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Real Time Online Energy Management at KNPC Refineries

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Abstract

Kuwait National Petroleum Company (KNPC) is a wholly owned subsidiary of Kuwait Petroleum Corporation (KPC). KNPC operates three (3) refineries viz., Mina Al-Ahmadi (MAA), Shuaiba (SHU) and Mina Abdulla (MAB). KPC internal directives required the implementation of a management process to optimize energy consumption through the formation of energy management cells (EMCs), which implemented an energy management program based on best international practices.

This paper describes the tasks performed to develop and implement real time, online models, to help with the three KNPC refineries energy cost minimization and energy management, which are scheduled to perform it automatically. They allow to clearly identify the different economic trade-offs that challenges the operation of the site wide energy systems at minimum cost while reducing the energy waste and, therefore, CO2 footprint. Recommendations given by the optimizers are taken into account by operations on a daily basis.

The same models used for the online, real time optimization, are also used in standalone mode, populated either with current or historical data, allowing to perform case studies for planning or to evaluate alternatives for a better and most economical operation of the energy systems.

As a result of the project, the information of each refinery energy system has been organized into models and reports to which everyone has access.

Introduction

It is Kuwait Petroleum Company (KPC) and its Subsidiaries policy to ensure that all energy will be managed in accordance with best engineering environmental practices and within regulatory compliance at all times [Ref. 1]. All operations must be committed to institute an energy efficiency programme and minimise the emissions of pollutants including global warming gases. As part of the activities to follow those premises, energy management cells (EMCs), have been formed at each of the Kuwait National Petroleum Company (KNPC) refineries: Mina Al-Ahmadi (MAA), Shuaiba (SHU) and Mina Abdulla (MAB). Such cells implemented an energy management program based on best international practices.

This paper describes the tasks performed to develop and implement real time, online models, to help with the three KNPC refineries energy cost minimization and energy management.

After describing the main project implementation tasks, the Real Time Energy Management System (ETEMS) functionalities are described and the optimization implementation procedures are commented.

Finally, some obtained results are shown.

Project implementation tasks

The main stages of the project have been:
- Define and Installation Stage
- Model Building and Configuration Stage
- Training Stage
- Site Acceptance Stage
- Commissioning Stage

Define and Installation Stage

The first stage of the project includes the tasks of data collection, control system review, software installation and detailed model scope definition.

Data collection consists basically in getting system diagrams, Real Time Database tags, and equipment information, plus price related information.

Control system review main goals are: to develop a good understanding of how the model optimization handles and process constraints are related through the site control system; and to identify any new control strategies or changes to existing strategies that are needed to implement the optimization. As a result of such a review, there is an alignment of the model with the real plant, making sure that the optimization suggestions can be properly implemented using the site's operating procedures, control strategies and control structure.

Software installation is done on a computer server, accessing the historian data via a standard OPC DA/HDA interface. Software installation at PC clients is also done for client server access to the model and also to work with the model in standalone mode.

In this stage, a document is prepared and approved with a detailed scope of the model to be implemented.

Model Building and Configuration Stage

A detailed model of the steam, fuels, electricity, emissions, boiler feed water and condensates systems has been built, including all the interactions among these systems, real plant constraints and degrees of freedom of their operation. Other utilities systems have been also modeled for monitoring purposes such as air, nitrogen, flaring system, cooling water, sea water and hydrogen networks.

Such a model is scheduled to perform automatic executions for the optimization of the entire system and is continually populated with validated, live plant data.

Figure 1 shows a screenshot of MAB refinery RTEMS model graphical user interface, general view.

The main optimization handles of the energy system are:
- Fired boilers steam production balancing (taking into account also the on-line calculated efficiencies)
- Steam letdowns
- Steam vents
- Pump swaps (steam turbine and electrical motor optional drivers)
- Fuels to fired boilers
- Makeup fuel to Fuel Gas network (Natural Gas)
- Electricity importation

The main constraints to be met are the following:
- Processes energy demand
- Burners capacity
- Emissions limits (NOx / SO2)
- Contractual constraints (e.g. Natural Gas and electricity supply contracts)
- Maximum and minimum operating limits for boilers

Recommendations given by the model are taken into account by operations on a daily basis.

The same model used for the online, real time optimization, is also used in standalone mode, populated either with current or historical data, to perform case studies for planning or to evaluate alternatives for a better operation of the energy system.
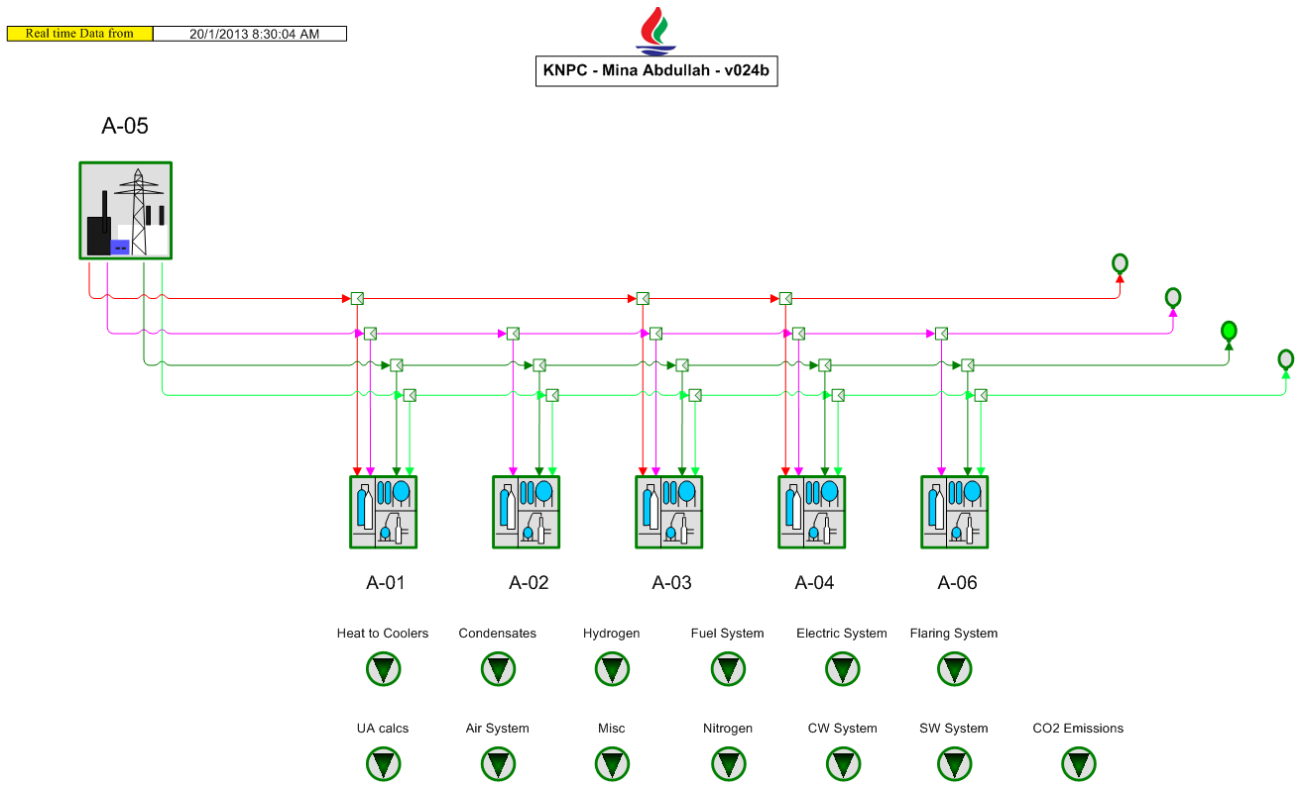

Figure 1. Graphical user interface of RTEMS model. General view. KNPC MAB refinery.

Training Stage

A midpoint review is done to review the model and optimization with users. At that time the users' training is done.

Burn in period corresponds to a fine tuning of the model, operating report and optimization based on Operations feedback in order to reach a day to day use of the application.

The usual way operators receive the set of recommendations is through a custom report. Figure 2 shows an example of such a report which corresponds to KNPC MAB refinery.

The EMC group contact every day the shift supervisor for coordinating and follow-up the changes.

Actionable Items

Boilers Production (klb/hr)	Actual	Optimized	Delta	
		After T/M swapped and Boilers biased		
B-31-101A	124.3	100.0	-24.3	MAN
B-31-101B	137.9			CAS
B-31-101C	111.3	100.0	-11.3	MAN
B-31-102A	146.4			CAS
B-31-102B	146.2			CAS
Total Boilers 900# Steam	666.1	629.5	-36.6	
B-06-101 (150# Steam)	58.7			MAN

U18 Letdowns (%opening)				
U-18 TR1 - 900# to 450# LD	10.0	5.0	-5.0	
U-18 TR2 - 900# to 450# LD	17.0			
U-18 TR3 - 900# to 450# LD	6.0	5.0	-1.0	

Turbines and Motors Swaps   Total T/M Swaps: 3

Unit	Driver	Name	Power (HP)	Steam cons. (meas.)	Actual Status	Optimized Status
U-31 (Utilities)	Turbine	P-31-101B-ST	286	0.00	Stopped	Running
U-31 (Utilities)	Motor	P-31-101B-M	286		Running	Stopped
U-37	Turbine	P-37-101B-ST	292	0.00	Stopped	Running
U-37	Motor	P-37-101B-M	292		Running	Stopped
U-37	Turbine	P-37-102B-ST	86	7.42	Running	Slow Roll
U-37	Motor	P-37-102C-M	86		Stopped	Running

Figure 2. Custom report example with RTEMS optimization recommendations

Site Acceptance Stage

This stage corresponds to the site acceptance test that is the check-list review of the functionalities required by the RTEMS.

Commissioning Stage

Along this stage, a full document is prepared and delivered with all the details of the system implemented, including troubleshooting and maintenance procedures. Benefits already obtained are also analized and reported. After the commissioning, the sustainability period begins with the main objective of sustain the benefits along the time.

RTEMS functionalities

The RTEMS has three main capabilities:

- Real Time Optimization
- What-if planning
- Auditing and Monitoring

Real Time Optimization

One of the main objetives is to operate the energy system at the minimum cost taking into account all the available resources and the real operational constraints (Ref. 2). Since the energy system is highly nonlinear and includes continuouys and discrete optimization variables, it requires a Mixed Integer Non Linear optimization technique.

The calculation core of the system is MESA (Modular Energy System Analyzer). For the solution of continuous nonlinear optimization problems, MESA employs an implementation of the Sequential Quadratic Programming (SQP) algorithm, developed by Dr. Leon Lasdon (Ref. 3). Lasdon's SQP solver has been fine-tuned specifically for the characteristics of energy system optimization with particular emphasis on robustness and speed. MESA uses a technique loosely based on "Relax and Cut" to deal with mixed integer nonlinear optimization problems resulting from the start/stop decision of equipment. In this technique, all integer decisions are converted to continuous variables by relaxing the bounds of the associated variables. This reduces the problem into a nonlinear continuous optimization problem that can be solved using Lasdon's SQP. This method has been highly adapted to suit the characteristics of steam, fuel, and power optimization on a real time basis, especially taking into consideration the time it would take to solve the mixed integer problem.

The objective function to be minimized is the total energy cost which is calculated as:

$$FuelsCosts + PowerCosts + OtherCosts$$

Under *FuelCosts* the following costs are included in the different energy systems refineries models:

- Natural Gas Cost
- Fuel Oil Cost
- LPG Cost

Under *PowerCosts* the following costs are included in the different energy systems refineries models:

- Purchased electricity cost

Under *OtherCosts* the following costs are included the different energy systems refineries models:

- Cooling water, sea water, distillate and fresh water costs

The following example corresponds to a case of real time optimization at SHU refinery. The set of optimization recommendations in this case have been:

- Steam production ratio among boilers
- Pump swaps (swappable turbines and motors in different plant areas)

A set of screenshots from the RTEMS graphical user interface corresponding to the Delta views, showing and highlithting the differences between actual and calculated optimum operating conditions is presented in Figure 3.

It can be observed part of the recommended solution: reduction of the total steam production at the fired boilers while balancing them, one of the recommended pump swaps in a process plant area and the resulting reduction in steam letdowns.

The hexagonal blocks with mountain icons inside shown in Figure 3 are optimizers blocks. Such items are used to define and configure optimization variables or degrees of freedom linked to the corresponding equipment. Furthermore, when they are colored inside, it is indicating the optimizers are at a limit, being one way to visually highlight the constraints the optimization is hitting during a given optimization case.

The Delta views are very useful to analyse and understand the optimization solution by navigating through the model, being configurable the threshold to show the changes and corresponding coloring code.
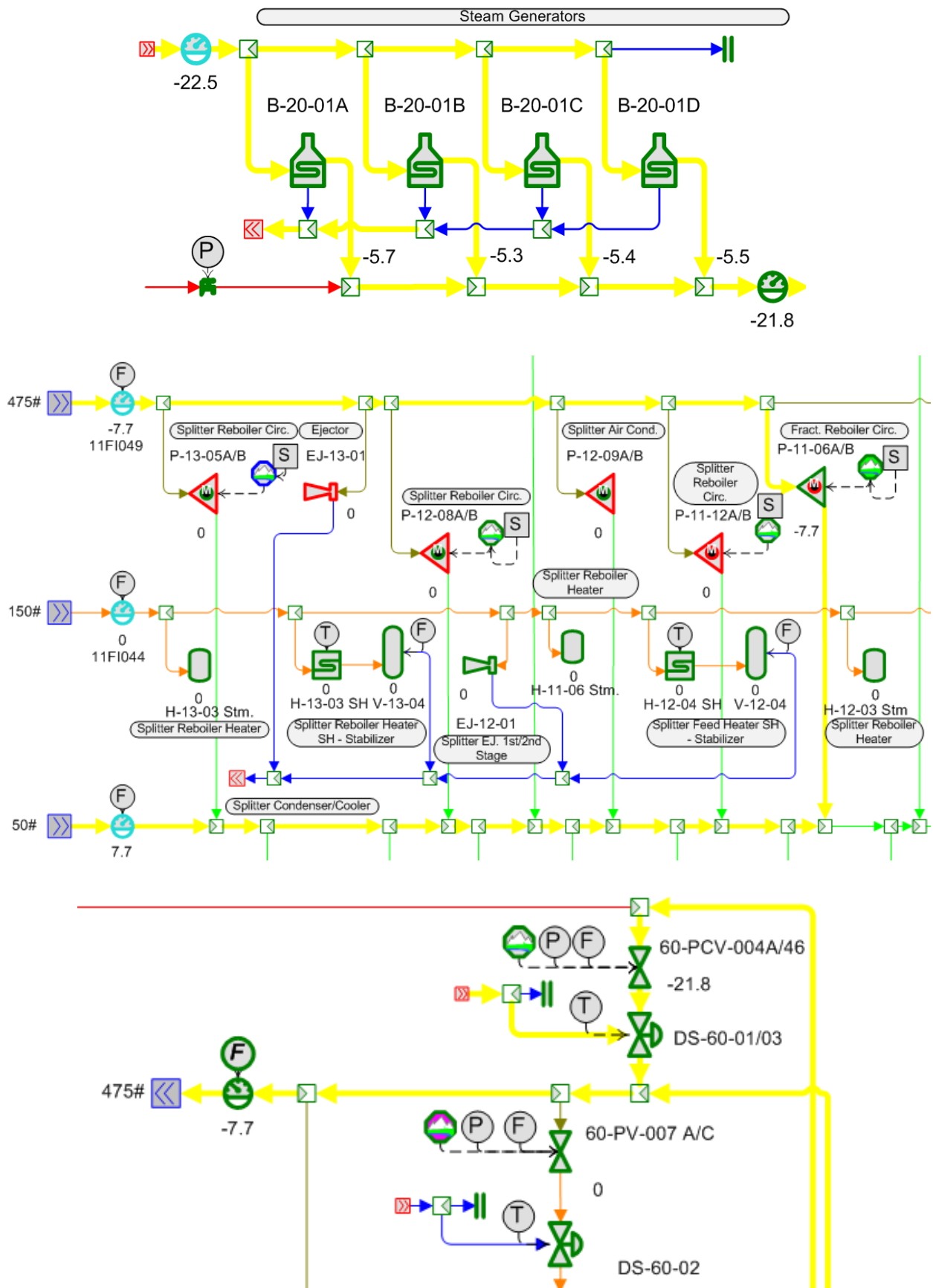
Figure 3. Example of Delta Views in a case of real time optimization at KNPC SHU refinery

Other interesting example corresponds to KNPC MAB refinery. In this case, a significant reduction in low pressure steam excess (venting and/or condensing) has been achieved after applying the RTEMS optimization solution on a daily basis.

Figure 4 shows the Delta view to illustrate this case of real time optimization. It can be observed the significant reduction in the excess of low pressure steam sent to the condenser (24.8 klb/h less of low pressure steam to the condenser, in this example).

Among the optimization actions, swaps between steam turbines and electrical motors have been done. As an example, in the same Figure 4, it is shown a group of turbines and motors giving the same service where the start of steam turbine and shutdown of an electrical motor was recommended.

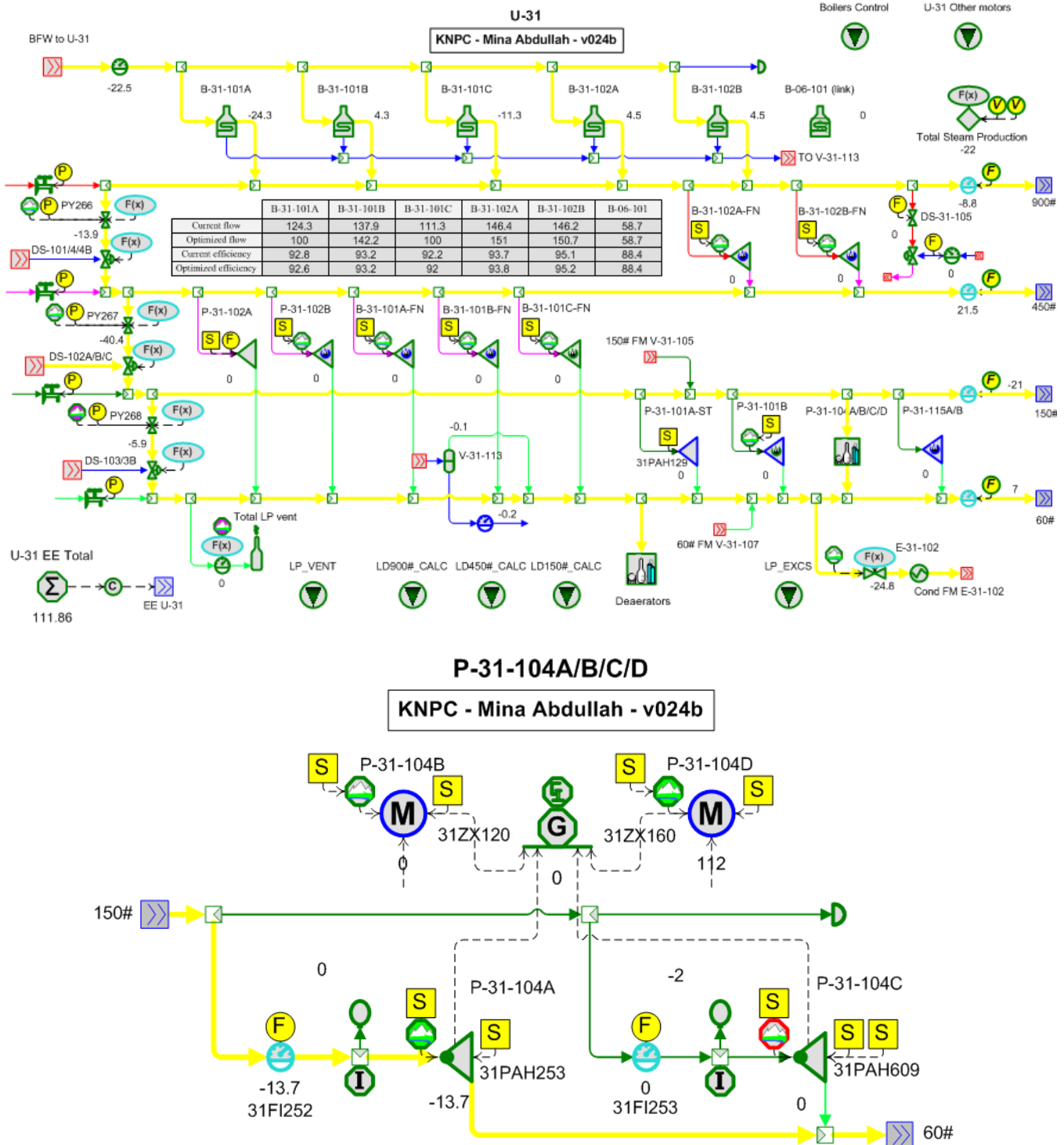|	B-31-101A	B-31-101B	B-31-101C	B-31-102A	B-31-102B	B-06-101
Current flow	124.3	137.9	111.3	146.4	146.2	58.7
Optimized flow	100	142.2	100	151	150.7	58.7
Current efficiency	92.8	93.2	92.2	93.7	95.1	88.4
Optimized efficiency	92.6	93.2	92	93.8	95.2	88.4

Figure 4. Example of Delta Views in a case of real time optimization at KNPC MAB refinery

What-if planning

By using the model in stand-alone mode, it helps to evaluate potential capital or operating changes to the complex and assess the economics and operability of the changes.

During a What-if study an actual site status (or also the corresponding calculated optimum) 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.

An example of these kind of studies is the following. It has been evaluated the impact on utilities system of reducing the Medium Pressure steam (450 psig) to the reformers. In this case, 16 kph less (8 kph to each cell) is sent to the steam methane reformers so a reduction of 0.8 in the Steam to Hydrocarbon ratio (S/HC ratio) is obtained. It was observed a decrease of 900 psi steam to the network from the unit (in this case 12.5 kph) and a decrease of Fuel gas consumed.

The corresponding effect on the power plant is a decrease in steam letdowns and low pressure steam vent and/or steam to condensing. Figure 5 shows the Delta View from RTEMS graphical user interface (differences between actual and comparison cases are highlighted).
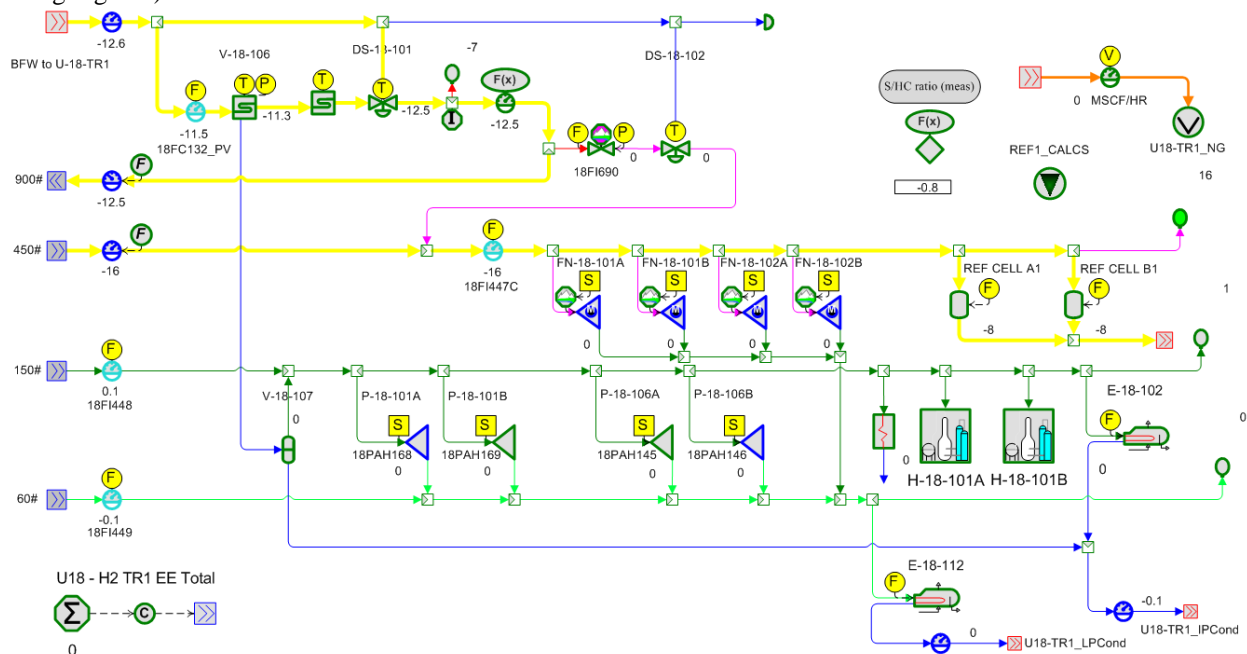

Figure 5. Delta view (differences between actual and comparison cases highlighted) – Case study example

Auditing and Monitoring

The auditing and monitoring of the energy system is an important task that the RTEMS carries out by helping in the follow-up of key paramenters such as equipment efficiencies and energy cost savings, and also in the validation of data.

At every automatic run, the RTEMS calculates and historizes:

- Fired boilers efficiencies
- Process heaters efficiencies
- Imbalances at every steam pressure level header
- Energy consumption per unit rate for every process unit
- Actual and optimal total energy cost

The potential gap between the current/actual operating costs and the minimum/optimal operating costs is also calculated and historized. The savings associated with this gap will be materialized only if all the suggested optimization movements are implemented simultaneously. These predicted savings constitute one of the main economic Key Performance Indicators (KPIs). It is expected that, if the operators implement all the proposed recommendations on a continuous basis, the potential gap will start decreasing over time. If in the future the system is in a new condition, a new potential gap will re-appear until the operators make the optimizing movements, and the cycle is repeated. If the projected savings are consistently high, this should prompt Management, Supervision and/or Engineering staff to identify any issue that is impeding the capture of the costs reduction.

Other important KPI is related to equipment efficiencies. Figure 6 shows an example of a report of a set of process heaters.

Heater	Current Efficiency (LHV %)	Target Efficiency (LHV %)	Current O2 %	Target (Design) O2 %	Current FG Flow (KSCF/H)	Curremt FG Duty (MMBTU/h)	At Target Efficiency FG Flow (KSCF/H)	At Target Efficiency FG Duty (MMBTU/h)	At Target Efficiency FG Duty Savings (MMBTU/h)	At Target Efficiency $ Savings per day
H-14-101	89.0	89.2	2.2	2.0	39.7	49.6	39.7	49.5	0.1	8.2
H-14-102	88.9	88.8	1.8	2.0	36.2	45.2				
H-14-103	91.4	91.2	1.5	2.0	163.5	204.4				
H-18-101A	82.4	82.1	1.7	2.0	135.1	168.9				
H-18-101B	82.7	82.4	1.7	2.0	132.3	165.4				
H-18-201A	82.6	82.4	1.9	2.0	132.6	165.8				
H-18-201B	82.8	82.6	1.9	2.0	130.5	163.2				
H-18-301A	83.1	82.6	1.4	2.0	135.9	169.8				
H-18-301B	82.5	81.9	1.4	2.0	132.1	165.1				
									0.1	8.2
H-12-101	77.1	86.22	9.5	2.0	27.8	34.8	27.8	31.1	3.7	301.9
H-12-102	82.5	85.9	5.6	2.0	33.5	41.9	33.5	40.2	1.7	138.7
H-12-103	81.9	84.0	4.1	2.0	16.5	20.6	16.5	20.1	0.5	40.8
H-12-201	88.8	93.0	9.6	2.0	29.4	36.7	29.3	35.1	1.6	130.5
H-12-202	86.4	89.4	6.2	2.0	31.6	39.5	31.6	38.2	1.3	106.1
H-15-101	83.6	84.4	2.8	2.0	21.6	27.0	21.6	26.8	0.2	16.3
H-16-101	81.4	84.9	5.5	2.0	29.2	36.4	29.1	34.9	1.5	122.4
H-17-101	80.5	85.5	6.8	2.0	13.8	17.3	13.8	16.2	1.1	89.7
									11.6	946

Figure 6. Example of heaters efficiencies monitoring report

The model calculates the incremental cost for the fuel burnt. Such a report allows prioritizing the actions to improve combustion based on economic impact.

By auditing the energy system, imbalances can be identified and actions can be taken to reduce it. Therefore, the data can be more and more relied upon to evaluate the value of energy production and usage, and wastes can be eliminated.

The methodology is based on getting inaccurate meters fixed, because imbalances are inherent to every real world steam system header calculation. The way the RTEMS deals with imbalances is as follows:

- Wherever there is a closed -mass, or mass and energy balances- the RTEMS calculates a real-time balance offset or bias (the so called balloons, see Figure 7) as the difference between the inlet and outlet streams to/from a given header.
- This offset is then held constant for optimization or case studies (considered as an unmeasured load).

Several actions can be taken based on the the imbalance magnitude:

- Big imbalances are visually identifiable (the size of the balloon increases and/or the color dynamically changes).
- Either visually or in a report, the RTEMS will flag these large imbalances to the user who can then focus maintenance attention on the meters associated to that balance.
- If a particularly important sensor fails in the validation test, the RTEMS could automatically shut down optimizers or force those constraints to which it is related or even shut down the entire site optimization.
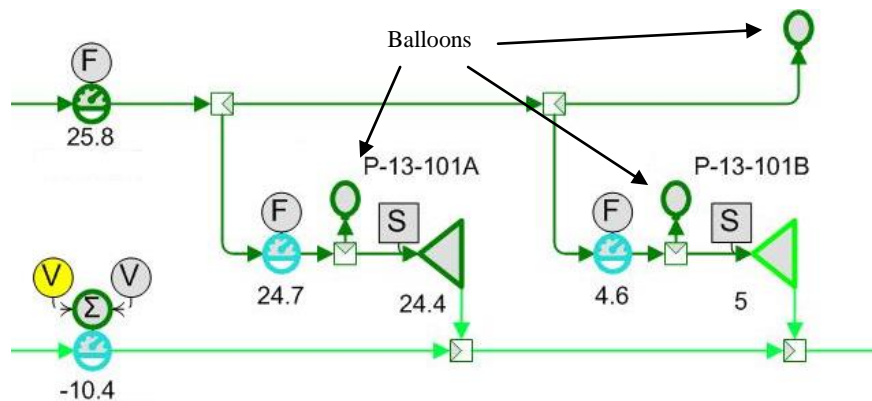

Figure 7. Balloons location example

Optimization implementation procedures

Operations apply on a daily basis, under the EMC supervision, the actions calculated and recommended by the RTEMS in order to minimize the total operating cost, following the implementation procedure shown in Figure 8.
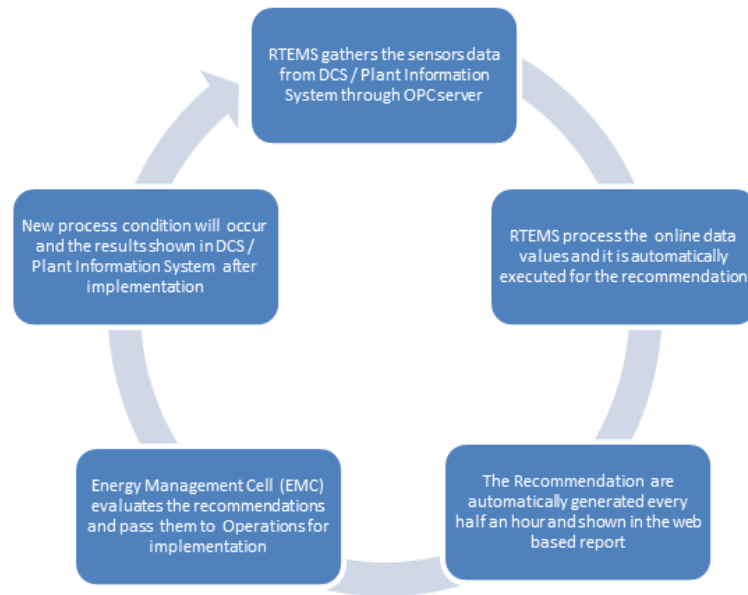
Figure 8. RTEMS optimization implementation procedures

Cost savings and CO2 emissions reduction

Figure 9 shows the reported results from one of the refineries (KNPC MAA). The base case was established when the model was completed in May 2012 with energy cost savings opportunity of about 680 $/hr. By the end of December'12 the energy cost savings potential were reduced to about 180 $/hr reflecting obtained savings of about 500 $/hr (4.4 MM$/year).

The cost savings and CO_2 emission reductions came from two main sources:

1.   Excess steam vent / condensing reduction (i.e., less fuel gas used for high pressure steam production because of the steam waste reduction)

2.   Letdown reduction (i.e., less power purchase for driving the pumps and compressors because of the use of turbines instead of motors)
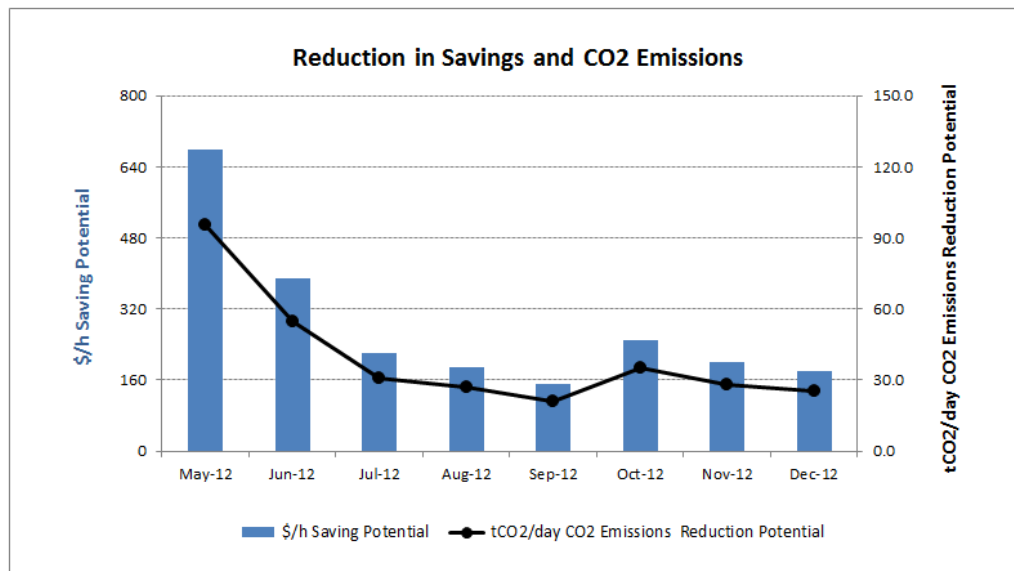

Figure 9. CO2 emissions and economic potential savings. KNPC MAA refinery. Their reduction corresponds to obtained savings.

In the following Figure 10, the CO2 emission reduction estimation basis is presented:

MAA CO2 Emission Reductions
Visual MESA based Real Time Energy Management System (RTEMS)

Factors:

Boilers fuel emission factor:	0.2	t CO2 / t UHP steam
Imported power emission factor:	0.0007055	t CO2 / kWh
Average Steam Rate for Steam Turbines:	48	kWh / t of steam

1. Excess steam vent / condensing reduction (i.e., less fuel gas used for UHP steam production because of the steam waste reduction)						
Reduction in excess fired steam:	9	t steam / h		1.8 t CO2 / h	43.2 t CO2 / day	15,768 t CO2 / year

2. Letdown reduction (i.e., less power purchase for driving the pumps and compressors because of the use of turbines instead of motors)						
Reduction in steam letdown:	40	t steam / h	1920 kW	1.4 t CO2 / h	32.5 t CO2 / day	11,866 t CO2 / year

Total CO2 emission reduction:				3.2 t CO2 / h	75.7 t CO2 / day	27,634 t CO2 / year

Figure 10. CO2 Emission reductions estimation as a result of the optimization action

Conclusions

The tasks performed to develop and implement real time, online models, to help with the three KNPC refineries energy cost minimization and energy management, which are scheduled to perform it automatically, have been described. They allow to clearly identify the different economic trade-offs that challenges the operation of the site wide energy systems at minimum cost while reducing the energy waste and, therefore, CO2 footprint. Recommendations given by the optimizers are taken into account by operations on a daily basis.

As a result of the project, the information of each refinery energy system has been organized into models and reports to which everyone has access. It has been also observed that having a model of the whole refinery energy system validated with real time data, in one environment that everyone has access to, also to understand all the decision variables and the associated constraints, which sometimes are hidden or ignored, helps in the coordination among plant areas in order to increase energy efficiency and reduce total energy costs.

References
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