INDUSTRIAL ENERGY MANAGEMENT BY USING AN ON LINE TOOL

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Abstract

Repsol La Coruña refinery is a high conversion Site with Coke and FCC units. The energy system is based around five steam headers and two cogeneration plants producing steam and electricity. Since the electrical system poses one of the main economic trade-offs with a steam system, electrical deregulation provides many new challenges to operate the overall combined system at minimum cost. In addition, Kyoto protocol introduces a new motivation to reduce CO2 emissions.

This paper describes the tasks performed, together with Soteica, using modern online information system tools to assist with the energy system management. A full model of the energy system has been done. All the constraints have been included and the model is continually being validated with live data. Performance monitoring is done and it includes the tracking of equipment efficiencies by utilizing validated data for its continuous calculation.

By auditing the energy system, imbalances can be identified and reduced. Therefore, the data can be relied on for evaluating the value of energy production and usage, and waste can be eliminated. Planning for a better operation of the energy system by performing case studies is usually done by using the validated model. Finally, it is important to mention that the optimization of operating conditions on a day to day basis is performed.

As a result of the project, new sensors have been located and substantial savings in global energy costs have been reported.
1. Introduction

Repsol YPF La Coruña Refinery operates a large and complex energy system, and consequently requires specific tools to assist with the energy management.

Refineries and large petrochemical complexes usually operate complex energy systems. For example, they use different kind of fuels, operate cogeneration units, have several steam pressure levels, feed different types of consumers and there are emission limits to be observed. In addition, the Kyoto protocol introduces a new motivation for industry to reduce CO2 emissions in many countries, with particular consideration given to the CO2 emission cost and how it should be taken into account when managing energy systems.

In general, these complex energy systems have several degrees of freedom. Manipulating these degrees of freedom with a cost based optimization program usually can result in significant savings in operating costs. This is particularly important within current deregulated electrical markets. Since the electrical system is one of the main economic trade-offs with the steam system, electrical deregulation provides many new challenges to operate the overall combined system at minimum cost.

Other important aspects are that utilities systems are continuously evolving (changes are frequent) and that also, sometimes, there is a lack of sensors that needs to be addressed properly.

Furthermore, utilities systems have several constraints coming usually from the operations side. For example, maximum flows and steam production cushions.

Finally it is important to mention that traditionally, given the complexity of the system, the optimization of the utilities is managed at the level of refinery areas. But the optimization of individual areas optimization does not necessarily give the true global refinery optimum.

In order to successfully address all the items mentioned above, a tool called Visual MESA has been used as the model and optimization engine. Visual MESA is a computer program designed to model steam, Boiler Feed Water (BFW), condensate, fuel, electrical systems and CO2 emission cost. It is an online program that receives live plant data from the steam, fuel, condensate, BFW, and electrical system metering.

Visual MESA can help reduce costs by performing the following tasks:

**Optimization:**

Visual MESA helps to find the most economical way to run the utilities system, while remaining within the real operating constraints.

Visual MESA enables plant personnel to:

- Understand steam/electrical system operation
• Rapidly evaluate the economics of a change in operation
• Optimize the overall cost of fuel for steam generation and electricity, including the choice of the most convenient combination of turbines and motors
• Improve data quality

**Monitoring:**
Visual MESA provides a number of monitoring features that help to access data, control data quality, and alert of changes to the system. These features are:
• Plant, Equipment and Stream Information
• Trending Data
• Alerting
• Data Quality (Mass Balance Balloons)

**Case Studies (“What If?” Planning):**
Visual MESA allows to perform and evaluate “What If?” cases that enable plant personnel to find ways to operate more efficiently and at less cost. Some examples are:
• Front-end loading on projects
• True “Plant-Wide” project evaluation
• Steam, fuel, BFW, condensate, and electrical system improvements
• CO2 emission cost

**Auditing & Accounting:**
Visual MESA helps plant personnel to find where waste steam is occurring in the steam system.

**2. Energy system description**
The La Coruña refinery is a high conversion refinery including a Coke and FCC units. The energy system is based around five steam headers and two cogenerations plants producing steam and electricity. The refinery has two main areas separated more than 3 km one from the other, called “Nostián” or Conversion area where the utilities plant area, FCC and Coke units are located, and “Bens” or Refinery area where several consumers such as crude units are located.

The steam network includes a “very high pressure” steam header, “high pressure” steam headers, two levels of “medium pressure” steam headers and “low pressure” steam headers.

The “very high pressure” steam header is generated in one of the cogeneration units.
The “high pressure” steam is generated mainly in four boilers, the heat recovery steam generator at the other cogeneration unit, the Calcination unit, FCC and Hydrogen boilers. The major high pressure steam users are the FCC and Coke units, Fuel oil heaters, a turbo generator and the cooling water system area.

One of the levels of the “medium pressure” steam headers is supplied by letdown from higher levels (through turbines or letdown valves) and by the turbogenerator. Users of this steam level are almost all the users at Refinery area (Bens).

The other level of “medium pressure” steam is supplied by letdown from upper levels (by let down valves or turbines) and by the FCC, Coke, Vacuum and the medium pressure heat recovery steam generator of one of the cogeneration units. Users of this steam level are almost all units of the Conversion area (Nostián).

The “low pressure” steam headers are supplied by letdown from upper levels (let down valves and turbines), some steam generators and also flash tanks. The users of this pressure level steam are units in both Conversion and Refinery areas.

Electricity generation is performed by the two cogeneration units, including turbo generators. The refinery is usually an exporter of electricity. The refinery is also able to import electricity if necessary since it is connected to the electricity external grid. The electricity system is especially interesting because of the current market which works on an hourly basis.

With respect to the fuel gas network, there are several suppliers and consumers of fuel gas being the most important consumer the gas turbine of one of the cogeneration units. When the fuel gas density or pressure decreases, propane is automatically added to the network.

3. Project objectives

The main objective of the project was to have available a tool for the on line optimization, auditing and monitoring the energy system.

Such a tool could be also used for engineering studies such as evaluations of operational changes, investment projects, and shutdown and startups, taking into account both the technical and the economical impact on the energy system.

The mentioned objectives have been defined taking into account the references of the other successful implementations using the same technology and implementers’ team, at the following sites of Repsol YPF group: Repsol Tarragona refinery, Petronor Somorrostro refinery, YPF La Plata refinery and Repsol Química Ensenada petrochemical complex.
4. Implementation Description

Soteica Europe has worked together with Repsol YPF – La Coruña Refinery, Operations and Process Department, in the implementation project, which included the following general activities:

- Data collection,
- Model building,
- Linking of Visual MESA to the Plant Information System,
- Build on-line optimization;
- Model and optimization review,
- Training for Visual MESA's users,
- Reports generation, and
- On Line, day to day optimization

In the following paragraphs, first the model building and optimization implementation are briefly described. After describing the software installation and system architecture, the reports generation and their use for energy management are explained.

4.1. Model Building

A complete model of the overall Energy System was built. The model includes the whole fuel, steam, boiler feed water, condensate and electrical system. Steam is generated in several different Units, with conventional boilers, heat recovery steam generators and a two cogeneration unit with possible steam injection. There are also two steam turbines that generate electric power.

The five steam pressure levels were modeled as well as all the units with a high level of detail, including all the consumers and suppliers to the respective steam, BFW and condensate headers.

Electricity and fuels supply contracts details have been included in the model obtaining the electricity market cost from the real time data base system.

Figure 1 and Figure 2 show views of the Visual MESA model of the two main refinery areas. By navigating through the model, each individual Unit of the system can be monitored in detail.
The fuel gas network was also modeled, as it is involved with the steam and power generation and all its constraints and degrees of freedoms are also taken into account by Visual MESA. It is shown on Figure 3.
4.2. Optimization configuration

Visual MESA has built-in mathematical models and optimization routines in order to calculate how to run the steam and electrical systems at the minimum overall cost and still meet the required plant steam demands and other plant constraints.

The optimization determines where to make incremental steam (which boilers or steam generators) and which turbines or letdown valves will most efficiently let the steam down between pressure levels.

Visual MESA uses an SQP (Successive Quadratic Programming) optimizer.

Visual MESA optimization can be organized into four levels:

- **Level 1**: includes basically the pressure control related devices: boilers, letdown valves and vents.
- **Level 2**: adds the optimization of other continuous variables including turbo generators, steam injection, extraction/induction/condensing turbines, steam turbine, etc.
- **Level 3**: adds turbine-motor switching optimization (i.e., discrete variables).
- **Level 4**: adds equipment that would create “heartburn” if equipment moves were to be made, such as running a coker-feed pump with a turbine, with a motor standby,
or equipment that you don’t want to optimize. Running at level 4 can tell you the cost of your insurance policy.

A well tuned model would generally be run at level 3, with a run at level 4 once in a while to evaluate potential operational changes.

The objective function Visual MESA optimizes is the total operating cost of the system, which is:

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Total \, Operating \, Cost = Total \, Fuel \, Cost + Total \, Electric \, Cost + \sum \, Miscellaneous \, Costs
\]

The SQP optimizer’s job is to minimize this objective function subject to operating constraints in the system.

Total fuel cost is determined from the fuel use of each boiler and combustion turbine multiplied by their respective fuel prices.

Total electric cost is determined from the net electric use of each motor, load, and generator multiplied by their respective electric prices. The electric generation (power selling) is just negative electric use. The model takes into account the electricity price corresponding to the actual hour of the day as well as the penalty associated to selling more or less of the market arranged exportation set point.

Miscellaneous costs are normally used to charge for demineralized water coming into the system, but can be used for any other cost related to the energy system (for example CO2 emission cost).

A model to calculate and optimize the CO2 emission cost has been developed and could run together the electric, steam and fuel optimization and help choose the best fuel to use in boilers and gas turbines taking into account the emission costs.

The fuel gas network was also modeled to consider the complex constraints and different fuel availability.

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4.3. Visual MESA architecture

The Visual MESA model gets live plant data from the Plant Information System via standard OPC interface.

Visual MESA is installed for two types of uses: Stand Alone use and Client Server use:

- Client server use: The purpose is to share the solutions, supporting multiple users. Visual MESA server runs as service on a PC. It automatically runs with no interruption every 15 minutes, writing results on the plant information system and generating reports. Any PC connected to the plant network can be configured to
access the model and the reports. Users can connect in many ways (HTML, Excel, Graphical User Interface)

- Stand alone use: The purpose of this installation is for individual users to be able to run case studies on their own PCs, using a snapshot of the current model or any other model the user may have built and the current data or historical data (automatically taken from the plant information system via standard OPC Historian Data Access).

4.4. Reports

MS Excel provides a familiar environment for users to generate reports and views of the Simulation and Optimization of the system. It also enables users who are not familiar with Visual MESA to take advantage of the information Visual MESA provides. Figure 4 shows an example of a report generated with Visual MESA. In the worksheet shown, steam generation and fuel consumption are reported for the current values and the optimized ones.

Figure 4. Excel Custom report example
Data comes to Excel directly from the model. As Visual MESA is built around .NET technology, it can seamlessly link the Excel spreadsheet with the actual data and optimum operation calculated by the model. Visual MESA also generates automatic HTML reports in order to allow to everyone on the intranet network to see how the utilities system is being operated and what the potential savings are.

5. Benefits
5.1. Auditing the Energy system
By auditing the energy system, imbalances can be identified and reduced. Therefore, the data can be relied on for evaluating the value of energy production and usage, and wastes can be eliminated.

Visual MESA helps to find where wasteful steam use is occurring in the steam system. A Balloon is a Visual MESA component used to measure steam balance closure. A Balloon performs the algebraic sum of all the flows for streams entering and leaving the balance. Since we have a value for the flow of every stream, the total should be 0.0 (all the steam that comes in must go out). If the net balance is not 0.0, there are either meters or estimated equipment flow rates in error, or there is steam leaving or entering the “balance” that has not been accounted for. Balloons dynamically show error by changing size and color depending on the amount of steam imbalance. A Balloon is connected to each portion of a steam header where the possibility exists to close a mass balance. Figure 5 shows an example.

![Figure 5. Balloon location example](image)

A closed mass balance is formed by: A group of flowmeters, equipment with associated meters, or a combination of equipment and flowmeters.
Balloons are used for two main purposes:

- To validate steam flow data
  - If all of the flows in a “balance” continually add to near zero, the flow data can be relied on for evaluating the value of production and use, and waste can be eliminated.
  - If the balance does not add to near zero, then meters could be bad or equipment steam flow rates could be different than estimated and there might be significant waste.
- To store model error where the error exists for use when comparing one case to another (i.e., the actual operation against the optimized one).

5.2. CO2 emissions reduction

CO2 emissions cost has been taken into account according to the Kyoto protocol. A special modeling block with the emissions factor for each fuel and the CO2 cost has been added. Visual MESA adds the CO2 emission cost to the total cost equation, so when Visual MESA minimizes the total cost, it is taken into account with all other costs (fuels, electricity, dematerialized water), and the optimum fuel feed to boilers and gas turbine is suggested.

In principle, as the energy cost reduction is given mainly by a reduction of fuels consumption, this always implies a CO2 emissions reduction, except in the case where the optimization recommendations are related to the consumption of a cheaper fuel but that generates more CO2 instead of using a more expensive fuel that generates less CO2. This could be the case when replacing Natural Gas with a heavy liquid fuel. This challenging tradeoff is affected directly by the CO2 allowance price.

5.3. What If Engineering Studies

Visual MESA helps to evaluate potential capital or operating changes to the Refinery and assess the economics and operability of the changes.

Visual MESA can also automatically evaluate multiples What If scenarios for example by using its Excel Add-in.

During a What If the current site status (or also the corresponding optimum calculated by Visual MESA) can be compared with the optimum case study and easy analyze how this change impacts on the site and how to operate the energy system after that change. All
imbalances are maintained constant and the steam production is allocated to the new demand / request proposed scenario.

*Example 1:*
The evaluation of the economical impact of adding a new Natural Gas line feed to the Gas Turbine has been done. This investment project would allow the replacement of its Gas Oil feed.

It can be done by simply change the fuel to the gas turbine and running Visual MESA on What If mode (Balloons locked). By running this What If study significant savings have been identified and of course a CO2 emissions reduction as well.

*Example 2:*
Another What If example is how to operate the Refinery when one plant is shut down. For instance, a unit that is a high steam supplier for the refinery (see the plant area called “AL” in Figure 1). It takes BFW, Fuel Gas and medium pressure steam and exports high pressure steam to the refinery. If this plant is shut down, the refinery has to adjust its steam production in order to adapt to the new situation.

This can be easily simulated with a What If case study and Visual MESA finds the most economical way to operate the energy system.

In order to make this What If there are just a few steps that need to be done with Visual MESA:

Working with the model in Stand alone mode, with the current operation values, run the optimization and set the results as the base case. Then, disable the plant area “AL” and finally run Visual MESA again with the balloons locked.

The solution can be observed through reports, and also by different views in the model. Visual MESA automatically allocates the steam production to satisfy the demand into the boilers and cogeneration units. As there is some Fuel Gas that it is not longer used by AL there is a trade off among boilers, gas turbine and its post-combustion unit that is done automatically by Visual MESA. As it can also generate electrical power, Visual MESA also suggests the most economical turbine and motors operation.

The following screen captures (Figures 6 and 7), with the highlighted steam lines, correspond to the Delta views (Nostián area and utilities plant area). That is, the difference between base case and the comparison case (AL disabled). The changes in the energy system to optimally manage the proposed situation can be observed.
Figure 6. Case study Delta view, Nostián area: a plant area that is steam supplier stopped

Figure 7. Case study Delta view utilities plant: a plant area that is steam supplier stopped
5.4. On line optimization

Operators have always available a set of recommendations to operate the energy system at a minimum cost. The tool also acts as a “watch dog” since supervisors can evaluate how operators manage the energy system. Prior to applying the recommendations (or when recommendations are not taken into account) there is variability in the way the energy system is operated and also potential benefits are usually found. As soon as Visual MESA is commissioned and put into use, this variability is eliminated as it was shown in other previous Visual MESA implementations (see References 1, 2, 3), Figure 8 shows the savings found during a week of operation (in terms of % respect with respect to the total energy costs) according to the usual way operators perform without any advisory help. Each point in the plot corresponds to an automatic Visual MESA run.

![Figure 8. Identified savings along a week](image)

6. Practical Issues

As part of the implementation, a review of the steam, power, and fuel control systems with knowledgeable experts has been performed. The goals of this Control System review have been:

- Develop a list of variables already controlled and how Visual MESA needs to relate to them
- Identify any needed control strategies or changes to existing strategies to implement optimization
As a result, the optimization suggestions can be achieved properly through the existing operating and control procedures.

Since Visual MESA is an operational oriented tool, the proper training of the operating personnel is a very important project step. The different shifts have been trained by using the La Coruña refinery model. Feedback from the operators during and after the training classes has been very useful to make the day-to-day application easier to use, improving the report views and the displayed information.

In order to facilitate the implementation, at the beginning the optimizer was running at level 2 (only continuous variables) so they can be handled by operators more easily. In a second stage, discrete variables are being considered.

With respect to lack of sensors, Visual MESA utilizes calculated or estimated data in case a sensor does not exist or has a temporary failed state. The most important sensor variables are those that directly participate in the optimization: Cogeneration (steam flow rate), Boilers (steam flow rate), Letdown valves, Vents, and Motor-Turbine on-off statuses. New sensors have been located to automate the capture of the on-off status from the plant information system.

Following in importance are those sensors that provide data to the model but that are not changed by the optimization. Optimization can still be performed and implemented without these Sensors (Reboiler Steam Flows, Temperatures and Pressures).

Less important sensors are those that are only used for monitoring and do not participate in the modeling.

6. Conclusions

An on line tool for the management, auditing and cost control of the Energy System has been installed at Repsol La Coruña Refinery.

Among the benefits of the implementation, the following ones should be highlighted:

- Organize the information of the refinery energy system in one model and one environment that everyone has access to.
- Understand all the decision variables and the associated constraints, which sometimes are hidden or ignored.
- Allow the centralization of the responsibilities of operating the system optimally.

Energy costs reductions can be obtained taking advantage of the Visual MESA software functionalities. It demonstrated to be a robust optimizer, well suited to be used on a routine basis by operators. The model is also used to evaluate a priori what-if scenarios that
include modifications or different operating alternatives of the Utilities Systems. Auditing and accounting of steam and Boiler Feed Water allows reducing waste steam and helps identifying imbalances. Finally, continuous monitoring allows preventing plant upsets and helps to quickly identify steam wastes.

It is important to emphasize the high involvement and motivation of plant operators since the beginning of the implementation. Coordination amongst plant areas in order to implement the proposed optimization recommendations is also a critical issue, so management involvement is crucial. The robustness of the tool helped operators to gain confidence on the system.

Final user’s acceptance and widespread use, for both engineers and operators, is one of the key issues for this successful implementation.

REFERENCES

