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Closed loop production optimization: One step closer to autonomy

Historically, operators have employed piecemeal strategies to optimize components of the production value chain. However, achieving autonomous operations will require a holistic approach, integrating traditionally disparate data sources to create a single digital twin that can be delivered with relatively small up-front investment.

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Upstream operators continue to forge ahead in the low-price environment, seeking new and innovative methods to drive out costs, increase output, lower emissions and extend the life of aging oil fields. The use of digital modeling and simulation tools to optimize production has emerged as an attractive option for achieving these goals, as it requires little in the way of equipment upgrades or CAPEX.

However, companies using simulators today cite many pain points, including the need to deploy separate, dedicated software models and offline workflows for various parts of the production value chain, including wells, production networks, gas-oil separator plants (GOSPs) and electrical submersible pumps (ESPs). Combining the results of these models is an arduous undertaking that requires a great deal of manual intervention, time and computing power. The generated optimized set points are often inaccurate, unreliable and outdated, which means that real-time optimization is virtually impossible. Thus, control systems must be open-loop (i.e., manual validation and implementation of optimized set points).

To address these shortcomings and move closer to autonomy, a more holistic approach is required, where various models are aggregated to create a unified digital twin, so that optimal set points for the entire oil field can be converged on rapidly. A system to filter and validate data without manual intervention, so that set points can be automatically pushed to the DCS or SCADA, is also required. Until recently, few (if any) commercial solutions with this capability were available on the marketplace. Over the past two years, Siemens Energy has been working to change that by leveraging the latest digitalization and equation-based modeling advancements to make "closed loop production optimization" a reality.

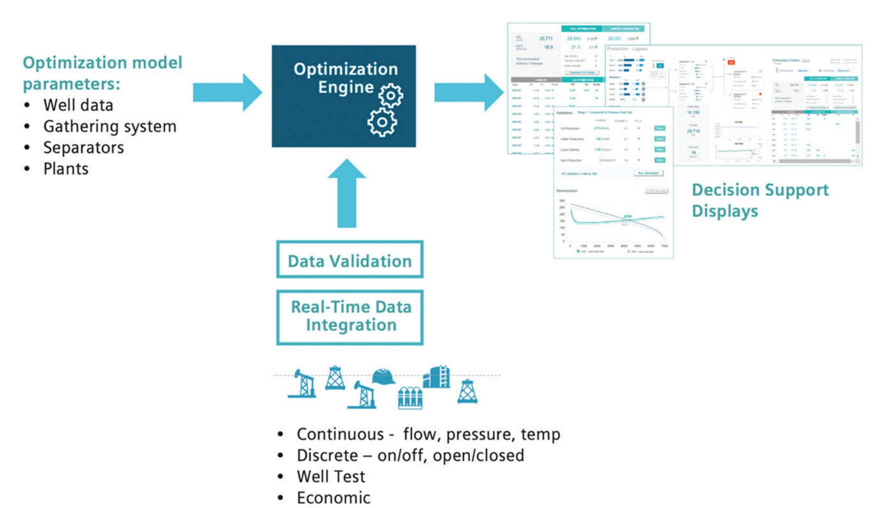
Production optimization pain points. Today, several techniques are used for production optimization. Offline modeling and simulation with software applications is generally viewed as default, and has proved valuable in real-world applications. With modeling, the goal is to identify optimal control setpoints for choke settings, gas lift rate, ESP speed and routing of oil.

Historically, one of the main challenges of this approach has been that several separate models must be developed for various systems, including the ESP, the gathering network and the GOSP. Because the results of one model do not necessarily consider the constraints or outputs of the other, production engineers have to conduct numerous iteration runs to converge on optimal set points—a process that can take hours and even days for large, complex fields with multiple separators.

The engineers are also required to validate the set points in a non-automated workstream. This is often an inexact science that relies heavily on intuition, habit, past experience, and generally accepted best practices. Further work is required by operators to input the set points into the DCS or SCADA manually. The time delay associated with this sequential modeling-simulation approach makes closed-loop control infeasible, because the set points generated do not reflect the current state of the well or field. Any direct in-field adjustments aimed at production improvements are also rendered ineffective.

Another problem is that multiple models generating set points can result in too many changes for field staff. In such cases, operators must manually prioritize which actions to take. As the functional modules

Fig. 1. An overview of the RTPO workstream.



do not share data, determining the right combination of actions to achieve KPIs is virtually impossible. The issue is often magnified when a field upset occurs, such as a compressor failure. Sequential simulation typically cannot perform optimization runs fast enough to determine what field changes are required to maintain high production levels while the condition is resolved. This is especially the case with aging fields on artificial lift, and large operations that include a wide array of new and old equipment assets, such as gas lift compressors, sucker rod pump (SRPs), valves and piping networks.

Enabling real-time production optimization. Addressing these challenges and moving closer to autonomous well operations requires integrating data from real-time and near-real-time sources, to feed a unified digital twin of the entire oil field. This includes:

- Static data for well completions, such as well geometry.
- Dynamic data for production network extracted from SCADA or historian (i.e., pressures, flows, temperatures).
- Transient data for well curves, including vertical lift performance (VLP) and inflow performance relationship (IPR). These can be obtained from the latest well test data or uploaded from an already available "well curve generation tool."
- Combined data for the centrifugal compressor (i.e., static compressor curves combined with the real-time operating conditions).
- Dynamic data for oil production separator, extracted from the SCADA or historian.

Another challenge lies in data cleaning and validation to recognize outliers and identify when a measurement is out of boundary. Missing data points need to be handled by introducing default values or trending values. Any optimizer that is to be integrated directly into the process control system must have the capability to perform these tasks to ensure robustness and reliability.

RAPID MODELING

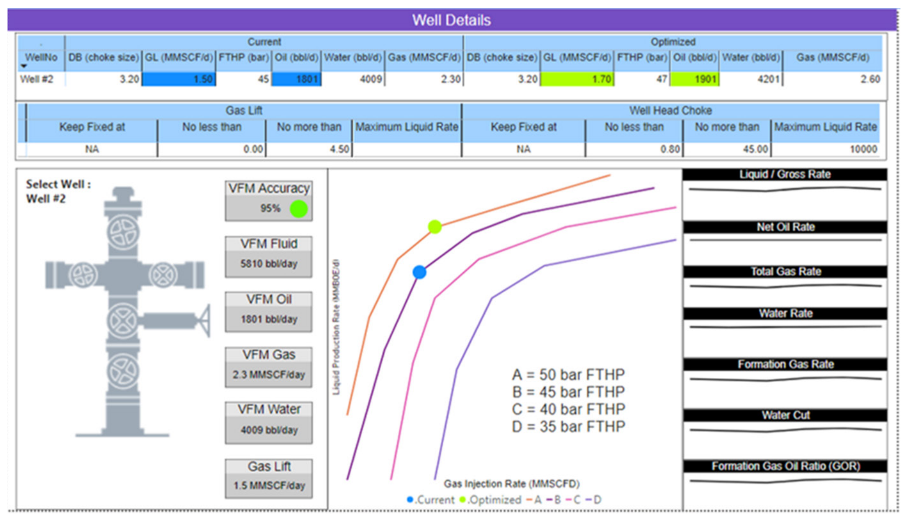
Two years ago, Siemens Energy set out to address these problems with Real-Time Production Optimization (RTPO). RTPO is a "vendor-agnostic" digital platform (delivered as a service), enabling rapid modeling and optimization of the entire upstream value chain—from the sand face through central processing facilities to the sale of the product, **Fig. 1.** It differs from conventional sequential modeling tools, in that it uses an equation-based optimization engine from Siemens Process Systems Enterprise, known as gPROMS Oilfield.

Model elements are represented in gPROMS as a set of equations that is solved synchronously. The primary benefit of this approach is that it requires far less computing power and time to conduct optimization runs. Control set points in highly complex fields can be converged on within minutes, instead of hours or even days. This provides several capabilities that are typically not available with sequential modeling simulations, including:

Fig. 2. Results of 120+ well field model, using RTPO (gPROMS).

		Separator gas rate constraint [MMScf/day] / separator			Oil rate [bbl/day]	Percent Change
		A (max 1030)	B (max 571)	C (max 161)		
Optimization (No routing)	Current Technology	974	555	157	215,380	
Optimization (No routing)	gPROMS	1,030	571	160	231,477	+7.5%
Full Optimizations	gPROMS	1,030	571	161	239,570	+11.2%
Limited changes Optimization	gPROMS	1,030	571	160	229,188	+6.4%

Fig. 3. A virtual flowmeter is capable of generating gas lift curves.



Strategic optimization. The equation-based optimizer can be used on an ongoing basis to determine the best set of oilfield set points, based on a set of specific constraints, such as cost, flaring, lift gas usage and energy consumption.

Exploration of "what if" scenarios. Operators can easily explore "what if" analysis scenarios, such as shutting in a group of wells, study the impact of a drilling campaign, taking equipment down for maintenance or changing constraints to see the impact on production

Real-time field upset. In the event of an unplanned failure of critical equipment like a big process gas compressor, the equation-based modeler can be used to quickly re-optimize the field to minimize production losses until the upset condition is resolved.

Limited changes optimization. In large fields with multiple separator plants, situations will inevitably arise when optimization requires numerous field changes, perhaps to the point of overwhelming the operating staff. RTPO addresses this problem with a built-in function that can limit the number of set point changes. The optimizer prioritizes the selected changes, based on their impact, thus minimizing the need for operators' manual work.

Routing optimization. With a single dynamic model, operators can optimize well and pipeline systems simultane-

Fig. 4. An example of a gas-lifted oil field.

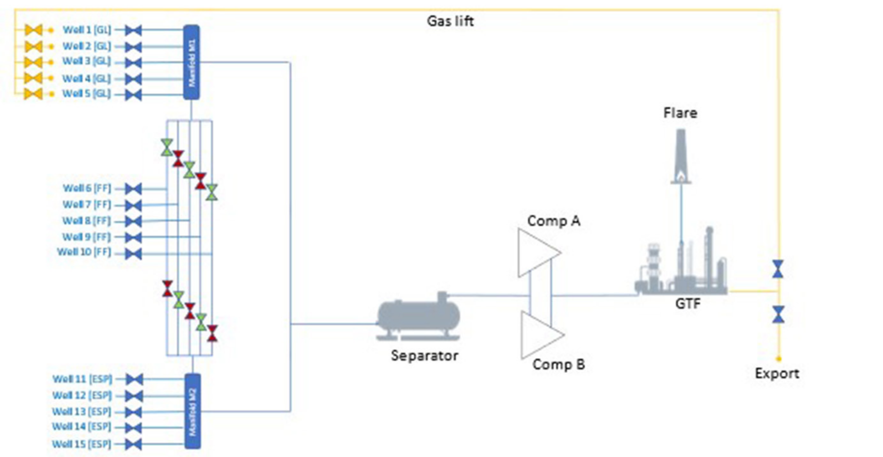


Fig. 5. Proof of value timeline and rollout scenario.

ously. RTPO can handle continuous (gas lift rates), in addition to discrete (routing and well status) decision variables. This unique feature is possible, because RTPO simulation is equation-oriented. Using discrete decisions, an optimum flow path can be identified within the framework of well dynamics, piping specifications and constraints of separators. This capability reveals its true strengths in highly complex operations, where millions of routing combinations are possible. RTPO is delivered via a subscription-based model. Its implementation does not require installing new field equipment. Recurring OPEX fees include all software and services for the duration of the contract.

USAGE CASES

A simulator that enables production optimization in real-time opens the door to many usage cases that have previously not been possible. For example:

Improved optimization with routing functionality. Today, a typical oil field can contain 100+ wells and two to three separators, along with hundreds of valves, pumps and piping runs. It is not out of the question for there to be more than one million flow path combinations available to route oil in such fields. Using a sequential modeling approach to identify the optimal routing path could potentially take hours and even days—making it of little use given the constantly changing state of the field.

An equation-based optimizer offers a solution to this problem. RTPO, for example, was used to model a field with 120 wells, three separators and an associated gathering system. The primary objective was to maximize production for separator capacity and well drawdown rates. **Figure 2** shows the results of different optimizations using the optimizer.

As seen, the current optimization technology generated a baseline production rate of 215,380 bopd. When using RTPO without well-routing optimization to the separator, the rate increased 7.5% to 231,477 bopd. When routing optimization was enabled, an additional 11.2% increase was observed. Furthermore, using the "limited changes" function, the optimizer showed a 6.4% production increase with just 10 field set point changes (instead of 93 with their current technology). Also, note that RTPO runs operations of facilities closer to its constraints (i.e., separator A, B, C), demonstrating its accuracy.

Optimizing on a gas lift well with a virtual flowmeter. A field on gas lift is an example where a modeler, which can handle complex multi-variant optimization, can be especially useful. Unfortunately, there is often limited real-time insight regarding the flow and phase composition (oil, water, gas) of wells in such fields. These parameters are usually estimated by referencing the latest well test, which can be up to six months old, resulting in outdated IPR and VLP well curves. Because the well curves are essential for a reliable and accurate optimization run, it can be valuable to combine RTPO with a virtual flowmeter (VFM) to enable real-time optimization and in turn, closed-loop operation.

The VFM, which acts as a soft sensor, can be trained to identify correlations between well flow test rates and actual measurements. Given sufficient training time (a few days), it has been shown that the VFM can generate production rates for oil-water-gas with approximately 95% accuracy. These data can be used to generate real-time well curves. RTPO can then generate gas lift curves. **Figure 3** shows real-time gas lift curves for a well, according to a number of back pressures.

Multi-objective optimization in a gas-lifted field. As previously mentioned, the unique equation-based approach made possible by the gPROMS Oilfield simulator in RTPO provides the capability to optimize production, based on one or more process constraints. Any number of constraints can be entered into the engine, giving operators and production engineers the ability to define a bespoke landscape for their optimization, based on several KPIs related to production, process, economics, and environmental requirements. Listed below are several possible optimization scenarios for an oil field with wells, production network, separator, compressors, and gas treatment facility, **Fig. 4.**

Scenario 1. **Production** objective:

- Optimized **oil production** from a field with limited, total lift gas.

Scenario 2. Production + **energy objective:**

- Optimized oil production from a field with limited, total lift gas.

- Optimized **energy consumption of compressors.**

Scenario 3. Production + energy objective + **sustainable objective:**
- Optimized oil production from a field with limited, total lift gas.
- Optimized energy consumption compressors.
- **Minimized flare** at a gas treatment facility. The gas quality and quantity are optimized for the facility by mixing and matching the production from the wells.

Scenario 4. Production + energy objective + sustainable objective + **economic objective:**
- Optimized oil production from a field with limited, total lift gas.
- Optimized energy consumption compressors.
- Minimized flare at a gas treatment facility.
- Maximize flow of gas to lift system to produce more oil? or maximize the amount of sales gas for export?

Any one of the above scenarios can be configured by the operator in the RTPO user interface.

Getting started with RTPO. When implementing any digital solution with transformative potential, a proof of value (POV) is required to minimize risk to the end-user. Small scale implementation must demonstrate value before scaling up. With RTPO, the POV is typically a four-month joint project to validate the solution architecture customer field operations, **Fig. 5.** Key steps include:
- Document success criteria
- Execute three parallel workstreams
- Data integration – identify operating data for model building and real-time operation
- Model development – build the field optimization model
- User interface – fine-tune the user interfaces for engineers and operators
- Workshop – validate model, checkpoint visualization screens; validate data integration approach; run optimization model and propose new field operating setpoints
- Deploy visualizations to operations center and integrate live data for a 60-day field trial
- Validate production increases and revenue impacts for final presentation.

Fig. 6. Roadmap to autonomous production operations.

The ultimate goal of the POV is to work collaboratively with the customer to understand unique organizational better and/or field requirements, and also to instill confidence in executives, production engineers, operators, and field personnel that the solution will deliver expected outcomes concerning operational, environmental, and economic KPIs.

The future: Further integration to achieve greater autonomy. Although closed-loop production optimization allows operators to achieve a step-change in operational excellence compared to sequential modeling, further integration of systems will be required to achieve full autonomy, **Fig. 6.** In particular, condition-monitoring systems will need to be incorporated into models to better predict how the equipment will perform, so that maintenance activities also can be optimized for KPIs. To this end, the combination of asset performance management (APM) software with production optimization solutions like RTPO can be enormously valuable.

In a future scenario, key equipment indicators from an APM platform, such as remaining useful life (RUL), health indexes, and even prescriptive advice, would automatically be fed into the process simulation. For example, analytics within the APM platform may determine that a pump, which is being run at 100% of its rated capacity, will fail in two weeks' time. However, it may also forecast that by running the pump at 90% power, the effective failure can be shifted to a scheduled maintenance period in three weeks. In an integrated framework, the APM system would automatically notify the RTPO production system, and a production constraint would be generated, thereby minimizing the risk that an unplanned failure will negatively impact production.

Rethinking old ways of working. When it comes to production optimization, upstream operators have historically employed a piecemeal strategy, in which separate models and solutions are applied to the production value chain's various components. While many companies have been able to capture value using this siloed approach, achieving the "holy grail" of autonomous operations will require a much more holistic view in which traditionally disparate data sources are integrated to create a single digital twin of the oil field.

With digital solutions like RTPO, which are delivered as a service, this is now possible with a relatively small upfront investment. Recurring OPEX fees for the solution include all software and services for the duration of the contract. In this way, the traditional sales equation is also transformed, as users pay for outcomes rather than for the technology itself. WO

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