time, it is possible to significantly reduce total energy use with just a few actions. Area by area, a site can quickly make improvements to improve efficiency and reduce consumption and emissions. On the other hand, large-scale improvement projects, such as installing a new cogeneration system, need careful examination for cost/benefit potential.

Process plants, manufacturing sites and communities need to consider what is the best way to produce, store, distribute, and mix the available energy options in the context of the energy transition to zero GHG emissions. Decarbonization initiatives can be grouped into three different scopes: direct emissions of the site, from energy imports and from products sold, as presented in Figure 1. First scope is essentially a site related issue which could be initially addressed by improving overall energy production and distribution efficiency.

Whether process plants use traditional, renewable or both energy sources, there is a need to find an effective way to adapt to this new context by integrating these sources or by fundamentally changing the existing energy system infrastructure. The final objective is to simultaneously reduce cost and GHG emissions in the current context, during the transition and continue doing it when a distributed, renewables-based energy system operates long after.

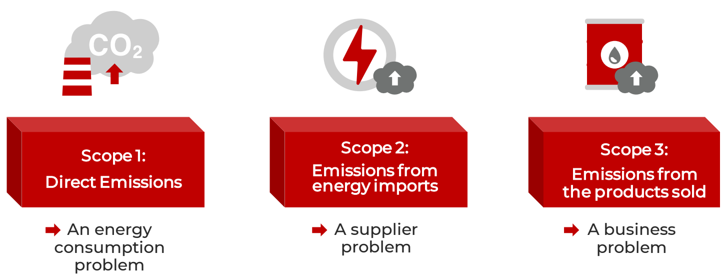

Figure 1 - Decarbonization of the hydrocarbon industry. Focusing on CO_2 emission reduction

Energy systems integration during energy transition

Energy transition was defined as the transformation of global and local energy systems from being predominantly centralized and hydrocarbon based to decentralized, low emission energy generation, transportation, storage, and use (Ref 1), as presented in Figure 2.

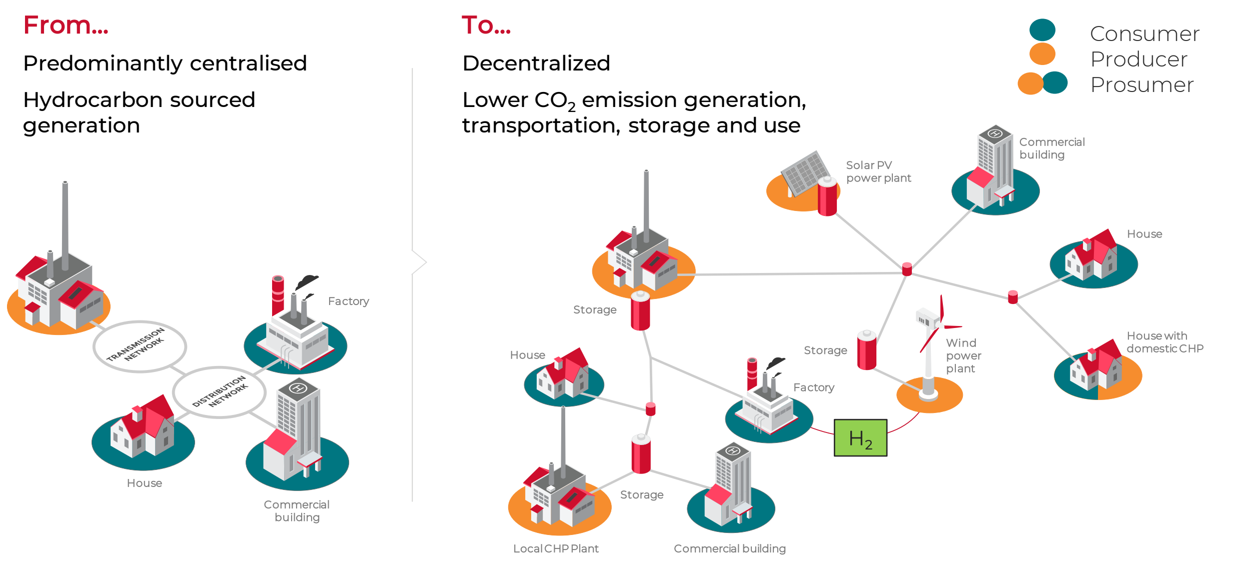

Figure 2 - Optimal energy management for the current energy systems operation and after the energy transition (Ref. 1)

The three forces driving the transition are

(1) Rise of hyper-connectivity and information availability; creating a significantly more informed global consumer base.

(2) Environmental sustainability: increasing recognition that greenhouse gas emissions must be radically reduced. The consequence is an increasingly discerning customer base and shift in behavior.

(3) Rapid Technological change: advancements in physical (such as solar panels and batteries) and digital technology (for example, real time energy management systems, artificial intelligence and cloud connected devices). These change the economics of different energy generation sources and distribution vectors, as well as making new business and digitally operated sites attractive.

Several solutions are available to reduce carbon emissions. Setting aside the economics of substitution vs carbon capture for liquid fuels at the consumer, the options available to reduce industrial GHG emissions can be broadly categorized as:

- Energy Efficiency
  - Reduction in core energy demand from more efficient equipment and processes
  - Improvements in energy re-use, particularly hot and cold energy recovery
  - Optimization of internal energy generation and supply, which in an industrial context typically means supply of power, steam, hydrogen, and refrigeration
  - Loss minimization, e.g., reductions in flaring, fugitive emissions etc
- Offsetting
  - Taking external actions such as tree planting to offset the emissions generated in industry
- Electrification
  - Use of renewable electricity to replace hydrocarbon combustion
- Carbon Capture
  - Capture of CO_2 and geological sequestration
  - Capture of CO_2 and conversion into useful products

The potential for energy efficiency is significant no matter what scenario plays out because it reduces both, operational expenditures (OpEx) and emissions, regardless of carbon price.

As it is stated in Ref. 1, energy supply optimisation has typically focussed on minimising the operating cost of existing systems or investing to improve the overall thermal efficiency of energy generation cycles. This has led to investments such as cogeneration, and substitution of higher carbon fuel oils for natural gas. However, the energy transition could cause the pendulum to swing much more towards import of low carbon power rather than self-generation. In addition, flexible smart grids will incentivise industrial facilities to balance demand and store, soak up or release energy to help balance the grid.

Decisions at the operational level, such as when to use the fossil fuel-based co-generators versus import of zero carbon energy, will not only depend on expected power and fuel prices but also on the predictions (i.e., forecasts) of renewable energy availability. This, in turn, depends on weather conditions, such as ambient temperature, wind speed, or solar intensity. Due to uncertainty on the factors that affect the generation of renewable energy, it is necessary to include power storage facilities and explicitly consider availability and constraints.

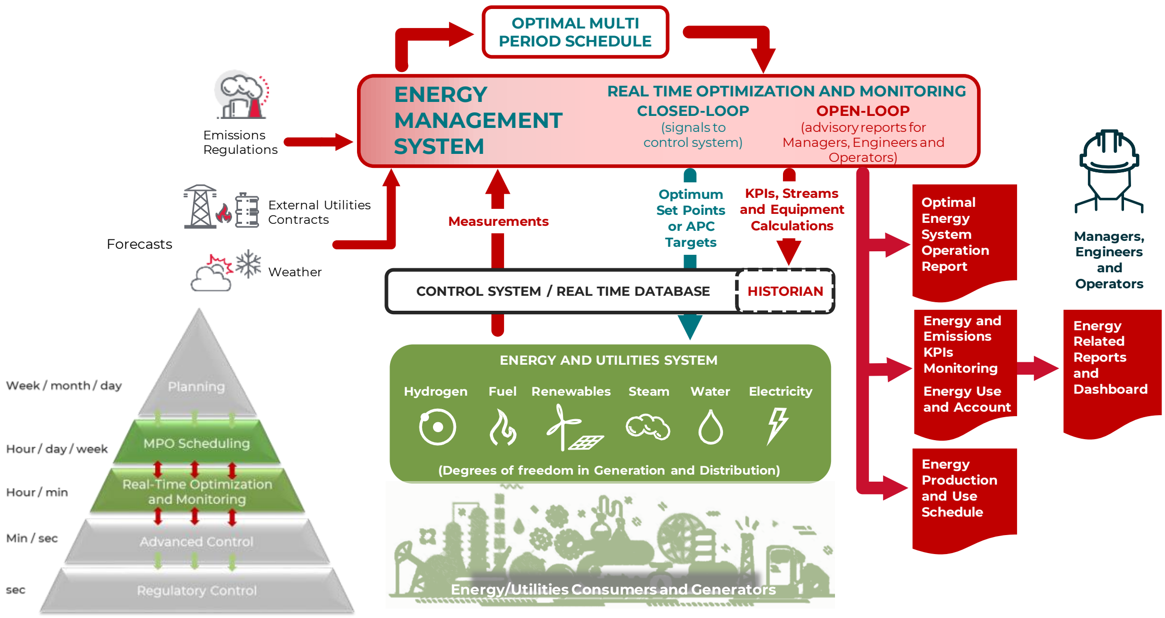

Figure 3 - Energy Management System functionalities for optimal and autonomous operation (Ref. 2)

The level of integration and complexity that would be achieved during the energy transition will introduce an increasing complexity in the management of these mixed energy systems. Digitalization will play a major part in accelerating efficiency gains. It will drive action by providing data transparency across portfolios, with real-time, model based automated energy management ensuring the systematic achievement of maximum potential.

With the objective to make this complex set of decisions feasible, we believe that any Energy Management System (EMS) supporting tool should include and provide the functionalities described below and presented in Figure 3.

- Provide integrated, holistic models, that considers not only equipment or subsystems usually encountered in conventional energy systems but also what relates to renewable energy sources, such as Photovoltaic (PV), wind, biomass, hydrogen, etc.

- Support forecasting, which estimates future operational site conditions and environment, like weather, power/fuels market conditions, process energy demand, etc.

- Allow the analysis and monitoring of current and past energy efficiency and performance of the site and renewable sources.

- Support the optimal energy scheduling, taking into consideration availability, forecasted consumption, variability in electricity prices and inventories, as well as multi-period related decisions.

- Automate the integration of the optimal schedule and real time recommendations to relieve schedulers and operators from complex and time-consuming decision-making activities.

- Target autonomous operation in the short and medium term, allowing a smooth information flow between the different decision levels, going from planning to the regulatory control layer.

Real-Time Optimization

Real time optimization was used elsewhere to manage energy systems at the minimum cost, while continuously reducing emissions. Two examples are presented:

Middle East Refinery: In Ref 3, the results obtained with an MES applied at KNPC Mina Al Ahmadi (MAA) refinery, Kuwait is discussed. The energy system modelled and optimized comprises steam, fuels, electric system, emissions, boiler feed water, condensates, demineralized water, furnace efficiencies, sea water, cooling water, heat exchangers UA, heat loss to product coolers, hydrogen and flaring.

Even at a region where energy costs are low, the project challenges were to reduce the total emissions and cost of the energy by automatically generating operational recommendations to help engineers and plant operators in the decision-making process. In addition, energy related KPIs were calculated in real time and historized. In Figure 6, a trend of the economic potential savings (bars) is superimposed with the CO_2 emissions reduction potential. The graphs shows that both objectives were fully met, since savings of 4.4 MM$/y were obtained (because of the potential savings being consistently captured), as well as CO_2 emission reduction of 27,600 tons per year was achieved,

European Refinery: In Ref 4, an MES implemented at TOTAL Antwerp refinery was presented. The site-wide energy system is monitored and optimized in real time. The EMS was built to be a “tool” for operations to produce electricity and steam at lowest cost, reduce steam losses and follow-up energy cost and performance KPIs on an hourly basis.

Energy cost savings of 1.5 to 3.5% (in the order of 1.8 to 2.8 MM€/y) and steam losses reduction of 20-30 t/h were achieved due to real time optimization, as shown in Figure 5. EMS was able to obtain an important overall site efficiency improvement and, since hydrocarbon-based fuel was used (Natural Gas), GHG emissions were also reduced. This is a clear example of an EMS solution that simultaneously optimized, cost, and emissions, as discussed before.

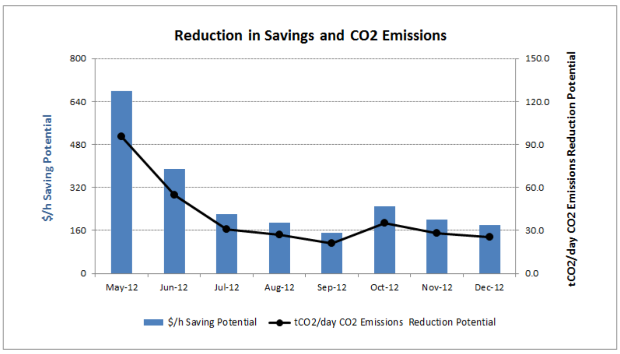

Figure 4 - Reduction in energy cost gap and CO2 emissions obtained with an EMS system (Ref. 3)

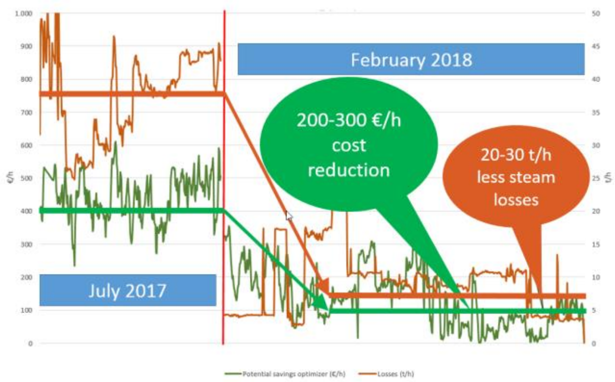

Figure 5 - Reduction in energy cost gap and steam losses with an EMS system (Ref. 4)

Multi-Period Optimization

Real time optimization and scheduling, working together and properly aligned, is of paramount importance to operate even better the energy systems at the minimum cost, in particular for those involving renewables. The inherent variability of the renewable energy sources and electricity market prices, along with the need to coordinate energy storage, conventional production backup and other time dependent constraints, makes optimal energy scheduling a key and pivotal need for tools that aim at managing these energy systems.

The multi-period optimization (MPO) technology accounts for restrictions that affect multiple time periods, usually in the future. It is indispensable for taking decisions when energy inventories, time-sensitive operating constraints (e.g., minimum down time or up time for pieces of equipment like boilers and gas turbines and its sequencing, etc.), or the start/stop schedule of complex equipment (e.g., gas turbines with their related heat recovery steam generation and steam turbo generator) are present. It is useful for different types of renewable energy systems. A few examples showing some of the potential uses are:

Concentrated Solar Power: to manage the energy storage and the start/stop of the system (pumping of the heating fluid, steam turbines) as a function of the solar intensity and other specific constraints.

Photovoltaic (PV) Solar Energy: managing the energy storage as a function of the prediction of the solar intensity and other specific restrictions and constraints. Decision variables could involve start/stop of ancillary or backup conventional systems, like boilers, gas turbines or turbine/motor drivers for pumps and compressors.

Wind Power: to manage the inventory of batteries and/or hydrogen, when it is produced to store energy, injected in a natural gas pipeline, or further processed in a production plant. To be done as a function of the prediction of the wind speed and other restrictions. MPO could eventually be used to define the start/stop of the wind turbines.

Biomass: MPO can be used to manage the biomass inventory that is used for the generation of steam or electricity as a function of the forecasted supply as well as constraints on the power and/or biomass storage capacity and alternative fuel costs.

As a case study of how the MPO is used in the new renewables landscape, an example is presented.

Hybrid Power Plant: it is a renewables-based generation facility in Europe where both, PV, and wind power production is done (from there came the *Hybrid Plant* term) as well as battery banks are used. In this case, MPO helps to optimally manage the batteries storage based on the solar and wind intensity forecasts, as well as the grid prices and demand.

Figure 6 shows a screenshot of the EMS real time optimizer and monitor web graphical user interface, with the Solar panels and batteries tied to the direct current (DC) line, and the wind turbines to the alternate current (AC) line. A converter tying both DC and AC lines. Figure 7 presents the results of the optimal batteries management, with its charge, discharge, and inventory schedule, based on the wind and PV power production forecast. The optimal schedule was produced with an Energy Management System which includes an MPO based application that helps drive the real-time optimal operation.

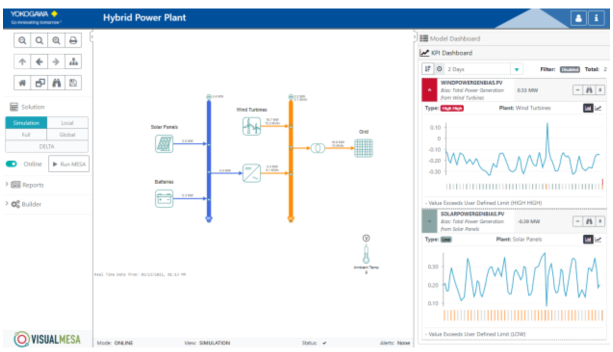

Figure 6 – Hybrid Power Plant EMS, web based Graphical User Interface for real time optimal operation and monitoring

Figure 7 - Hybrid Power Plant EMS, wind, and PV power production forecast and MPO based batteries charge/discharge and inventory optimal schedule

Conclusions

Energy transition activities introduce several challenges when trying to effectively manage energy use in process plants.

When planning, monitoring, or managing in real-time, either for a single site or a set of interconnected facilities, a detailed knowledge of the sources and uses of energy is necessary. The coordination of information, forecasts, scheduling activities, regulations, reporting, and control activities are necessary for consistent and optimal decision-making. This requires the appropriate set of software support tools.

An ideal EMS should be based on a real time, digital twin model of the energy system to help always operate at the lowest economic cost and minimum GHG emissions. This will allow to monitor the past while optimizing the current operations with the advantage of looking into the future.

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