Combined Cycle Plant Duct Burner Optimization Using ProcessLink

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Rationale

- NeuCo has been optimizing processes in coal plants for a long time
- Conversations with friends and customers at Combined Cycle (CC) plants suggested that it could be useful in those as well

The Project

Independence Station

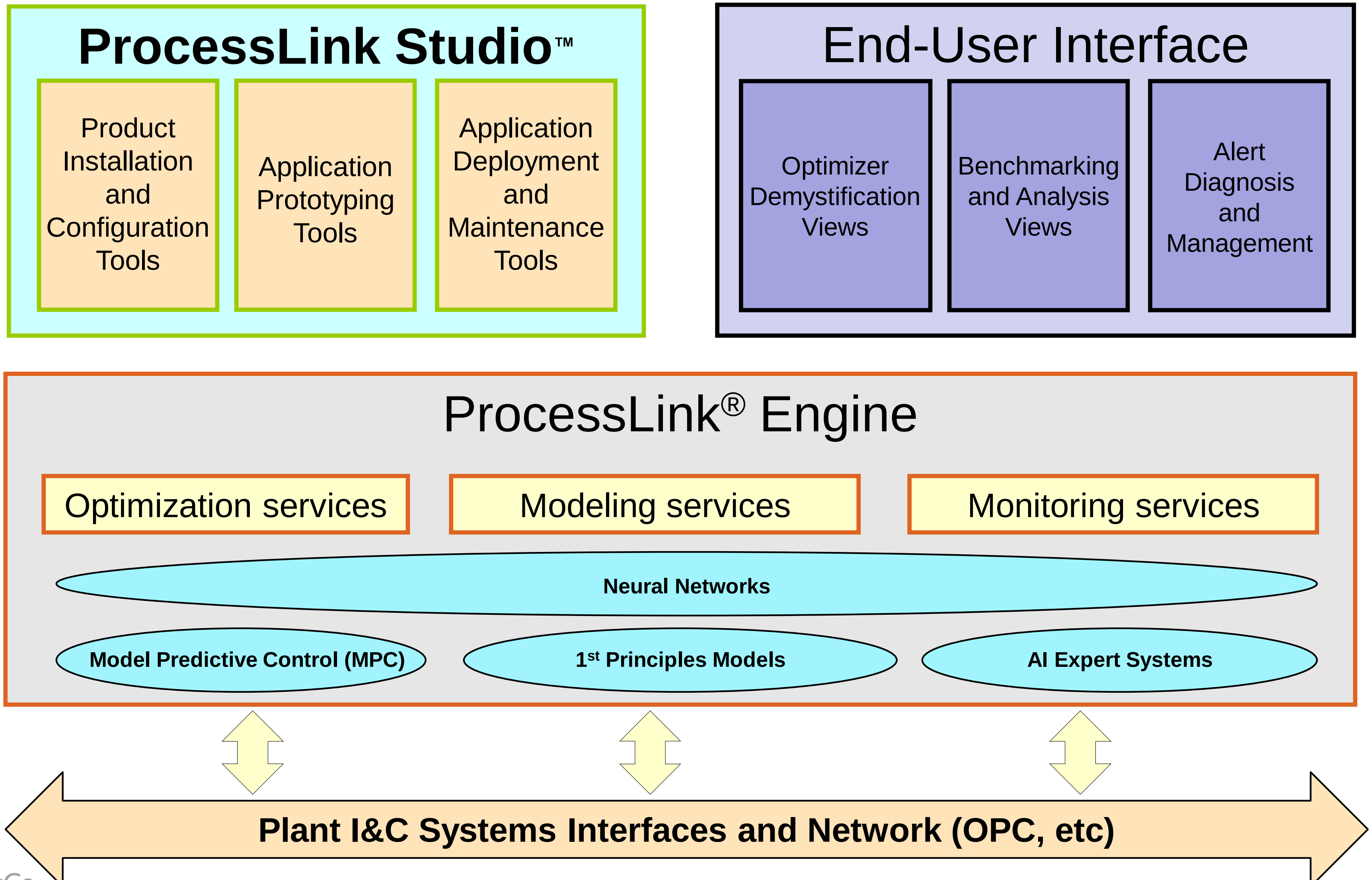
- Oswego, NY
- 1000 MW Total Capacity
- 2 x 2on1 CC
- GE Units with STAG 207FA (165 MW) GTs
- Vogt HRSGs and BOP controls
- Duct Burners add 88 MW of capacity
- Sell into the NYISO market
- Started bidding into Regulation Market 4 years ago

Indentified Optimization Opportunities

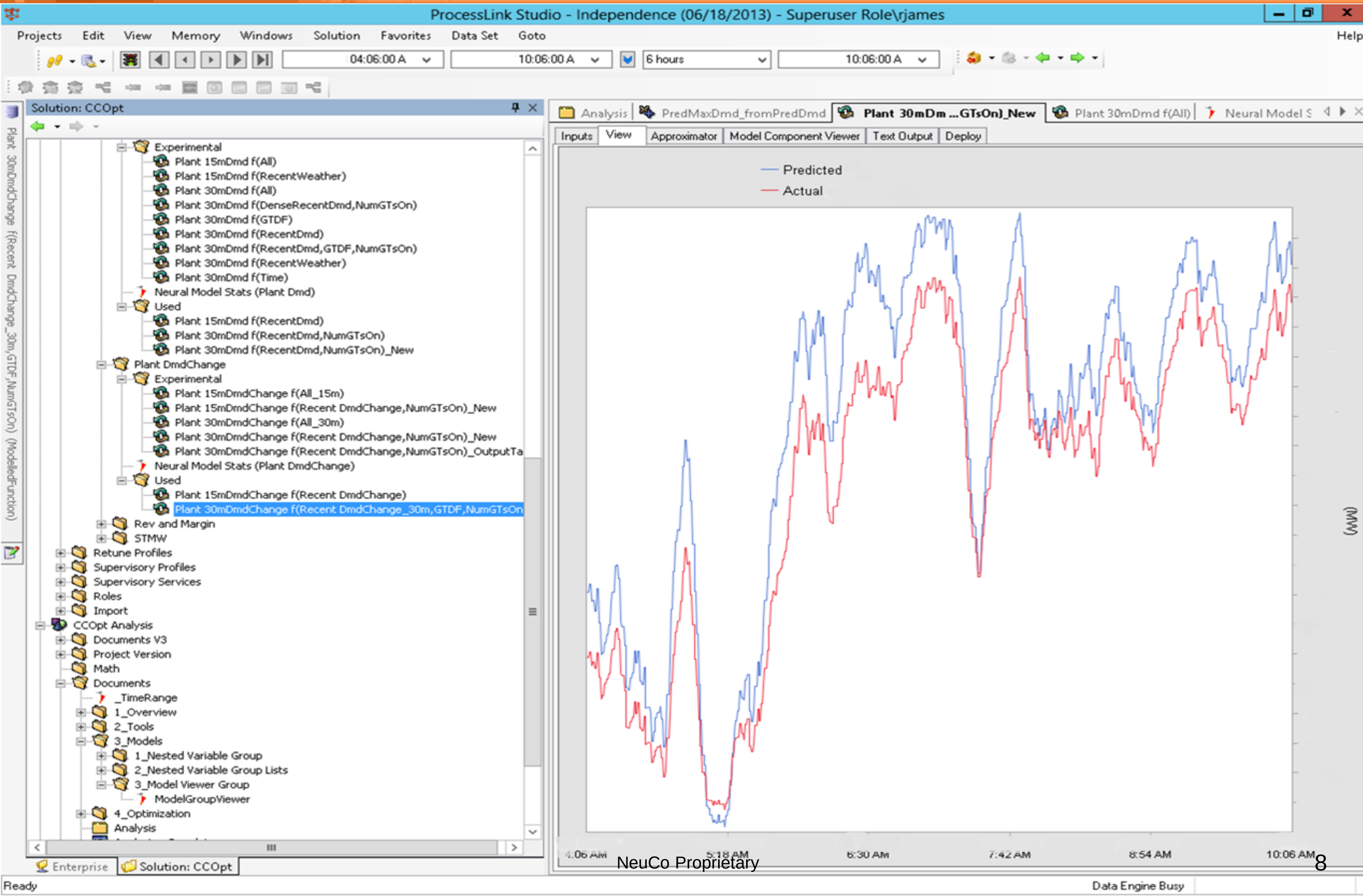
- Maximize plant capability for high Ramp-Rate (RR) Ancillary Services
  - Started development Jan 2013, deployed in closed-loop in Sept 2013. results evaluated.
- Optimize Dynamics of the Combined Cycle
- Enhance Day Ahead Capability Prediction and Provide Production Analytics
- Detect Analyze and Diagnose Anomalies and Changes
- GT Combustion Monitoring/Tuning
- Power Augmentation Management

The Tools

The ProcessLink Platform



The ProcessLink Platform



Maximize Capability for High Ramp-Rate Ancillary Services

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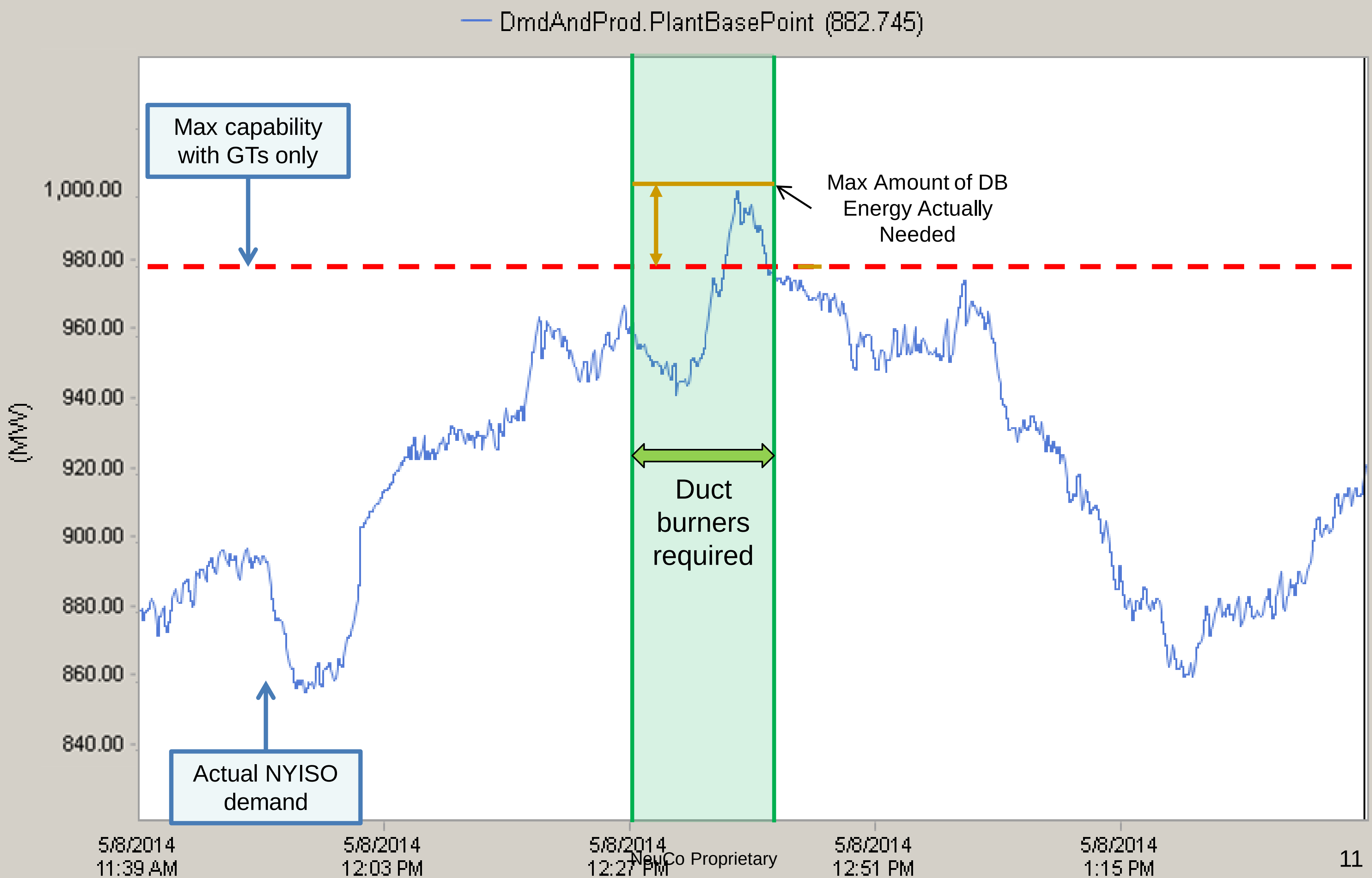
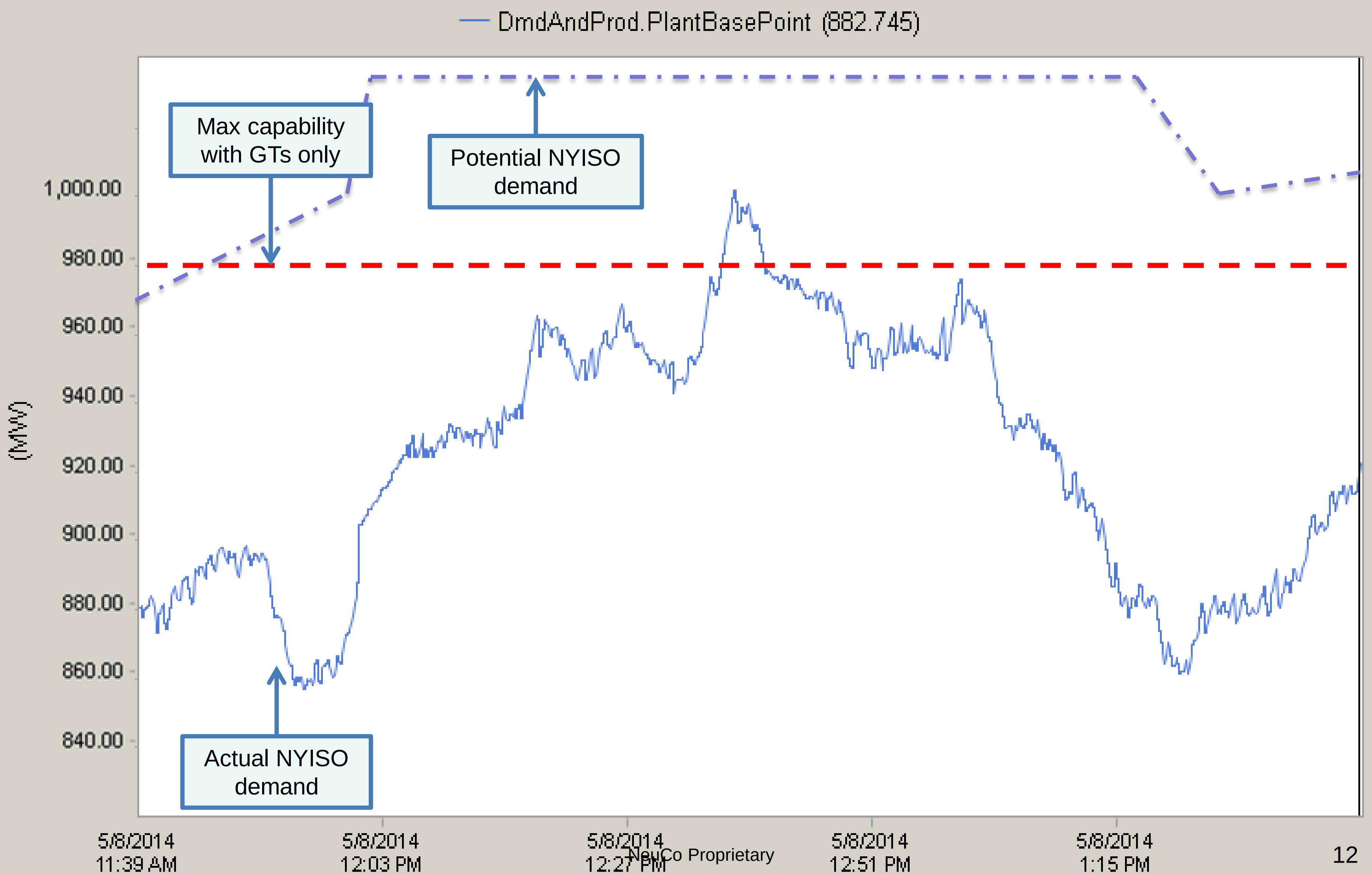
The Challenge

- For Independence, bidding into the Ancillary Services Regulation Market is believed to have had a substantial positive revenue impact
- They bid 100 MW of ramp at 5MW/min (or 100MW over 20min) up to 1088 (all 1000 GTMW and 88 Duct Burner MW) into the Day Ahead Ancillary Service Regulation Capacity Market
- They can add the Duct Burners to free up some GT capacity in case they are asked to ramp at 5MW/minute all the way to 1088 (or plant max)
- But there is Heat Rate Penalty

Optimal Use of Duct Burners for Regulation Support

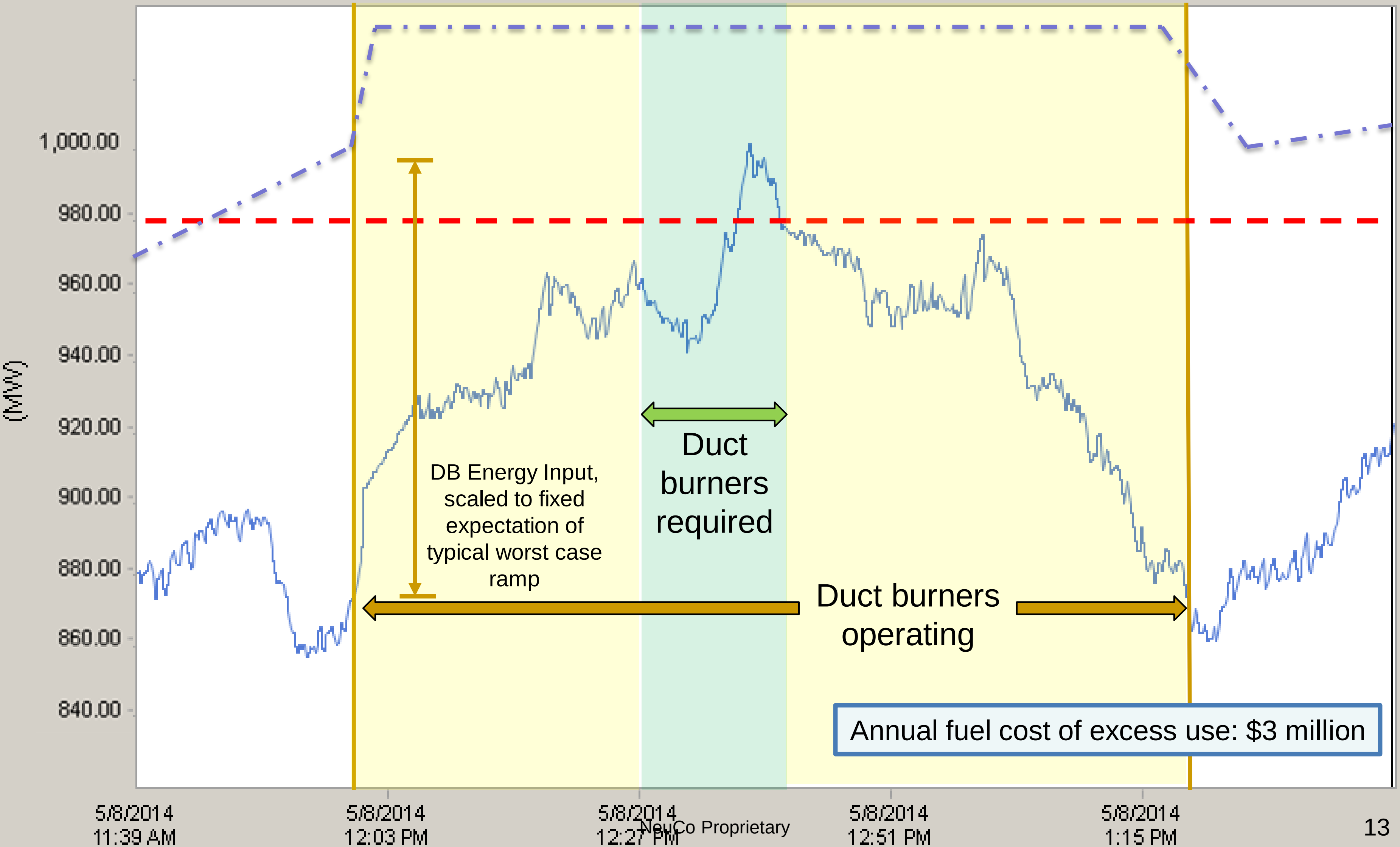


Predicting Peak Output



Duct Burner Management Before Optimization

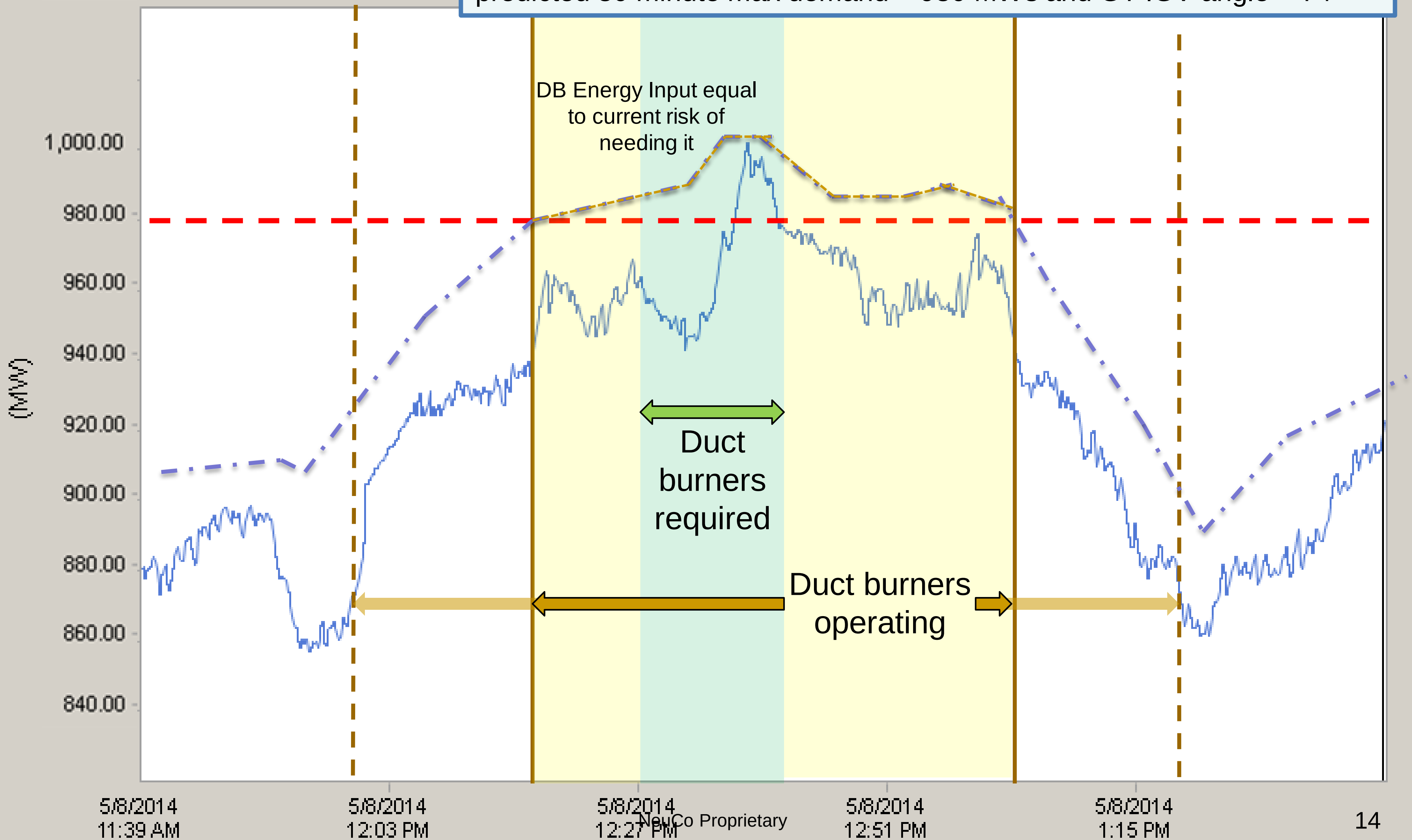
Duct burners were turned on when GT IGV angle > 74°



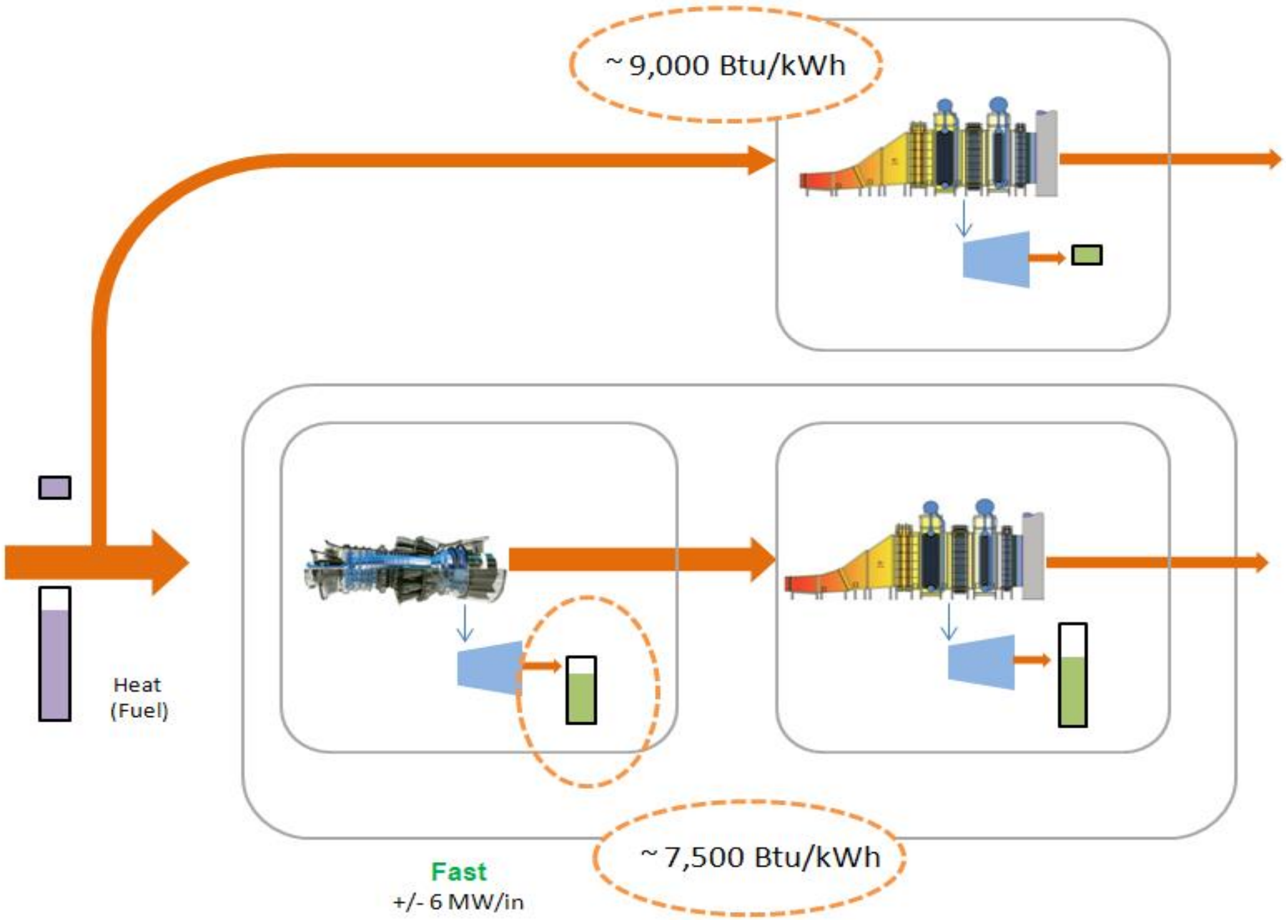
Annual fuel cost of excess use: $3 million

Duct Burner Management After Optimization

Duct burners were turned on when
predicted 30 minute max demand > 980 MWs and GT IGV angle > 74º



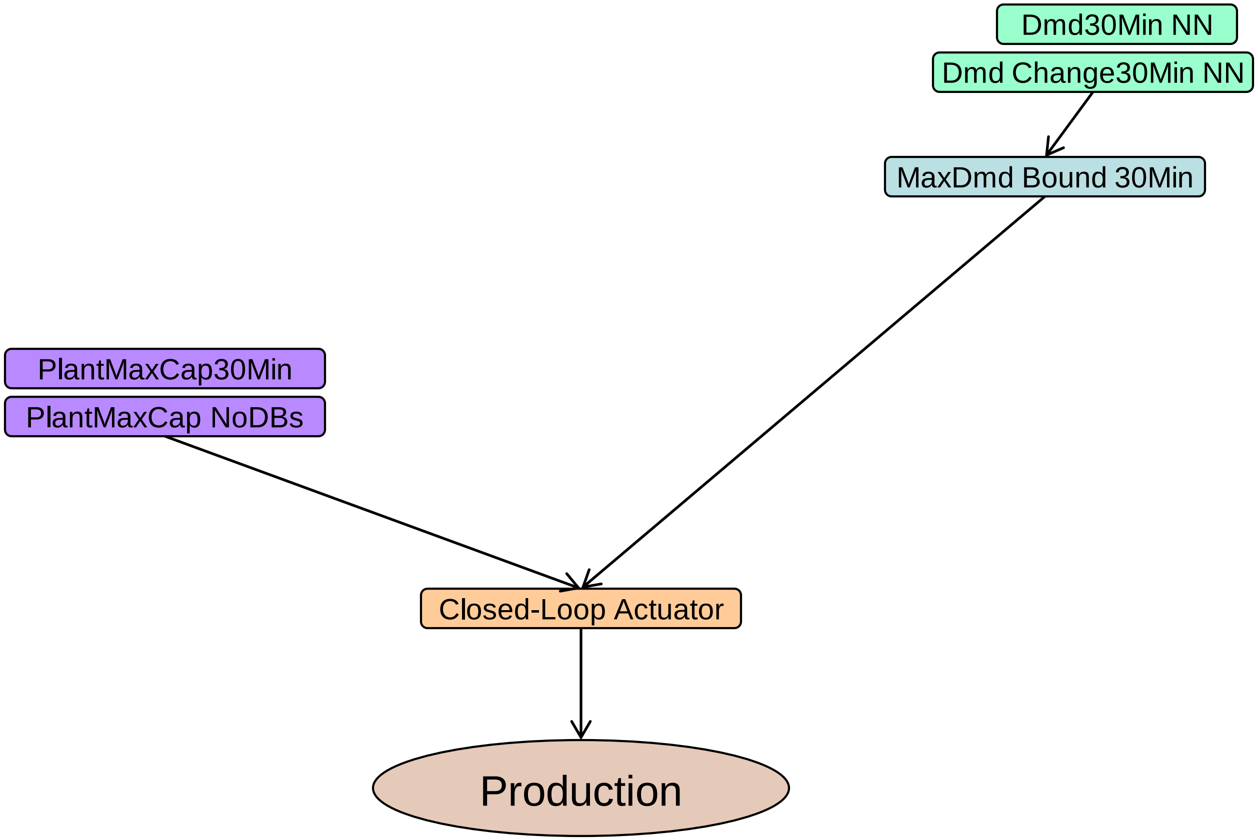
HR vs. Ramp Rate Readiness



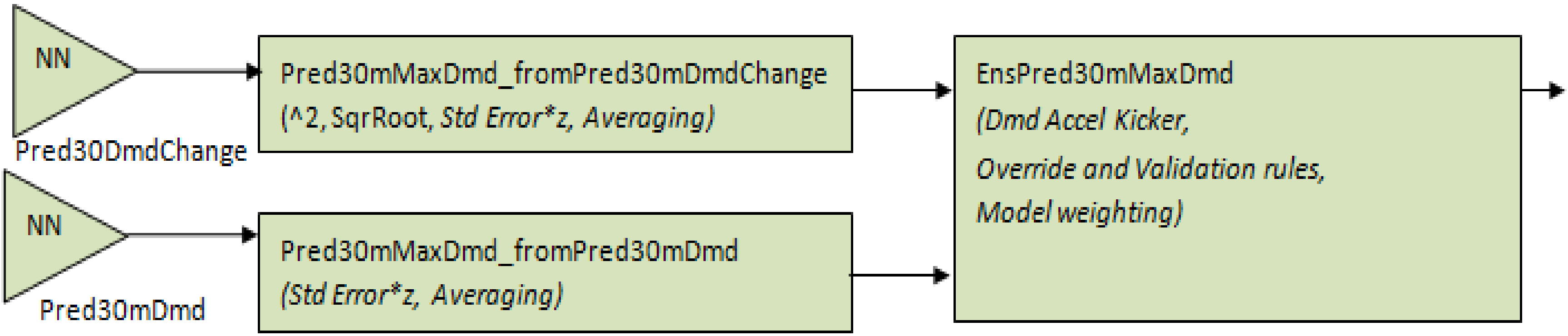
How The Optimizer Works

- Predicts maximum likely demand over the next 30 minutes
- Adds only enough Duct Burner fuel to offset shortfall in case of maximum likely demand
- Uses dynamic modeling to avoid over-shooting and under-shooting
- Predicts true combined cycle capability without duct burners in 30 minutes given current state and history
- Enables users to specify how certain they want to be that they'll meet demand

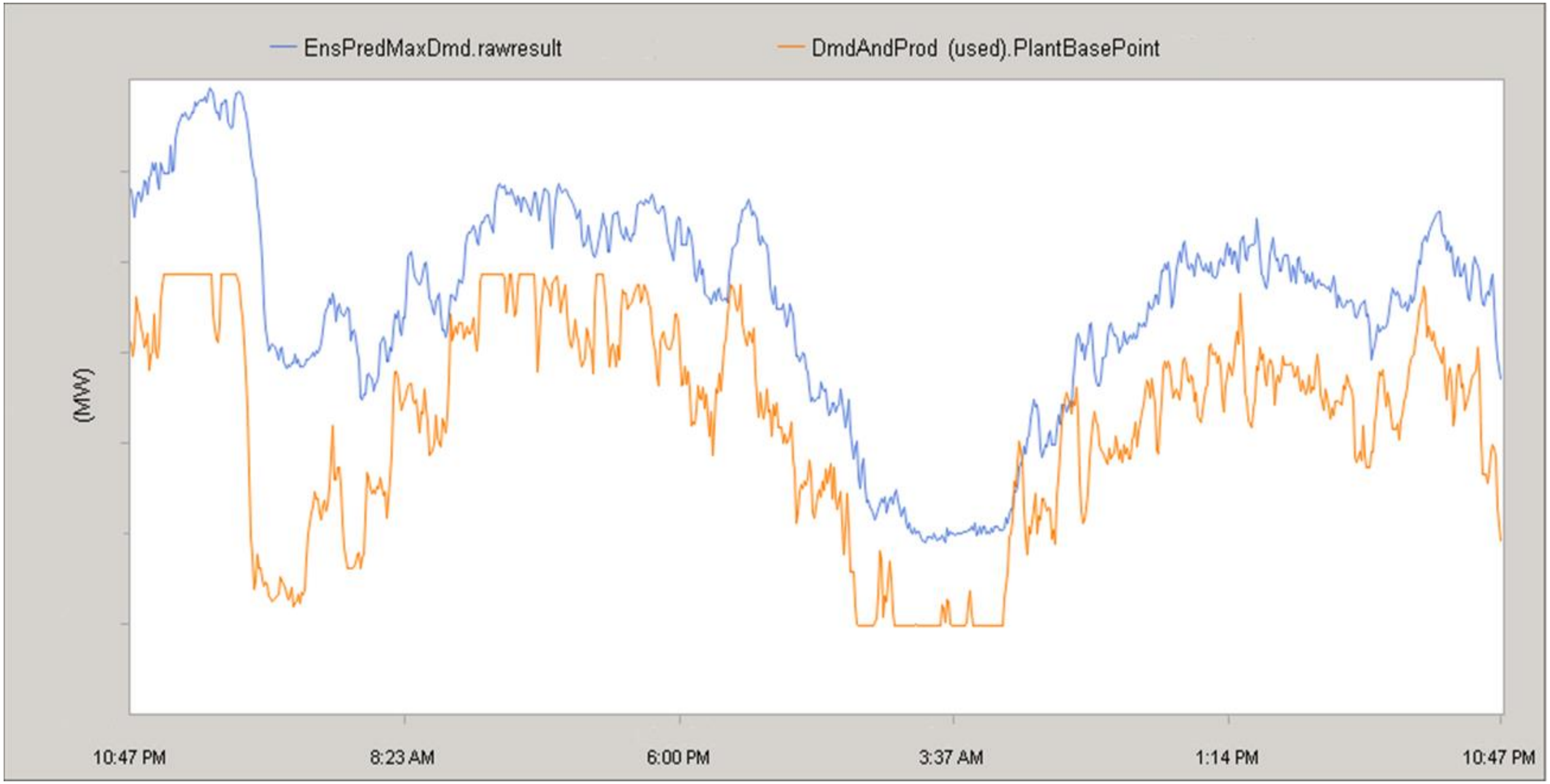
Application Evolution



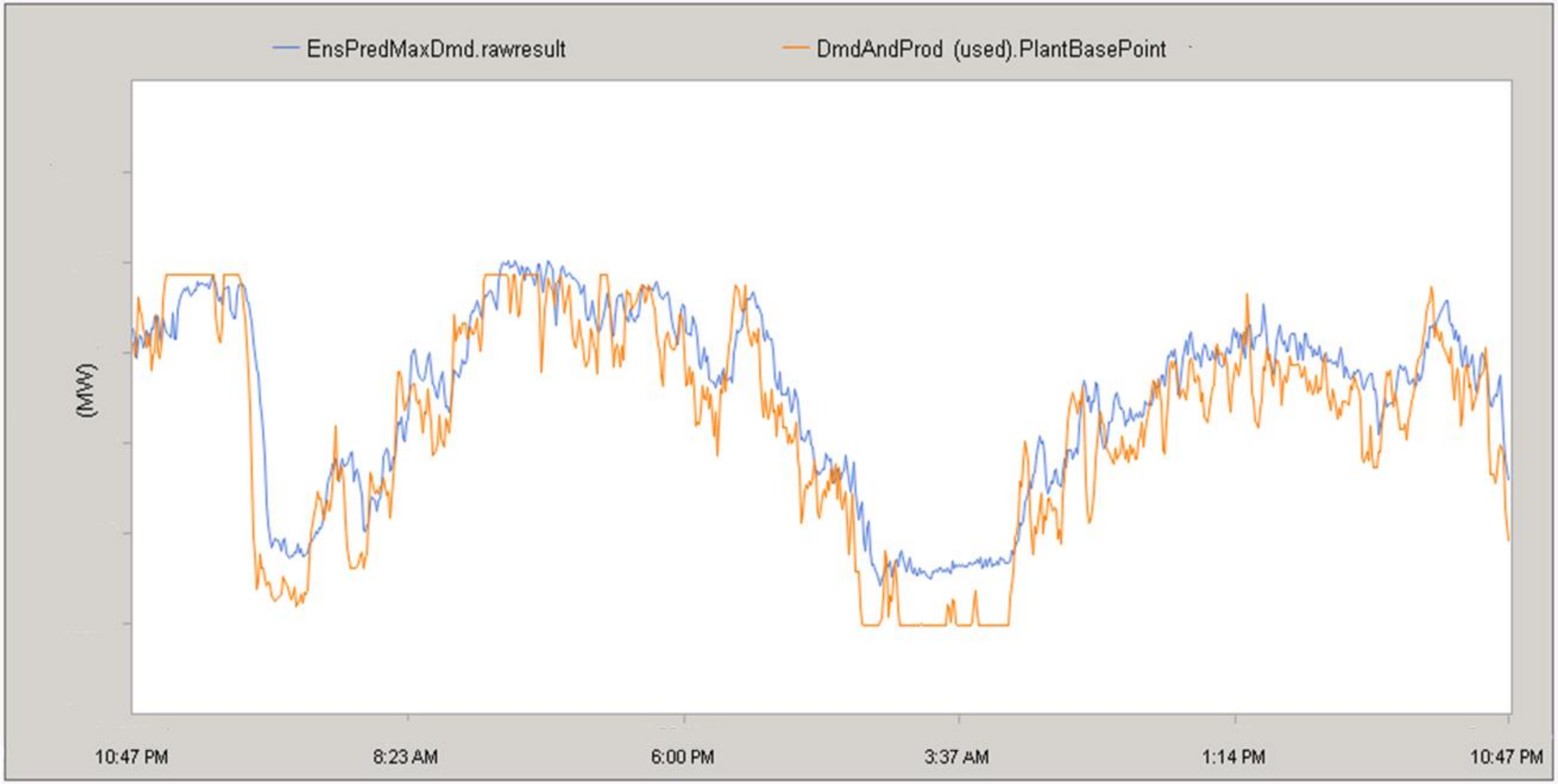
Max Thirty Minute Demand Predictor (Model Ensemble)



Max Thirty Minute Demand Predictor (Conservatively tuned)



Thirty Minute Max Demand Predictor (Aggressively tuned)



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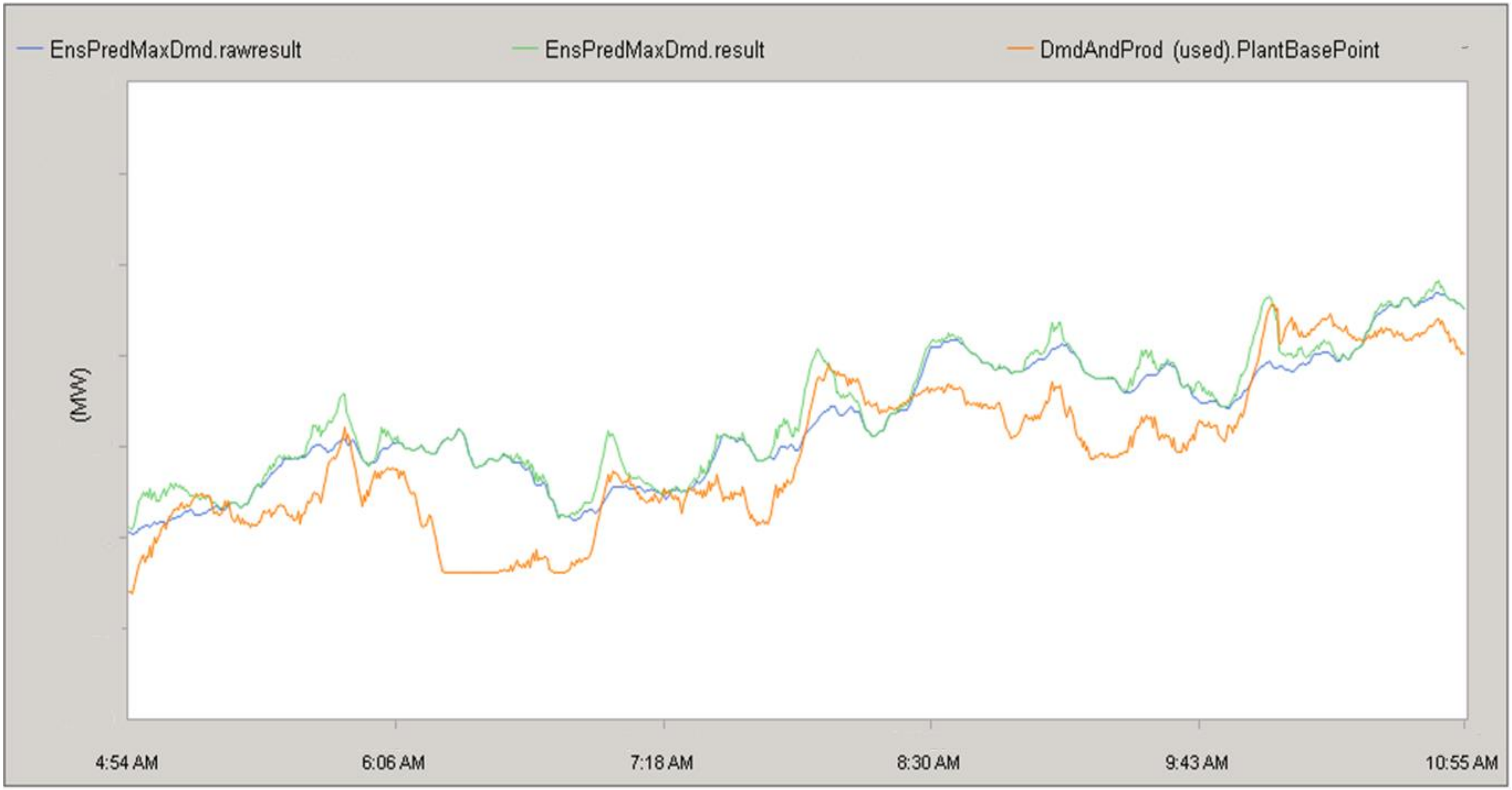
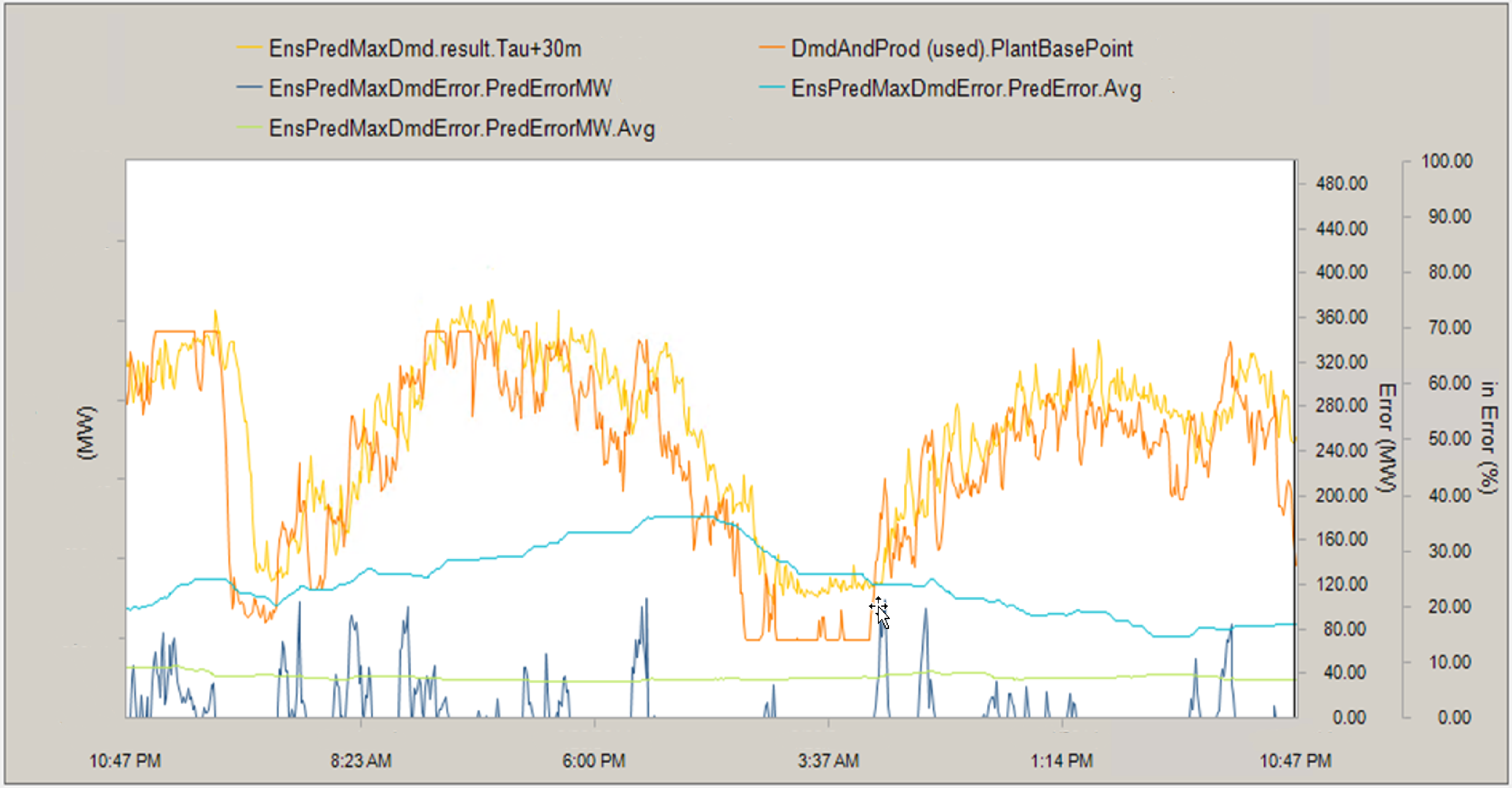
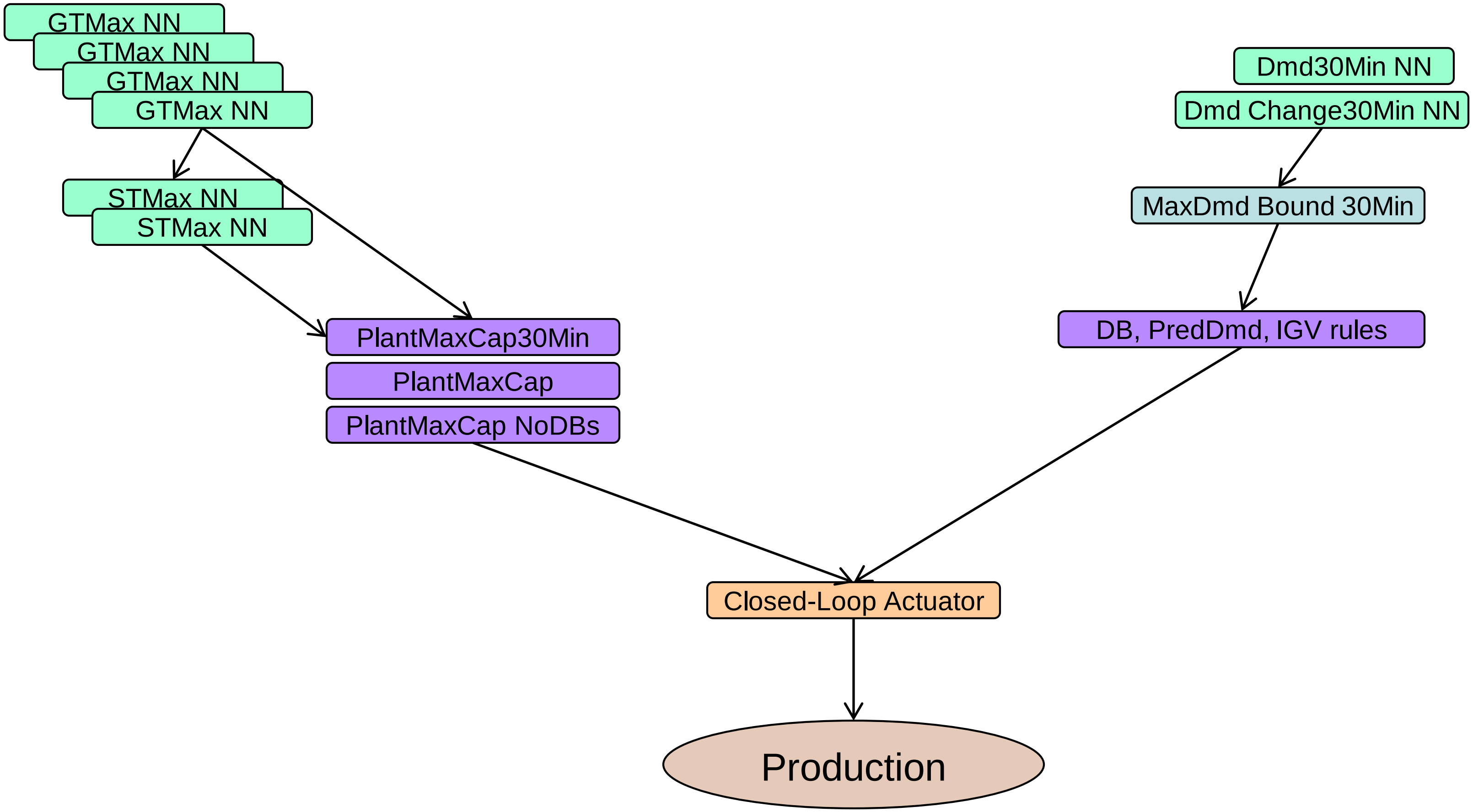
Thirty Minute Max Demand Predictor (Aggressively tuned + Expert Rules)



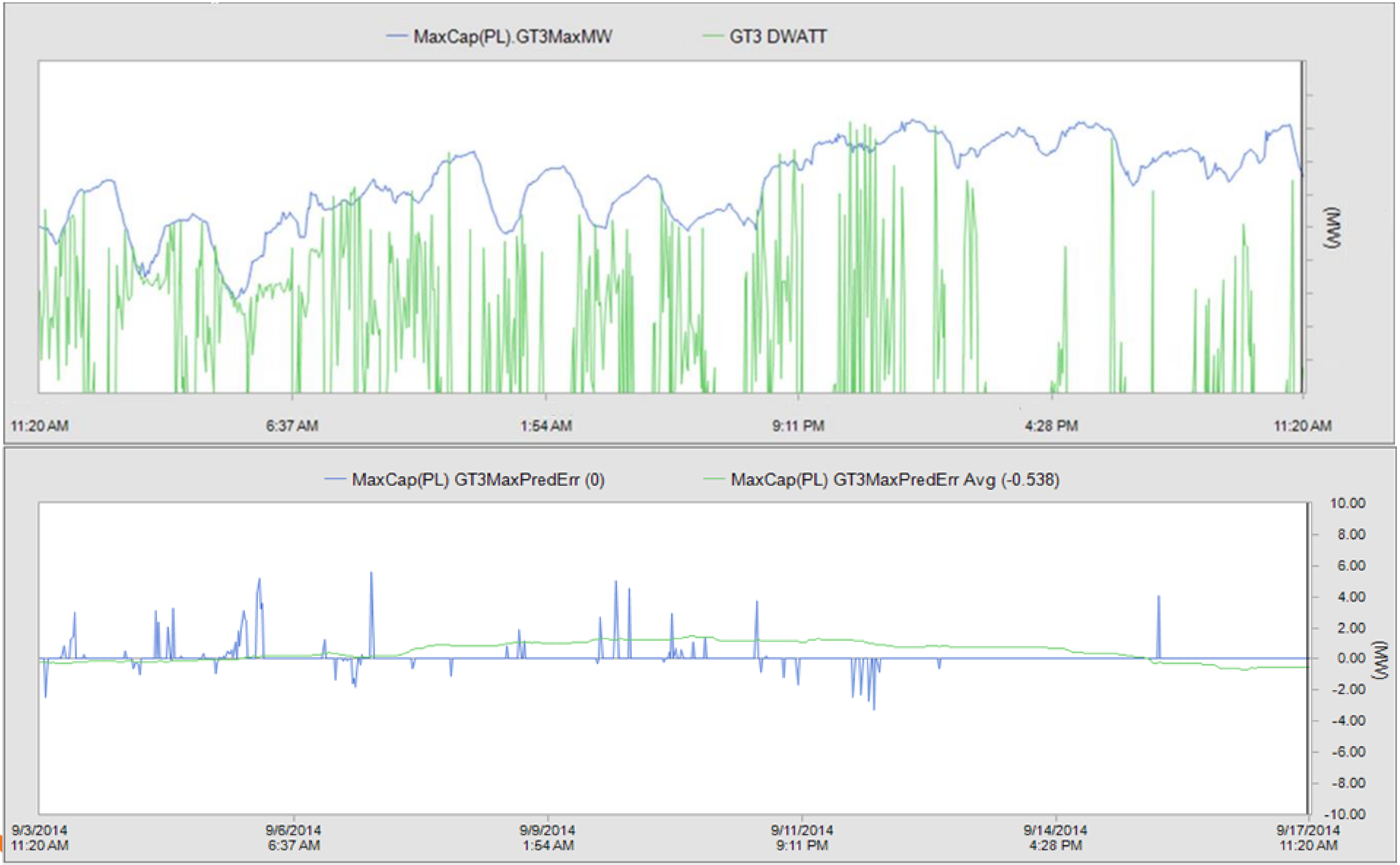
Thirty Minute Max Demand Prediction Error



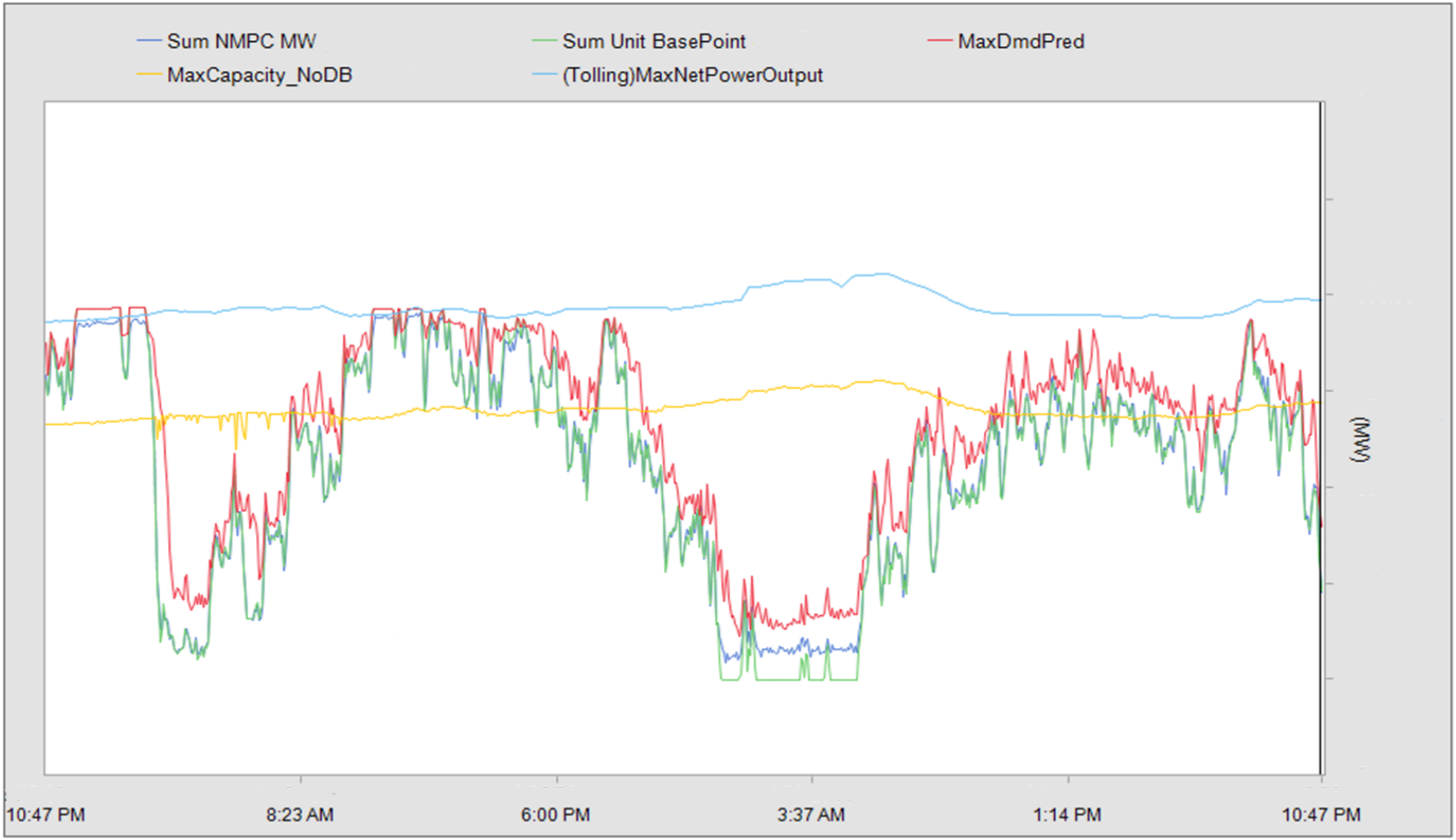
Application Evolution



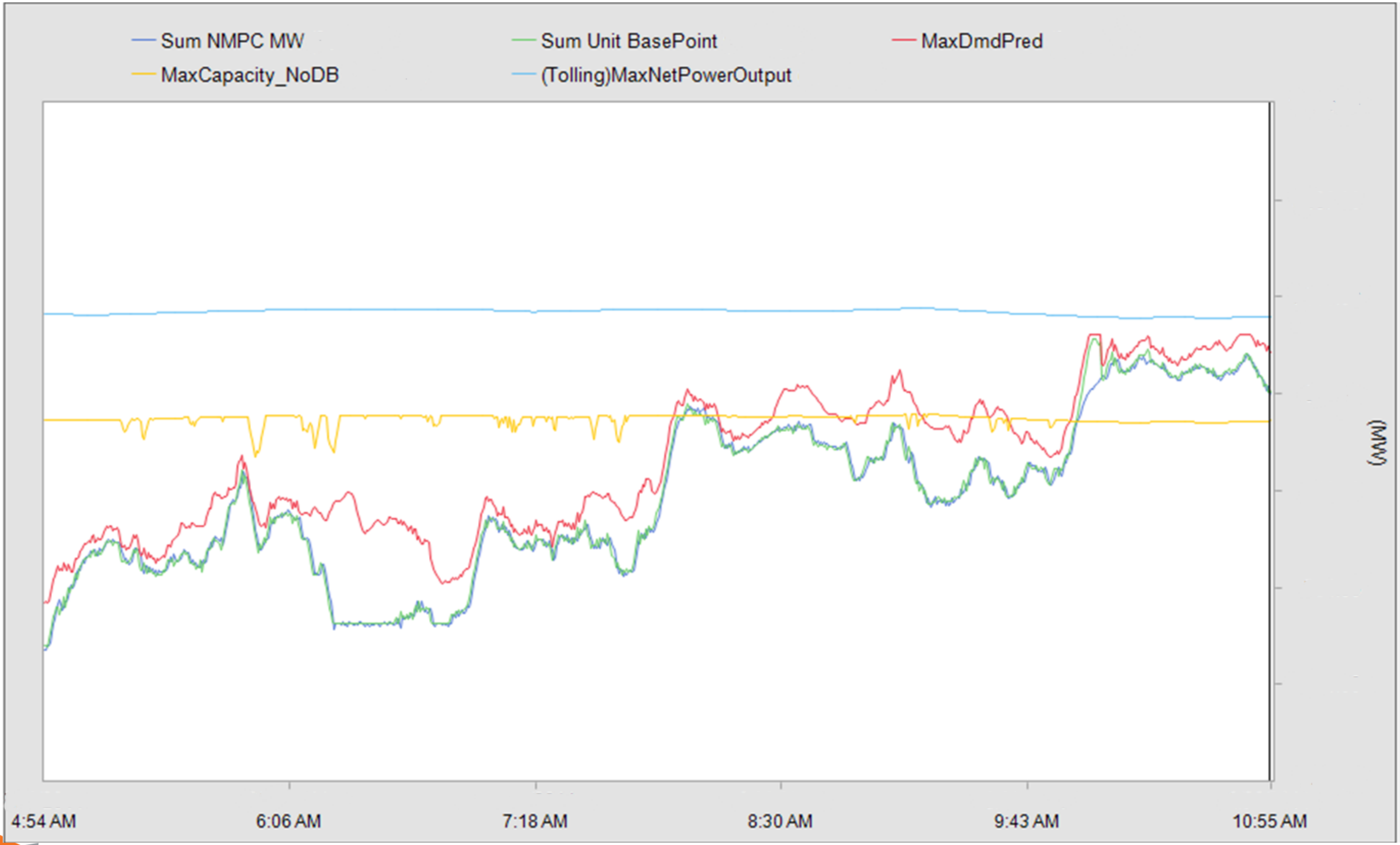
Neural Model Prediction of GT Max Capability



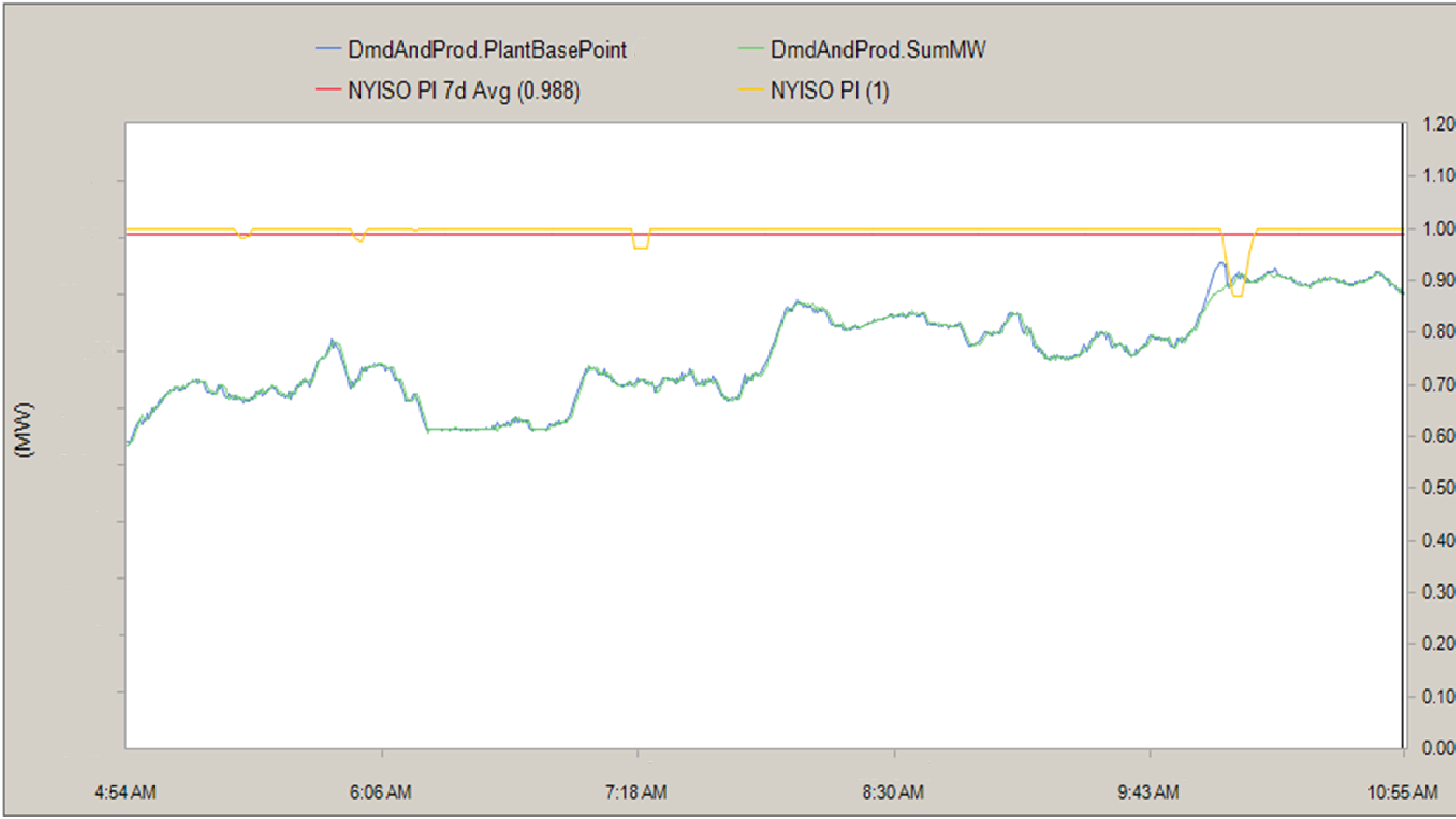
Max 30 minute Demand and Max Capability Predictions



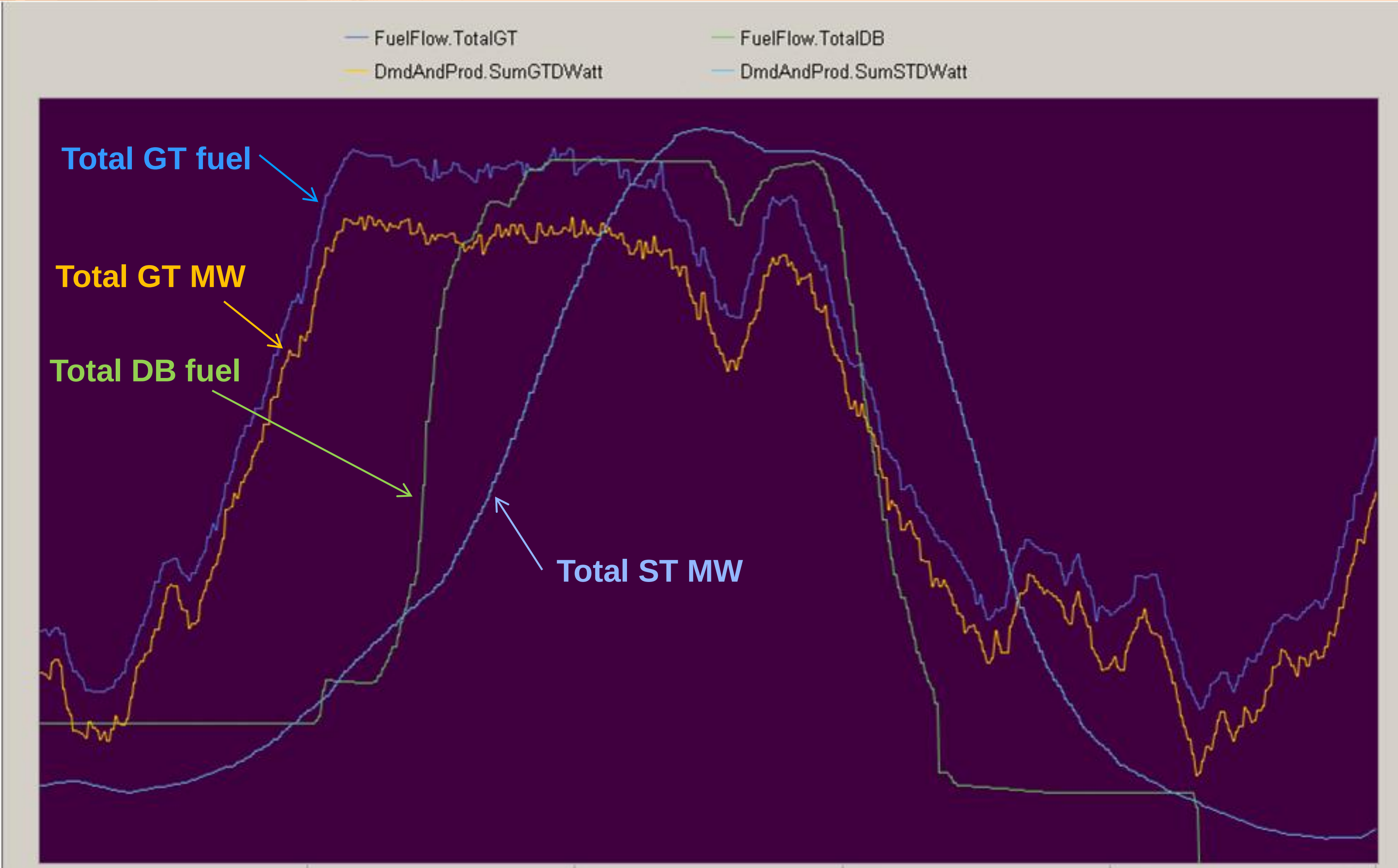
Max 30 minute Demand and Max Capability Predictions



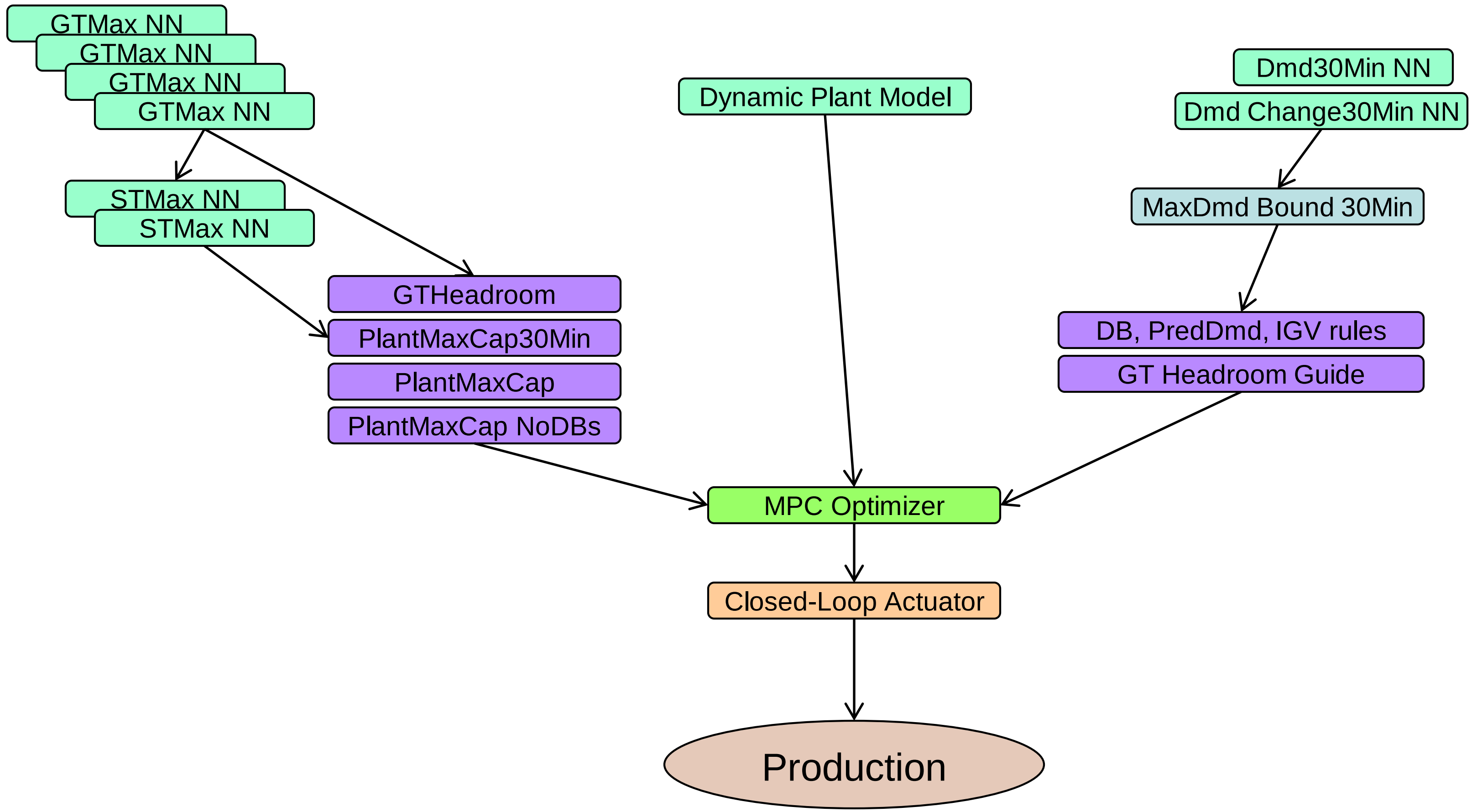
ISO Regulation Ancillary Services "Performance Index"



The Challenge



Evolution


GTMax NN
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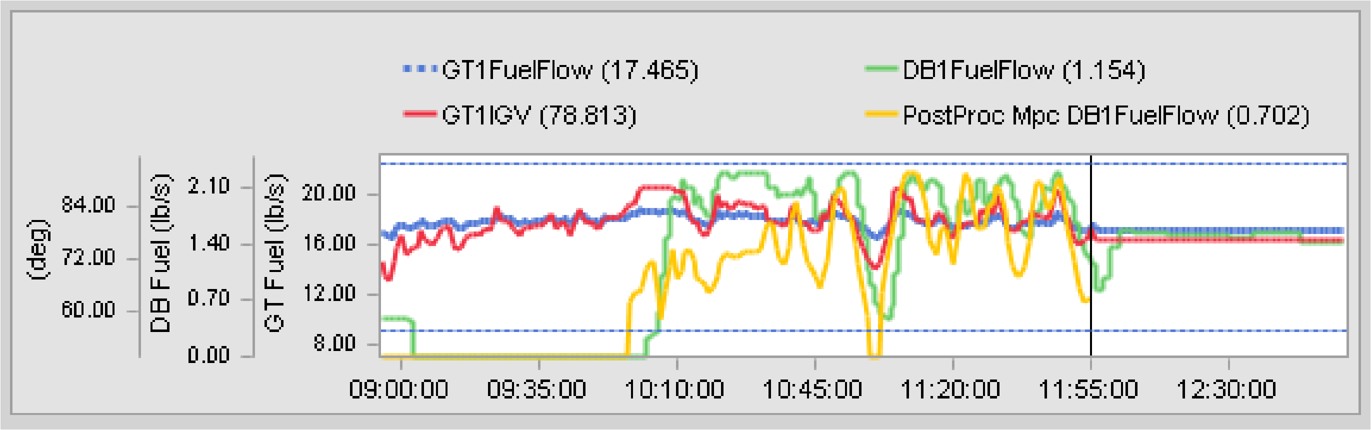
STMax NN
STMax NN
GTHeadroom
PlantMaxCap30Min
PlantMaxCap
PlantMaxCap NoDBs
Dynamic Plant Model
Dmd30Min NN
Dmd Change30Min NN
MaxDmd Bound 30Min
DB, PredDmd, IGV rules
GT Headroom Guide
MPC Optimizer
Closed-Loop Actuator
Production

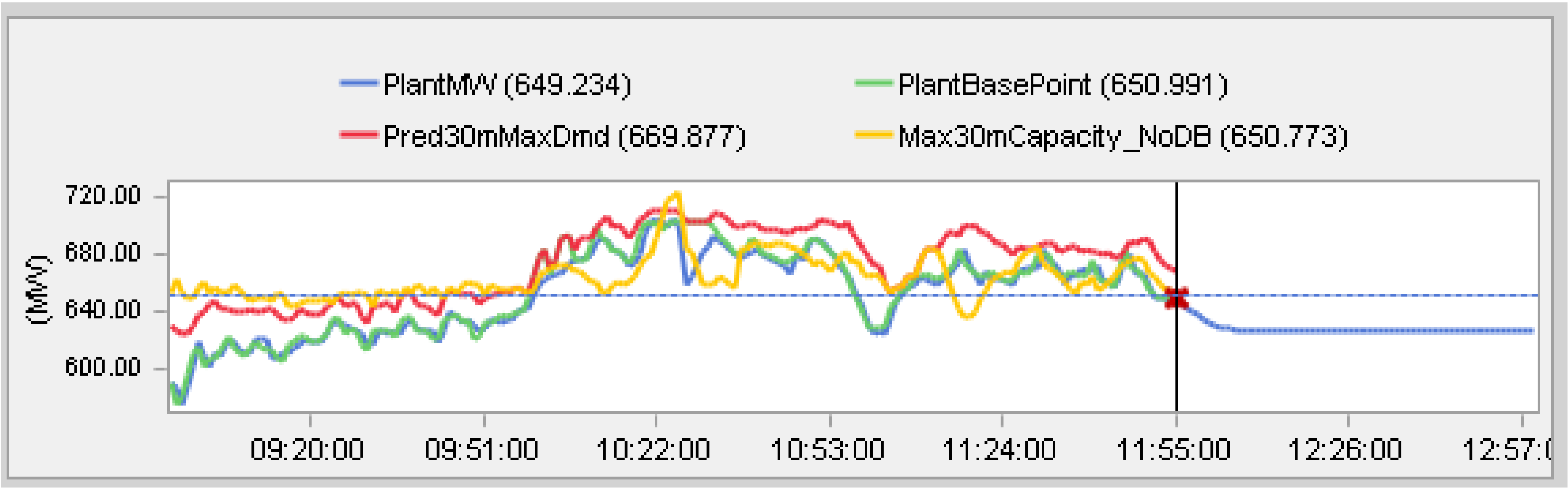
Closed-Loop MPC Duct Burner Optimizer

Closed-Loop Optimizer Manipulated Variables



- Optimizer uses a dynamic model to predict optimal Duct Burner (DB) fuel flow trajectory (GT fuel flow trajectory can also be predicted)
- Then it biases the IGV angle start and stop thresholds in the DCS to inhibit or encourage burner activation
- And biases the DCS fuel flow curve to control DB heat input more precisely, once a DB is running

Predicting 30 Minute Max Demand



- Neural Net model of future demand and demand variance in 30 minutes
- Inputs: Past demand/demand-variance (series of tap delays), time of day, day of week, ambient temp, humidity, barometric pressure.
- Combined in an ensemble, with a set of rules that leverage the model's prediction error, enforce limits to deal with special cases, and allow for tuning of risk
- To create a max limit for likely demand over the next 30 minutes

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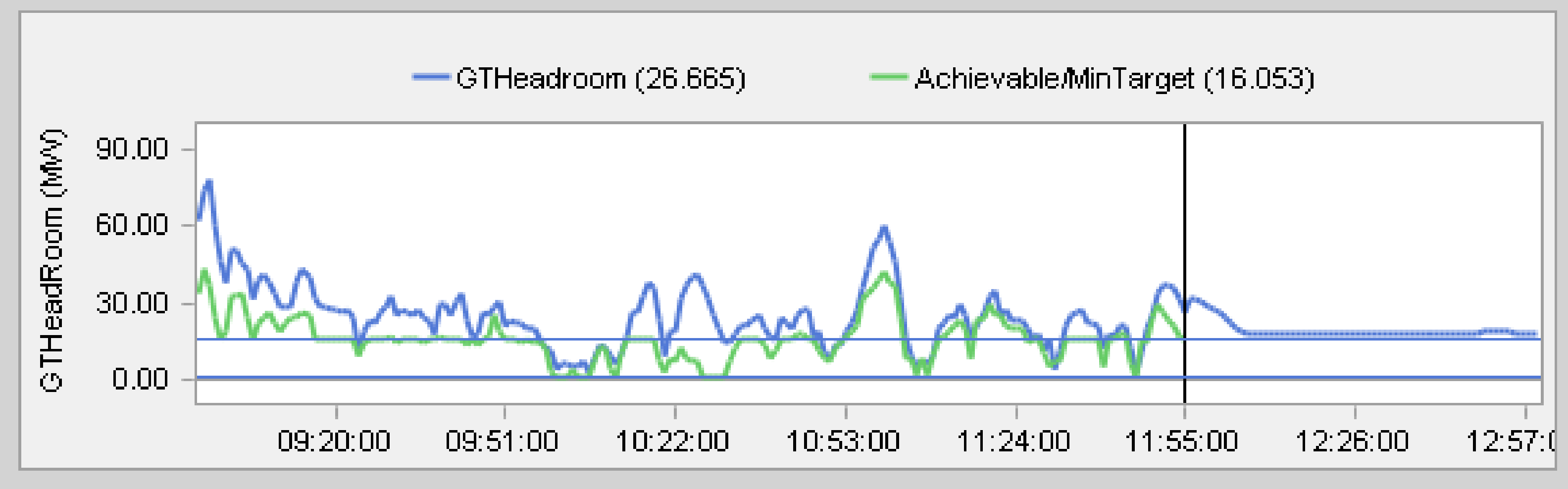
Predicting 30 Minute Max Demand

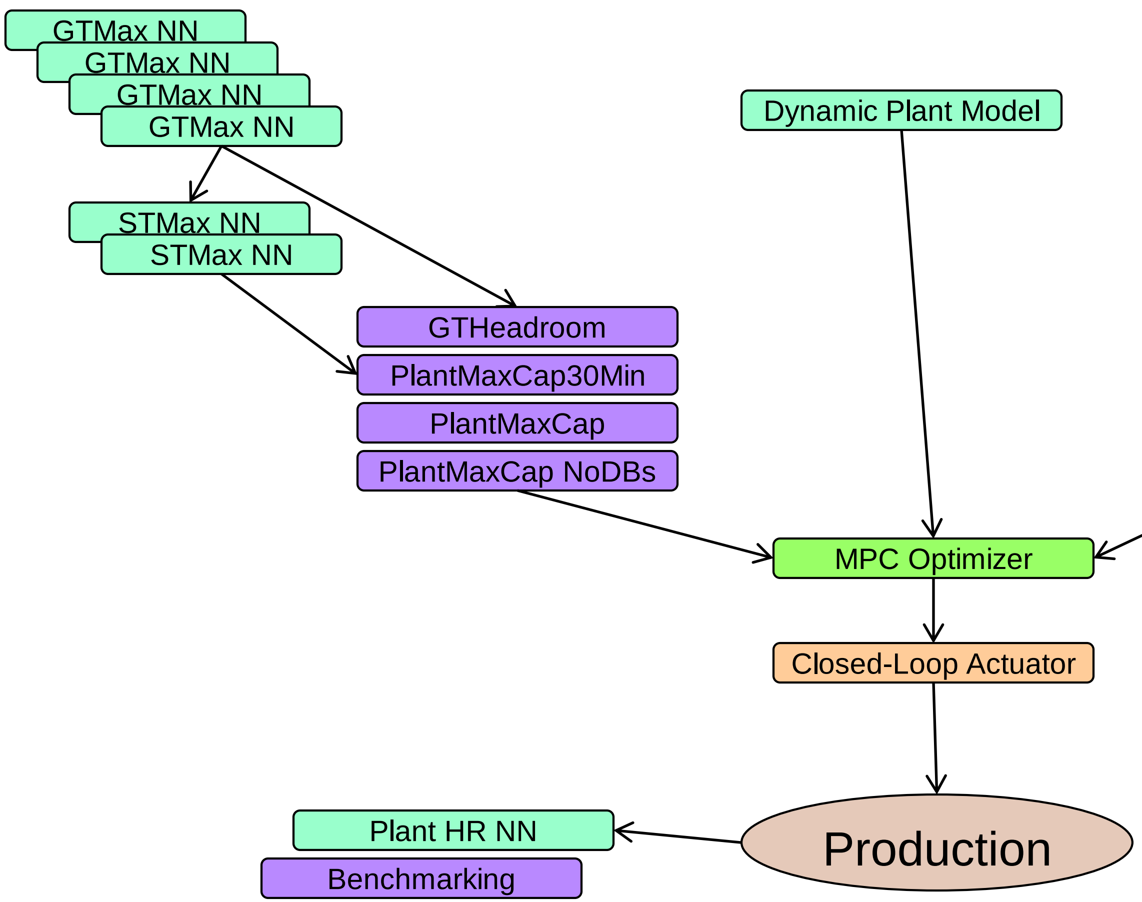


- Prediction of 30-minute max likely demand is compared to 30 minute max plant capability
- Any *potential* shortfall needs to be compensated for by adding duct burner energy and running with more GT capacity in reserve (aka more "GT headroom")

Closed-Loop Optimizer Objectives

- Dampen ST swings
- Maintain sufficient spare GT capacity to meet possible future demand ramps
- Minimize DB fuel

Evolution



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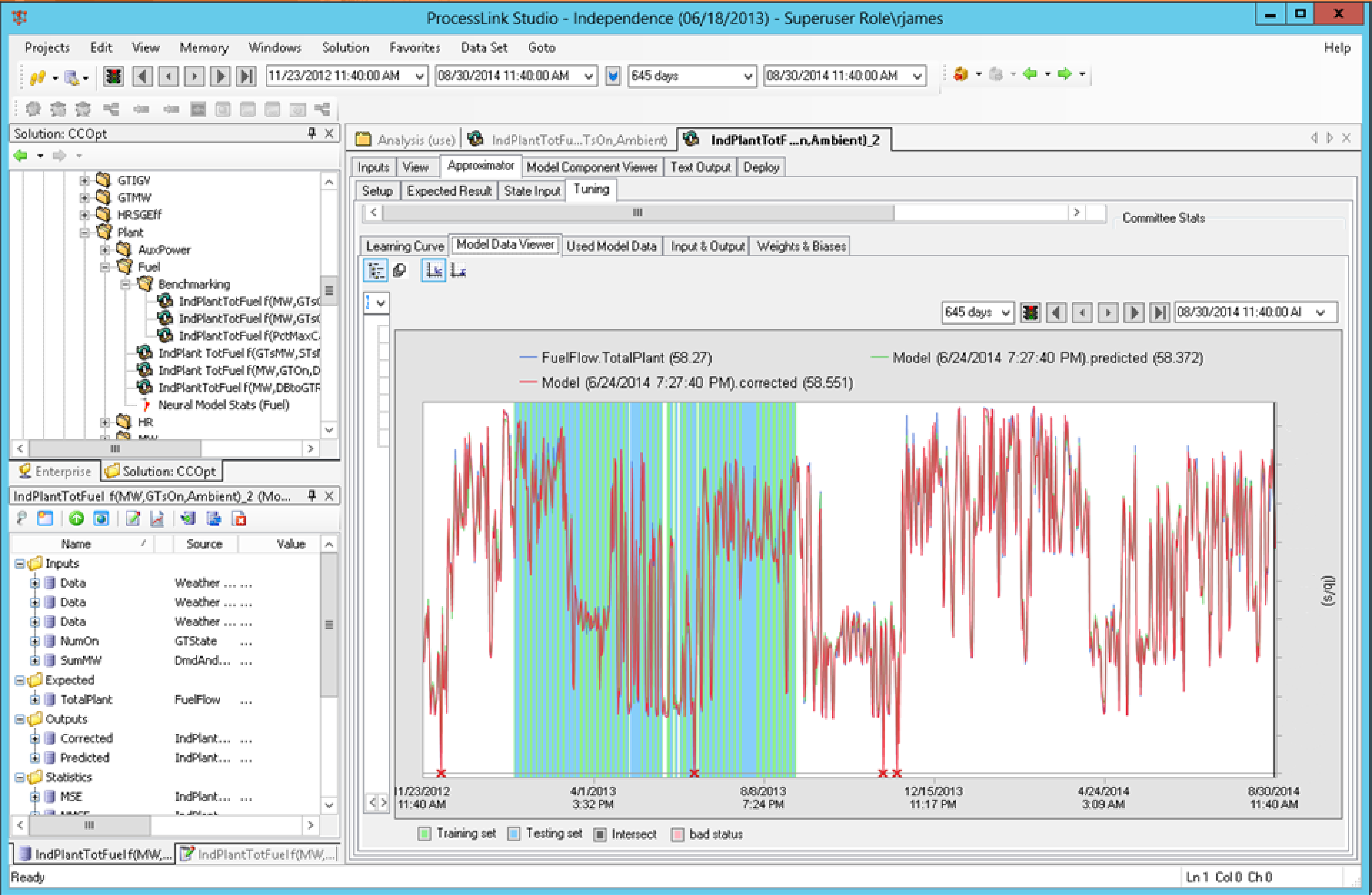
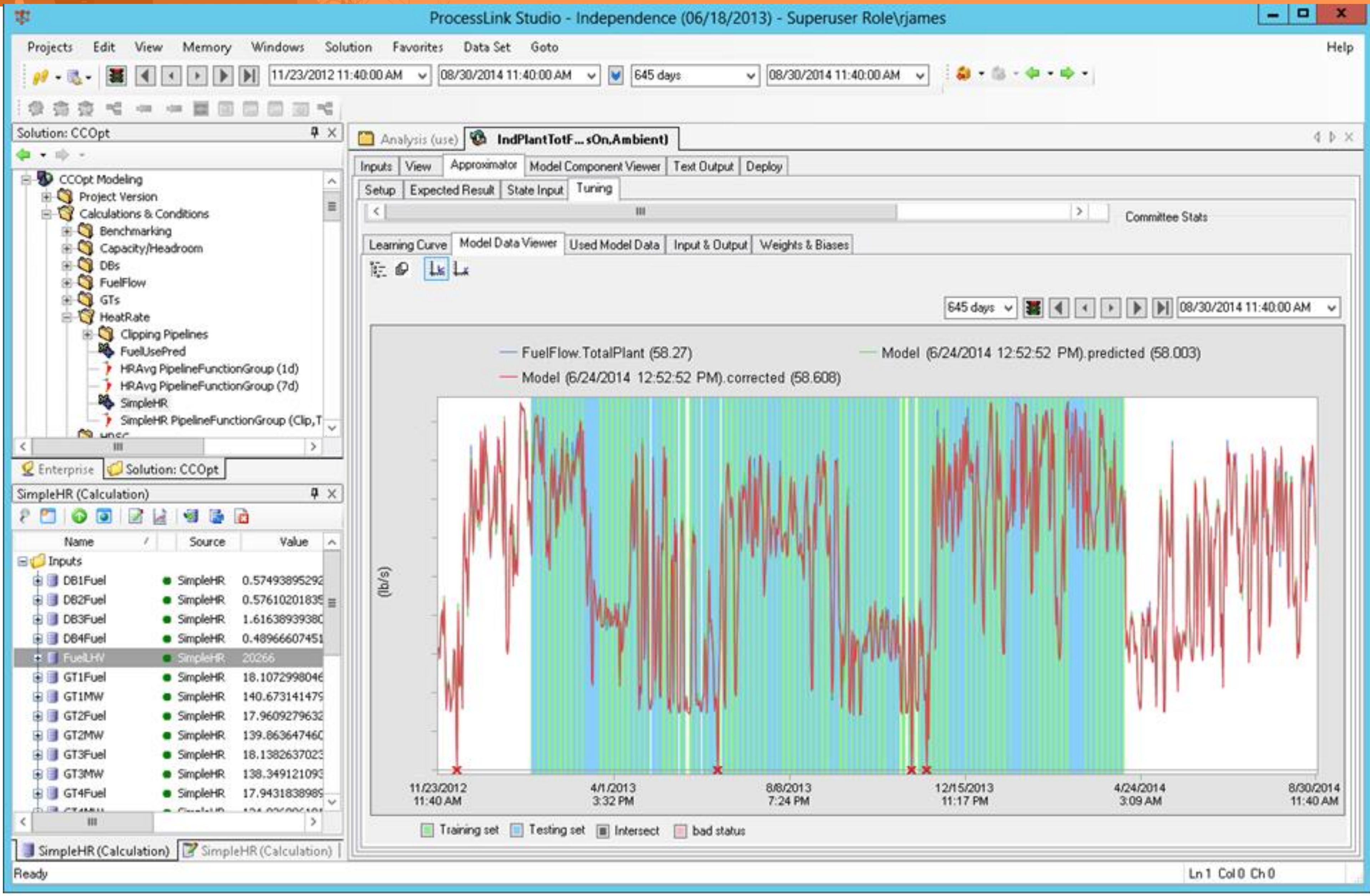
Plant HR NN
Benchmarking

Real-Time Analytics: Benchmarking



Real-time Analytics: Benefits Benchmarking



Benefits Benchmarking

Project Timeline:

- March 2013 Project kickoff
- September 2013 Initial closed-loop optimizer was tested.
- April 2014 New version of the optimizer was deployed using Model Predictive Control (MPC) and a neural-first principles hybrid model to predict max plant capability

			Test Set : #2 (9/1/13-6/24/14)		Test Set: #1 (4/11/14-6/24/14)	
		Training Bias	Estimated Change	Estimated Change minus Training Bias	Estimated Change	Estimated Change minus Training Bias
NNModel 1	Trained on all available data prior to 4/11/14	$ (43,250)			$ (915,402)	$ (872,152)
NNModel 2	Trained on all available data prior to 9/1/13	$ (396,753)	$ (808,459)	$ (411,706)	$ (1,615,300)	$ (1,218,546)

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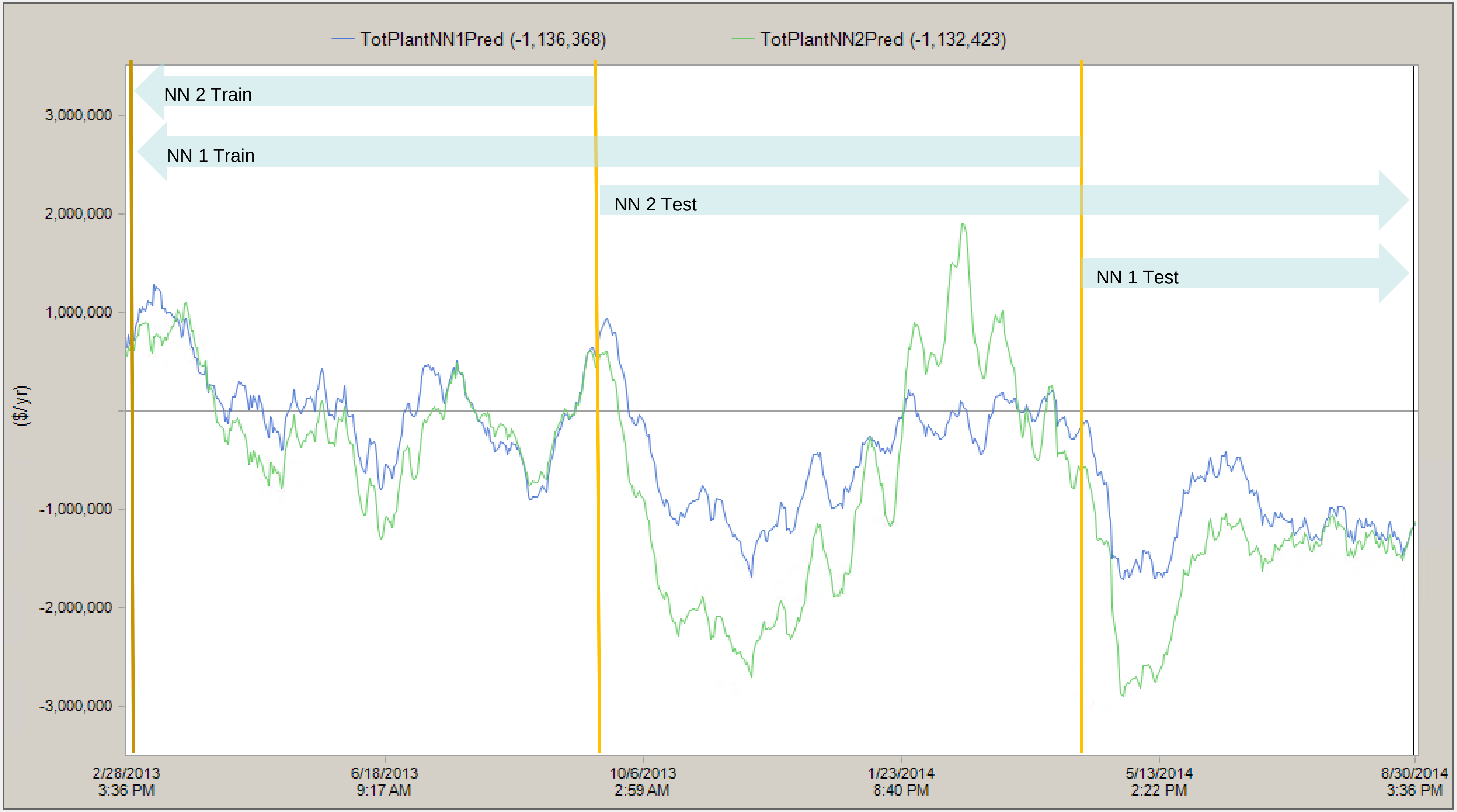
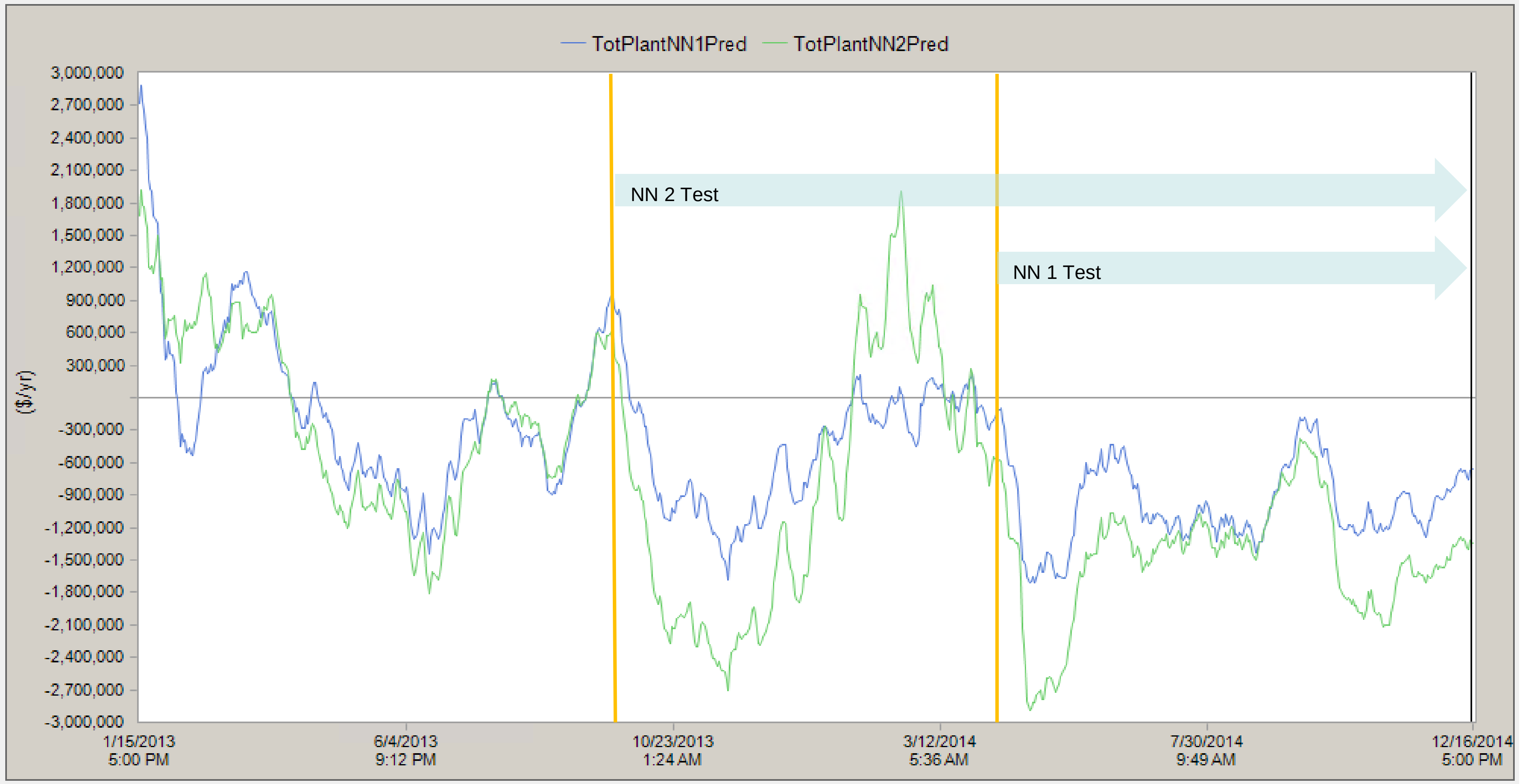
Benefits Benchmarking (8/30/14)



Benefits Update (12/16/2014)



Benefits Update (12/22/2014)