AI Driven Autonomous Plant Operation for Shell Scotford

Donald Dalawampu
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Shell’s operating plan, outlook and budgets are forecasted for a ten-year period and are updated every year. They reflect the current economic environment and what management believes to expect over the next ten years. Accordingly, they reflect our Scope I, Scope 2 and Net Carbon Footprint (NCF) targets over the next ten years. However, Shell’s operating plans cannot reflect our 2050 net-zero emissions target and 2035 NCF target, as these targets are currently outside our planning period. In the future, as society moves towards net-zero emissions, we expect Shell’s operating plans to reflect this movement. However, if society is not net zero in 2050, as of today, there would be significant risk that Shell may not meet this target.

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Donald Dalawampu, Project Lead, Digital and Business Transformation:

Donald is the lead for Shell Scotford’s proof-of-concept that tested the feasibility of implementing AI into Process Control. He has 17 years of downstream oil industry experience, spending the last decade contributing significantly to the growth and transformation of the company’s assets as a Business Improvement and Engineering Lead. He earned his Chemical Engineering degree from the University of the Philippines, and Project Management Qualification from the Association for Project Management. He is passionate about exploring new solutions to solve complex problems and drive continuous improvement.

Celine Thomerson, Principal Consultant, Simulation Delivery:

Celine is the technical lead on the Scotford MEG Simulator project, logging over 700 hours working with MEG operators and operations engineer. Over the last 15 years, she has completed more than a dozen simulation project, provided training for panel operators and been a panel operator herself. The simulation projects include both engineering studies and operator training simulators. She earned BS and MS degrees in Chemical Engineering from the University of Houston.

Dr. David Smith, Principal AI Engineer, AI Center of Excellence, United Kingdom:

Dr. Smith is a Chartered Mechanical Engineer and holds a Ph.D. in Fluid Mechanics from Imperial College London. Spending the first half of his career in industry mainly with EPC companies, he leads design, development, and commissioning of Power Plant processes and combustion systems. Moving to AVEVA, Dr. Smith joined the AI Center of Excellence where his main activities are the integration of AI technologies with AVEVA’s first principles simulation products for asset management and autonomous operations.
Background

Shell Explores Using AI in Controls
Shell Energy and Chemicals Park Scotford

- The Shell Energy and Chemicals Park Scotford, located 40 kilometers northeast of Edmonton, Alberta, Canada, consists of a bitumen upgrader, oil refinery, chemicals plant and a carbon capture and storage (CCS) facility. It is one of North America’s most efficient, modern and integrated hydrocarbon processing sites, converting oil sands bitumen into finished, marketable products.
- The Shell Scotford Chemicals Plant uses byproducts from the adjacent Shell Scotford Refinery to help manufacture styrene monomer and ethylene glycol. The plant has two units – the styrene plant and the glycol plant. The Shell Scotford Chemical Plant products are shipped by pipeline, rail cars and truck to be marketed and sold across North America.
- The Glycol product is primarily sold to customers in North America for use in making products such as plastic drinking bottles and antifreeze.

Shell’s Transformation Building Blocks

- Shell has been exploring the use of digitalization and AI to support the Powering Progress Strategy to accelerate transition of our businesses to net-zero emissions while creating more value to our shareholders, customers, and wider society.
- We are actively working on a range of digital technologies to improve safety and efficiency, as well as facilitate the energy transition.
- One of these building blocks involves creating a number of small semi-autonomous applications.
  - To aid not only during steady-state, but more so during upsets
## Opportunity

**Current Condition**

Typical process control systems struggle to effectively mitigate plant upsets and emergencies or in general, manage transient conditions.

**Gap**

The conventional control methods lack the ability to respond quickly to sudden disturbances in the process.

**Opportunity**

Test the feasibility of implementing an AI application/agent into Shell Scotford’s process control system and allow the agent to perform higher level / complex decisions in managing different ‘upset/transition’ scenarios.
2

Test Problem

Shell Scotford MEG Total Reflux
MEG Plant ‘Total Reflux’

- Shell Scotford ethylene glycol unit comprises a series of columns which separate Mono, Di and Tetra Ethylene Glycol (MEG, DEG and TEG) from the feed mixture.

- During plant upsets, causing an interruption to the incoming feed, these columns need to enter a stable total reflux operation mode, maintaining the appropriate heat input to the inventory in readiness for the later re-introduction of feed.

- If the columns are allowed to slump this can cause considerable lost time to bring them back into a condition for feed re-introduction. All of these actions are currently performed manually by operators.
**MEG Plant ‘Total Reflux’**

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**AI’s Main Goal:**

Establish a stable Total Reflux Operation of the MEG column following a trip from the upstream.

**WHILE...**

Managing all the upsets that may be encountered during the period.
MEG Plant ‘Total Reflux’

Objective is to manage hibernation of the column in total reflux state. This means we want to manage the heat input to the reboilers and reflux rates to stabilise and hibernate the column and then restart the column once feed is available to be reintroduced.

1 Upstream upset
2 Hibernate column
3 Return to feed

Maintain Levels
Keep vacpac pressure < limit
Adjust reflux flow to 60% of steady state flow

Maintain Levels
Keep vacpac pressure < limit
Increase reflux flow to 100% of steady state flow
Solution

Reinforcement Learning for Autonomous Operation
Reinforcement Learning for Autonomous Operations

**AVEVA® Dynamic Simulation**

+ **Reinforcement Learning Toolchain**

= **Trained DRL Algorithm:** the ‘Brain’

**Autonomous Operations for Process Plant**

- Minimize production impact of plant upset by stabilizing product quality in shorter time than human operator
- Reduce complex start-up and shut-down times to maximize production throughput
- Improve control of batch processes to deliver consistent and repeatable product quality

Reduce complex start-up and shut-down times to maximize production throughput
Reinforcement Learning for Autonomous Operations

- Is this A or B?
- How much - or - How many?
- Is this weird?
- How is this organized?

Supervised Learning

Unsupervised Learning

Reinforcement Learning
Reinforcement Learning for Autonomous Operations
DRL Problem Formulation: States and Actions

**State Space**
- LT-BOTTOM
- LT-DRAWOFF
- LT-REFLUX-TANK
- PT-VAC PAC
- ZT-STEAMVALVE
- FT-REFLUX
- FT-DRAWOFFRETURN
- FT-FEEDFLOW
- PT-STEAM

**Action Space**
- ΔZ-STEAMVALVE
- ΔF-REFLUX
- ΔF-DRAWOFF
DRL Problem Formulation: Goals

LEVELS:
- DRIVE: TARGET
- RANGE 40-60%
- AVOID: 0%
- AVOID: 100%

VAC PAC PRESSURE:
- AVOID: >35kPa

REFLUX RATE:
- DRIVE: 60% of SS Hibernating
- DRIVE: 100% of SS Restart

STEAM VALVE:
- DRIVE: >3% open
- MINIMIZE: <0.5%/minute
DRL Problem Formulation: Lessons

- Inventory: different starting levels for column and reflux tank
- Boiler feedwater disturbance
- Steam systems disturbance
- VAC Pac disturbance
- Ambient conditions
- Feed introduction

- PT
- COND
- VAC
- STEAM
- FW
- LI
- MEG
- DEG + TEG
- EG FEED
- DRUM
- DYHD
- LI
- LI
- LI
DRL Training

AVEVA Dynamic Simulation Development on Desktop App

Sim <-> RL Adaptor

Containerized Simulator Instance

CONFIGURE

Multiple Simulator Instances Running in Azure

Learning Configuration

MS Bonsai RL Platform

TRAIN

Wood Middleware

OTS / Plant Control System

TEST & DEPLOY

Brain
4

Result

AI’s Performance vs. Baseline Data Testing using OTS Lite
OTS Lite Testing Architecture

Reference Operator Runs

Permissive

Hibernate
Start-up
Switch to Op

Microsoft Bonsai Brain wood. Middleware AVEVA OTS + AVEVA™ PI Vision

Reference Operator Runs
Brain Evaluation Testing

Total of 27 Cases Evaluated

Start Up

2

Trip

3

Normal

4

Upset

18

- Cold Front
- Steam Supply to Reboiler Dip
- Cooling Water
- Pump Swap Over
- Warm Front
- Water leak into Column Feed
- Loss of inventory from Overhead Drum
- Loss of inventory from Draw-Off tray
- Loss of Inventory from Bottom level
- Dip in Overhead Condenser Pressure
- Air leak into Vacuum Column
- Trouble in the Vacuum system

Initial Fill from tankage after turnaround
Run for an extended time period
Transition from Hibernate to Ready for Feed
Transition from ready for feed to Hibernate Mode

September 2023
Brain vs Benchmarks Results

For each of the tests the brain evaluated based on the following criteria:

✓ Operator Benchmark – Created on the full Operator Training Simulator at site
✓ Historian Data from the plant
✓ Operator Experience
The column starts out operating normally, with the brain in standby.
Conclusions

What it means for us?
I did some of the final testing and was very impressed with the response it had to major upsets. In areas that it did well, it performed way better than expected. Throwing very dramatic upsets at it and came out in good shape holding all the levels it was supposed to.

To be able to cut feed into and out of a column with no other intervention was definitely not something I felt was possible by automation. With the right people building and testing, it will be a big asset and common tool someday.

- Experienced Plant Operator for 14 years
I was involved in the project from the start, and I had my doubts as to how well the “AI brain” would do. The strategy we employed to get the brain to react to every conceivable upset condition from loss of air pressure to upset steam conditions, etc. was crucial for the brain training, which by the way took weeks on each upset scenario.

As it turned out, it was time well spent. When we finally had all the training completed and when we put the brain through the tasks of loss of feed flow to the column, plant trips, etc., it performed well proving that the AI application will work for process distillation columns and other process plant equipment. Just like the APCs before it, AI control will further enhance process operations performance and efficiency.

- MEG Plant Operations SME
Challenge

- Conventional control methods including PID and APC (Advanced Process Controls) are very useful for maintaining and optimizing steady-state operations. They, however, lack the ability to respond quickly to sudden disturbances or unpredictable situations such as trips and big process upsets leaving operations exposed to process safety risks and margin losses.

Solution

- Developed AI Agent using Deep Reinforcement Learning which was trained to handle multiple transient scenarios using Aveva’s Dynamic Simulation of the plant.

Results

- Trained AI agents were able to manage the controls and bring the plant into a stable condition. This translates to fewer alarms (safer operation), shorter stabilization period (higher uptime/margin), and more energy-efficient operation (~59% lesser steam consumption translating to reduced CO2 footprint).¹

¹ Compared to baseline data from 1) actual performance of SMEs and 2) historical process trends.
### Key Contributors

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Shell Scotford Successfully Completes First Steps in Achieving Autonomous Operations

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