

# Enhancement of Hydrocracker Plant's Operational Efficiency by Using Yokogawa's Dynamic Real Time Optimizer (RT-OP)

## Aramco Riyadh Refinery

**Location:** Saudi Arabia  
**Completion:** 2023  
**Industry:** Oil & Gas Downstream



### Dynamic real time optimizer for hydrocracker unit in refinery

The rapid evolution of digitalization technologies is fundamentally reshaping the global landscape, as nearly every industry eagerly adopts these innovations to enhance both operational efficiency and safety. The Aramco Riyadh Refinery advanced process control team and the Yokogawa digitalization team have achieved a noteworthy milestone by proficiently deploying the Dynamic Real-Time Optimizer (RT-OP) as an advanced solution at the Aramco Riyadh refinery hydrocracker unit (HCU), exemplifying a proactive approach towards comprehensive digital transformation in the oil & gas industry.

### Why the need for dynamic real-time optimization?

In the realm of refinery plant operations, ensuring consistent stability & operational efficiency poses a formidable challenge for distributed control system (DCS) operators. This challenge stems from fluctuations in unit feed properties and conditions, influenced by various uncontrollable factors such as changes in upstream operations, variations in ambient conditions, and shifts in unit performance.

Although advanced process control (APC) systems have become commonplace within refinery units, their primary role typically centers on maintaining plant stability, rather than guaranteeing optimized operational outcomes for the entire facility. While APC systems adeptly handle fluctuations within the plant, they fall short of delivering holistic optimization. This limitation opens the door for the implementation of RT-OP, a solution that calculates optimal setpoints dynamically in response to the ever-changing conditions of the plant. Whether prompted by shifts in plant feed conditions or product price fluctuations driven by market demand, a dynamic real-time optimization solution can consistently guide and maintain plant setpoints at the optimized operation point.

In essence, RT-OP represents a significant opportunity to enhance refinery operations by continually aligning them with optimal performance criteria. It extends beyond the limitations of traditional APC systems, offering the potential for improved operational efficiency in refinery processes.

### Brief summary of RT-OP's benefits

- 1. Optimal Set Point Guidance:** RT-OP provides a clear direction to advanced process control (APC) systems, enabling them to achieve the most optimized set points for plant operations.
- 2. Operational efficiency maximization:** It effectively handles changes in product prices driven by market demand fluctuations, allowing for the attainment of maximum production efficiency.
- 3. Adaptive feed & product management:** It efficiently manages plant feed property changes, most profitable product yields, and directs the APC system accordingly, ensuring smooth & efficient operations.

## HCU in oil refinery

The Riyadh Refinery HCU receives both hot and cold vacuum gas oil (VGO) feed, occasionally supplemented with demetallized oil (DMO) feed from upstream units. The primary function of the HCU is to process VGO feed, characterized by its higher boiling range, by breaking down heavy molecules into lighter products. This conversion occurs in the presence of hydrogen ( $H_2$ ) and a specialized catalyst.

The HCU is designed as a combination of treating and cracking catalyst beds, each operating within different temperature ranges. This strategic arrangement allows for precise control of the conversion processes and product output. Within the reactor downstream section, a debutanizer column is employed to extract the C4 component from the reactor effluent, which serves as the liquefied petroleum gas (LPG) product. This step is crucial for optimizing the composition and purity of the final product.

Subsequently, the bottom effluent from the debutanizer column is directed to a fractionator column, where fractionation happens and products like light & heavy naphtha, light & heavy diesel, and kerosene are separated. The unconverted oil (UCO) fraction can either be recycled within the system to enhance operational efficiency or directed to another designated unit. Typical hydrocracker process flow diagram is shown in Figure-01.

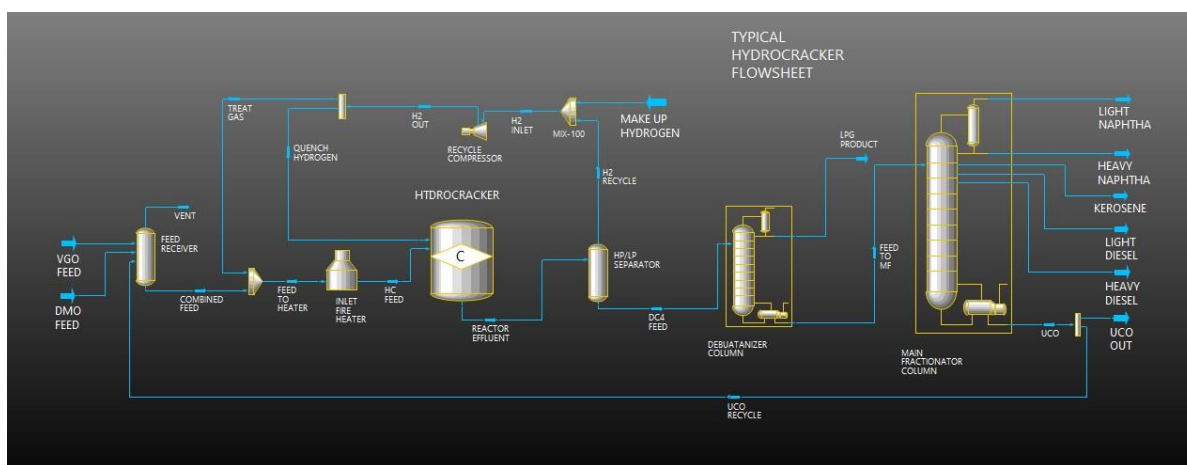


Figure.01- Typical Hydrocracker Process Flow Diagram in Oil Refinery.

### Operational challenges in the HCU

- 1. Feed quality variability:** The HCU encounters a persistent challenge stemming from the fluctuations in feed quality. It receives a combination of hot & cold VGO and DMO from upstream units. The proportions and qualities of these individual feeds continually shift in response to the dynamics of upstream operations.
- 2. Market demand dynamics:** Naphtha, diesel, and kerosene are the final products derived from the main fractionator column. Operators grapple with the ever-changing landscape of market demand, always striving to maximize operational efficiency by aligning production with market preferences. This constant adaptation to volatile market conditions poses a formidable challenge.
- 3. Maintaining product quality:** The HCU operators are consistently challenged to uphold product distillation quality parameters, such as maintaining the D86 95 point for diesel within the desired range. This task demands vigilant attention and precision to ensure that the final product consistently meets quality standards.

## What are the limitations of APC in optimizing the entire HCU?

APC systems have a proven track record in industry, known for their ability to maintain multivariable control within plants, greatly benefiting operators and simplifying their tasks. In a single HCU, for instance, multiple APC controllers can be configured, each dedicated to a specific area such as the reactor section, debutanizer section, and main fractionator section.

An APC can offer localized optimization capabilities tailored to the scope of each controller. For example, the main fractionator APC can be configured with built-in optimization modes to maximize the production of diesel or naphtha. However, there are certain limitations in achieving plant-wide optimization targets:

- **Complex interactions:** A plant consists of multiple interconnected processes and units. Changes in one area of the plant can affect others, creating complex interactions. APC solutions typically focus on individual processes and may not account for these interactions. The reactor section presents a challenging dynamic control loop. Directly adjusting hydrotreater and hydrocracker reactor temperature setpoints to maximize diesel or naphtha production is intricate due to the complex and large dynamic nature of this loop. APC systems may struggle to handle such complexity effectively.
- **APC modeling challenges:** APC systems rely on gain relationships to make control decisions. These relationships can be challenging to establish comprehensively, especially when dealing with various feedstock variations. The intricacies of feedstock variations make it difficult to design controllers that can effectively capture all potential scenarios. Creating comprehensive models for an entire plant with varying operating conditions can be impractical and may lead to modelling inaccuracies.

## How does Yokogawa's RT-OP solution enhance APC capabilities?

In the current digitalization era, where computing power continues to advance, process simulation has emerged as an invaluable tool for creating a digital twin of complex and large-scale process plants. A process digital twin solution, rooted in simulation technology, has the capability to harness real-time plant data and perform intricate process simulation calculations.

This process simulation serves a crucial role in generating complex and extensive dynamic gain relationships, a task often challenging during the traditional step test phase of APC model development.

Yokogawa-KBC's **Petro-SIM** features the specialized HCR-SIM module for refinery HCU reactors. Yokogawa's consultants excel in creating high-fidelity simulation models for refinery reactors, which can be integrated into a complete plant digital twin. This integration serves various objectives, including complex plant KPI generation and dynamic gain matrix computation. The dynamic gain matrix data derived from this digital twin model is then seamlessly integrated into Yokogawa's optimization system. This integration empowers the optimization system to calculate and recommend optimal setpoints for the APC system in real time, ensuring the plant operates at peak efficiency and performance.

Yokogawa successfully developed a high-fidelity process digital twin for the entire HCU, utilizing Petro-SIM/HCRSIM simulation tools and integrating them with the Yokogawa optimizer for real-time plant optimization. This solution intelligently analyzes live plant data, identifies stable operational periods to ensure error-free computations amid variable fluctuations, and operates entirely autonomously, eliminating the need for human intervention to maintain continuous plant optimization.

## Dynamic real-time optimization solution by Yokogawa

The Yokogawa team undertook a comprehensive pre-project phase, involving the collection and analysis of plant historical data, coupled with close collaboration with Aramco's APC experts. This preparatory phase aimed at identifying areas for improvement before the project's execution. The Riyadh Refinery had already been reaping the benefits of the existing Yokogawa APC solution, which underwent further enhancement by incorporating the reactor section into the APC and RT-OP scope.

The architecture of the Yokogawa RT-OP solution is visually depicted in Figure 02. This solution leverages real-time plant data, processing it through the high-fidelity simulation model in Petro-SIM. The outcome of this process includes the generation of the dynamic gain matrix and comprehensive plant key performance indicators (KPIs). These gain matrices are subsequently employed by RT-OP to calculate optimal target setpoints for the APC system, ensuring that manipulated and controlled variable limits are never violated.

The collaborative efforts of the Yokogawa and Aramco teams extended beyond gain matrix generation. They meticulously harnessed the potential of the real-time-based digital twin simulation of the plant, extracting valuable insights for complex plant KPIs. These encompass assessments of equipment efficiency, plant mass balance, product quality, hydrogen balance, and other critical KPIs that are not readily available on the DCS. To facilitate convenient monitoring and access, these KPIs are elegantly presented on a dedicated dashboard.

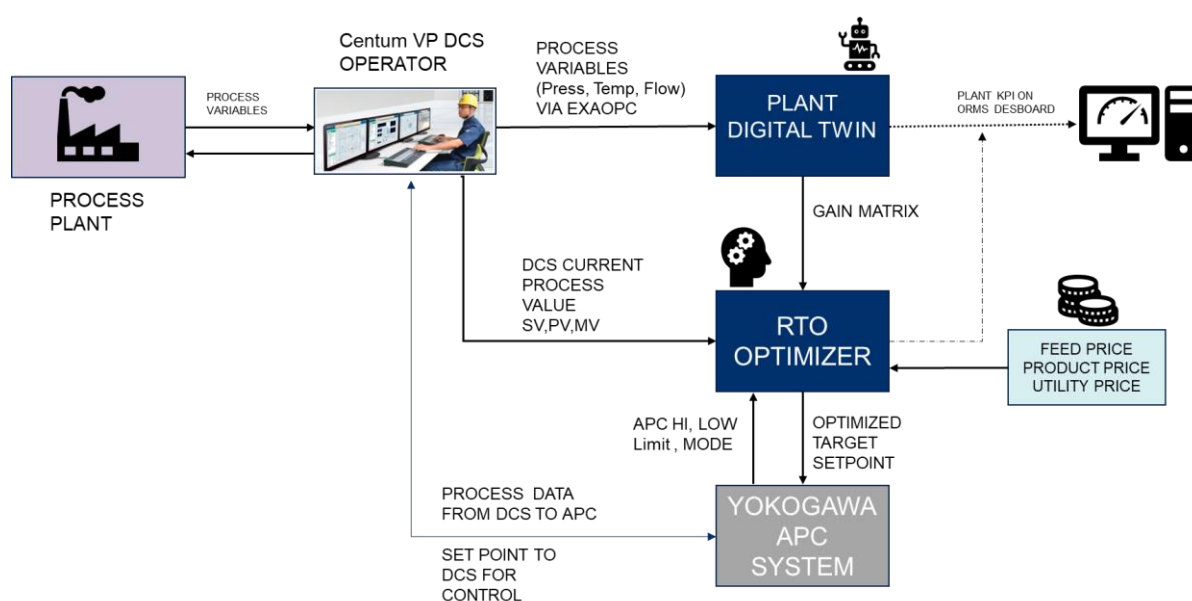


Figure-02- Yokogawa RT-OP solution

### Advantages of RT-OP for HCU process engineer:

- 1. Frequent steady state simulation cases:** RT-OP generates steady-state simulation cases every 2 hours using real plant data. Process engineers can readily employ these cases for offline what-if and what-best analyses.
- 2. Real-time KPI utilization:** Process engineers can utilize real-time KPIs such as mass balance, equipment performance, and product quality that are conveniently available on the dashboard.

## Key highlights of Yokogawa's RT-OP HCU project

- ✓ **Enhanced plant operational efficiency:** The project anticipates higher plant operational efficiency compared to traditional real-time optimization (RTO) strategies. Refer to Figure 04.
- ✓ **Optimized gain matrix utilization:** Utilizing wider dynamic gain matrix data, the project aims to maximize operational efficiency within the HCU.
- ✓ **Integrated high-fidelity digital twin model:** An intricately integrated high-fidelity digital twin model ensures enhanced accuracy and the ability to provide frequent solutions.
- ✓ **Robust solution with advanced technologies:** The project leverages the robustness of Yokogawa's APC technology, specifically the Platform for Advanced Control and Estimation (PACE Run-Time), in conjunction with KBC's simulator technologies, including Petro-SIM and the hydrocracker reactor simulator HCR-SIM.
- ✓ **Comprehensive process digital twin benefits:** RT-OP offers the added advantage of fulfilling all the benefits associated with a process digital twin, encompassing a wide range of advantages within a single solution. Refer to Figure 06.

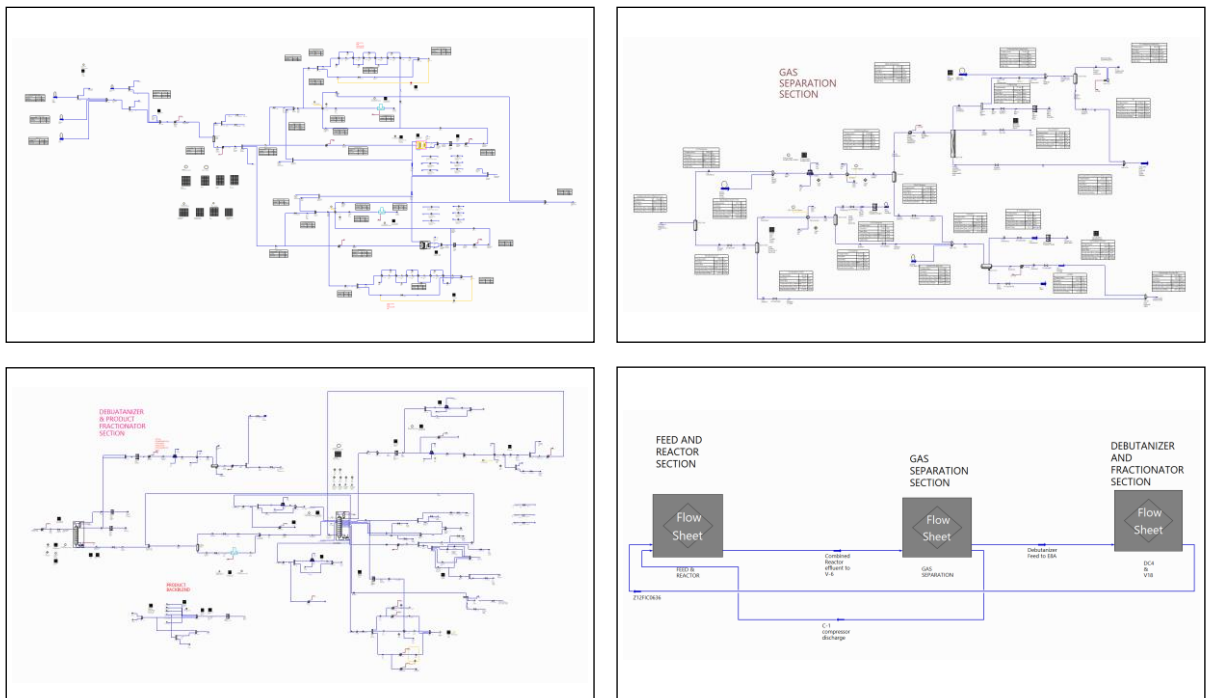


Figure-03- High fidelity HCU simulation model

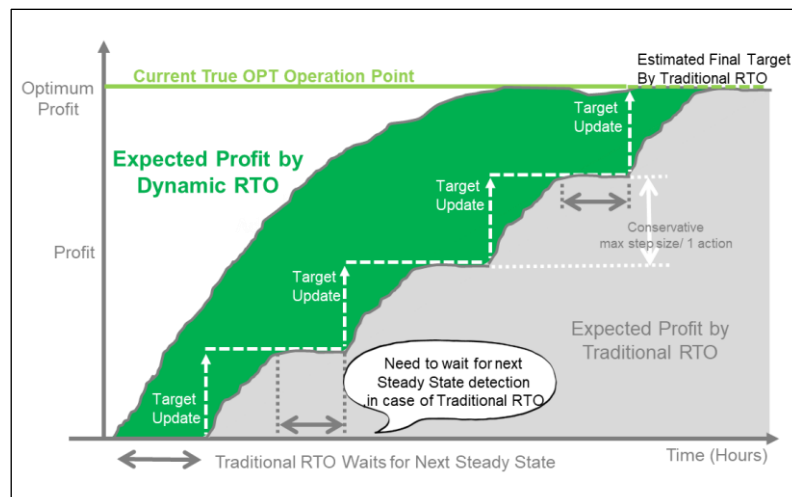


Figure-04- Yokogawa RT-OP vs traditional RTO

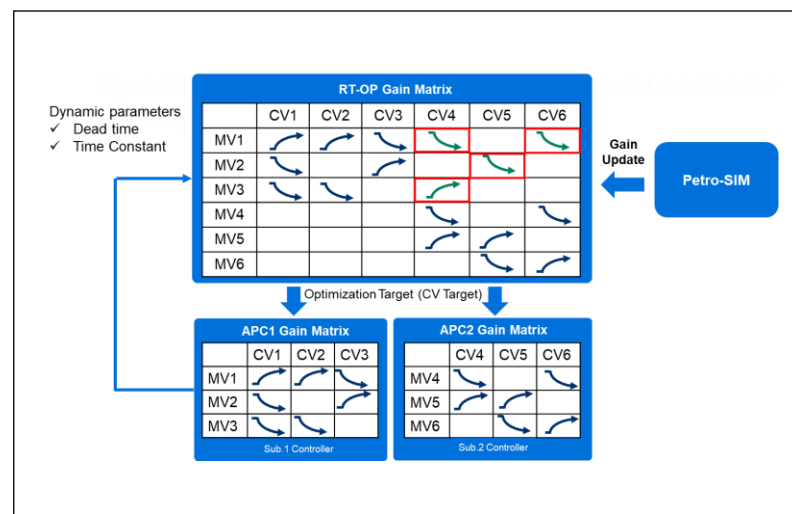


Figure-05- Wider gain matrix in Yokogawa RT-OP

## Yokogawa RT-OP HCU project dashboard

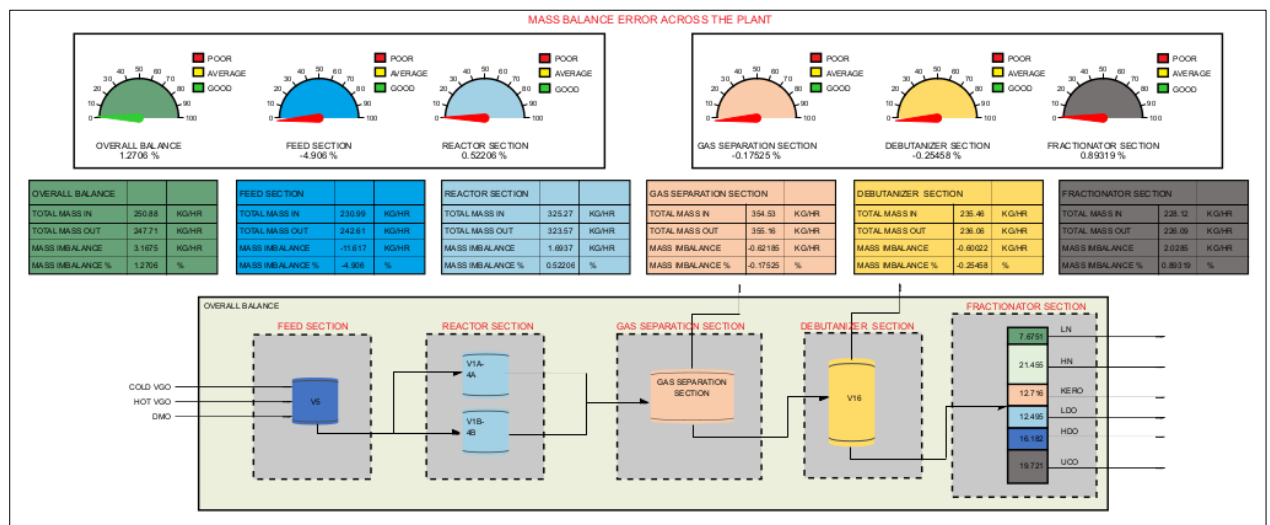


Figure-06- Mass balance based on real time plant operation

The Yokogawa RT-OP solution features inherent integration with a dashboard solution, facilitating effortless monitoring of RT-OP performance by key variables. This seamless collaboration between the Yokogawa RT-OP team and Aramco's APC experts has resulted in the extraction of crucial parameters from the RT-OP solution and the digital twin model. These key parameters are prominently displayed on the page of the dashboard, as illustrated in Figure-07.

1. APC & RTO running status
2. Online RT-OP running benefit
3. Plant stability
4. HCU reactor-HCRSIM calibration status
5. Plant KPI's monitoring



Figure-07- Yokogawa RT-OP dashboard

## About the HCU RT-OP project key members

### Essam Bazuher (APC Expert- Saudi Aramco)

Mr. Essam, a process control system expert at the Aramco Riyadh Refinery, holds an engineering degree from the University of Huddersfield and a Master's in Sustainable Energy from KFUPM. His career is dedicated to driving Industry 4.0 transformation, leading initiatives for operational optimization and digital innovation. As a skilled leader, he guides cross-functional teams, fosters collaboration, and consistently achieves organizational goals. Notably, his contributions encompass analyzing opportunities within the HCU unit and serving as a valuable team member representing Aramco in the successful HCU RT-OP project with Yokogawa.

### Junichi Watanabe (Consultant -Yokogawa Japan)

Mr. Watanabe is a chemical engineer and specializes in rigorous model-based online optimization technologies. With nearly four decades of experience, he excels in technical consultation, project execution, and project management in the domains of refining and petrochemical processes. His expertise covers energy management and integrated refinery optimization. He possesses in-depth knowledge of oil refining and petrochemical processes and is proficient in various APC technologies. He is known for his skill in rigorous model-based simulation and optimization, and he has a deep understanding of fundamental chemical engineering unit operations.

### Hiroaki Sorimachi (Consultant Yokogawa Bahrain)

Mr. Sorimachi possesses 20+ years of professional experience, during which he has excelled as a lead engineer in physical modelling, real time optimization (RTO) for refinery plants, operator training systems (OTS) for LNG plants, statistical modelling, and software development. His diverse expertise spans a broad spectrum of engineering and analytical domains, making him a valuable contributor for RT-OP projects. Additionally, he holds the esteemed title of Qualified Energy Manager in Japan, further underscoring his commitment to excellence in energy management.

### Vikas Salunkhe (RTO & DT Lead Engineer Yokogawa Bahrain)

Mr. Salunkhe is a chemical engineer, holding a master's degree from Pune University, India, and boasting a remarkable 17+year career in the oil & gas industry. He has spearheaded and contributed to multiple simulation-based projects, including MPDS (Multipurpose Dynamic Simulator) for a FLNG facility, operator training simulation, and efficiency improvement initiatives. His professional journey began as a process engineer in a biofuel technology licensor company.



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