# Predictive Maintenance on Gas Turbine Compressor

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# Agenda

- Pampa Energía S.A. – Genelba Introduction
- Business Challenge
- Background
- Research
- Applications and Use Case / How the PI System was Applied
- Implementation Details
- Results Obtained and Business Impact
- Conclusion

# Introduction to Pampa Energía S.A.

## ELECTRICITY

### Generation
#1 IPP, operating 4.8 GW
*12% market share*

| | |
|---|---|
| Thermal | 3,607 MW + 471 MW expansions[1] |
| Hydro | 938 MW |
| Wind farms | 206 MW[2] |

### Transmission
Co-control of Transener
*85% of market share*

| | |
|---|---|
| HV Lines | 20,933 km of lines |
| Stations | 160 transformer stations |

### Distribution
Control of edenor
*19% market share*

| | |
|---|---|
| Concession area | 3.1 million end users<br>20 TWh of sales |

## OIL & GAS

### Upstream
Leading producer
*6% market share*

| | |
|---|---|
| Blocks | 11 Productive + 7 Exploratory |
| Production | 50 kboepd, 90% gas |

### Midstream
Co-control of tgs
*#1 gas transporter,*
*#2 NGL producer*

| | |
|---|---|
| Pipelines | 9,231 km for natural gas |
| NGL | 1 million ton per year |

### Petrochemicals
*80-100% market share*

| | |
|---|---|
| Plants | Styrene (160k ton/year)<br>S. Rubber (55k ton/year)<br>Polystyrene (65k ton/year) |

### Other affiliates

| | |
|---|---|
| refinor[3] | 25.8 kbpd of refining capacity.<br>90 gas stations |

# Introduction to Pampa Energía S.A.

**We are the largest independent power company in Argentina**

Operating 15 Power Plants,
4,751 MW Across Argentina

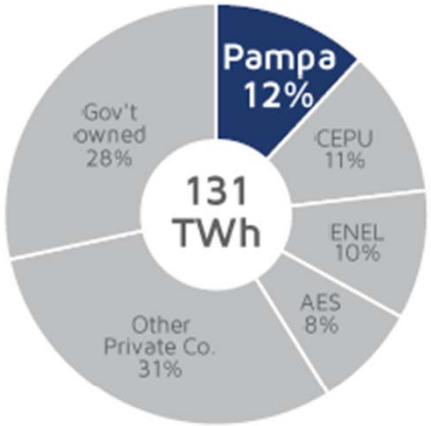
- 3 hydro plants, 938 MW
- 3 wind farms, 206 MW[2]
- 9 thermal plants, 3,607 MW[3]

| | |
|---|---|
| 4,751 MW | installed capacity |
| + 471 MW | under construction[3] |
| 5,222 MW | total capacity |

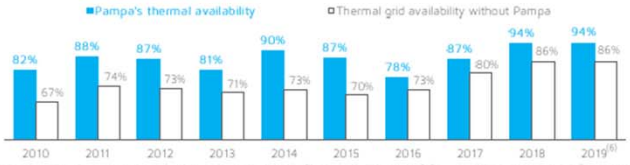
'legacy' capacity[4] 60%

'new' capacity[5] 40%

Argentina's Power Generation Market Share[1]




Pampa's Historical Availability v. Peers, in %



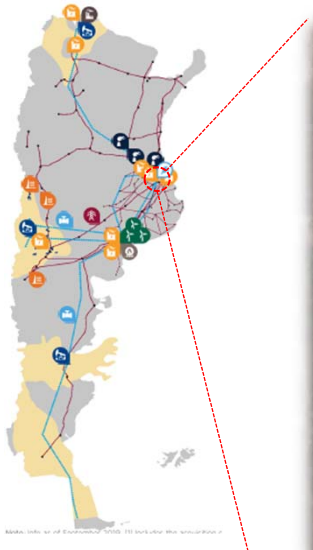

Note: (1) Source: Cammesa. igencotrusts such as FONINVEMEM are considered as gov't owned. As of December 2019. (2) Considers PEMC wind farm with 100 MW operated by Pampa, 50% equity ownership. (3) It includes CTEB plant with 567 MW acquired in May 2019 and operated by Pampa (50% equity ownership). (4) 383 MW awarded through thermal tender (of which 207 MW is commissioned on June 2019), 280 MW of expansions at CTEB and 15 MW under receivables swap capacity program signed in 2014. (4) Remunerated under Res. 1/19. (5) Under PPAs or contracts. (6) As of August 2019.

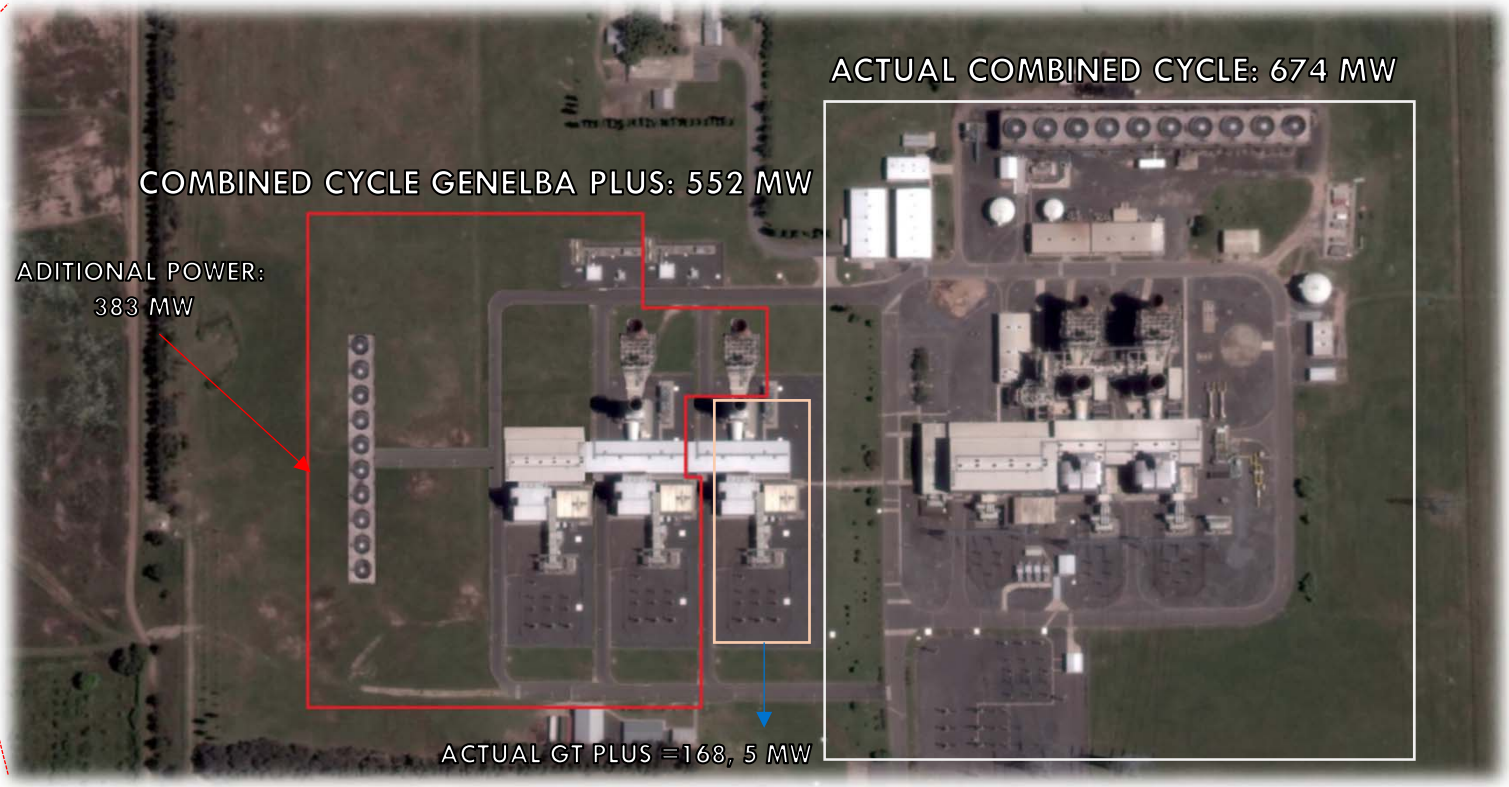
# Working together: IT&OT

- Preparing for the future: Digital Transformation
- Convergence of Information technology and Operational Technology is about a new way of thinking
- Benefits:
  - Cyber Security
  - Synergy in Specific Skills (Networking, Industrial Processes, Sensors, Analytics, Data Management)
  - Data Governance Practices

# Introduction to Genelba

Near Future Installed Power 1.226 MW





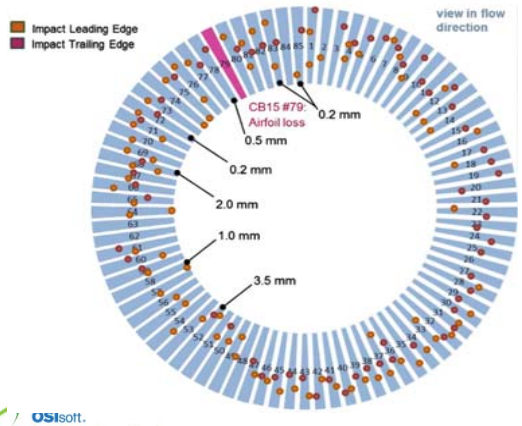
# Business Challenge

Avoid catastrophic failures in the compressors of the Gas Turbines, implementing a predictive maintenance algorithm that allows early detection of a failure in the compressors of the Gas Turbines.

# Background

At 00:33 am on 2018-08-14, an operator detected a compressor bearing casing vibration step change from 2.1 mm/s to 2.8 mm/s occurred. All further bearing casing vibrations, i.e., GT TE, GN TE and GN EE were only slightly affected. As well as a power decrease of approx. 5 MW were reported. **No alarm appeared in the control system**.

Since this operational behavior was unusual for SGT5-4000F units with 17 stage compressor, a shutdown of the unit and a subsequent borescope inspection of the compressor and turbine sections was recommended.





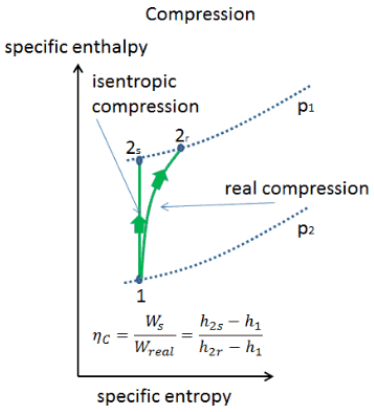
Parte faltante (desprendida),
De diafragma

# Research

From the root cause analysis, the following observations were made based on operational data analysis, i.e., comparison before and after “bearing vibration step change incident”

- **Slight decrease in compressor efficiency (irreversible), two days before the operator detects the fault**

The isentropic efficiency of a compressor is defined as a ratio of energy that would be transmitted in an ideal process to the energy supplied in a real process




$$\eta_{\mathrm{ad_c}} = \frac{\text{Isentropic work}}{\text{Actual work}} = \frac{(h_{2t} - h_{1t})\text{id}}{(h_{2't} - h_{1t})\text{act}}$$

$$\eta_{\mathrm{ad_c}} = \left[\left(\frac{P_{2t}}{P_{1t}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \Big/ \left[\frac{T_{2t}}{T_{1t}} - 1\right]$$

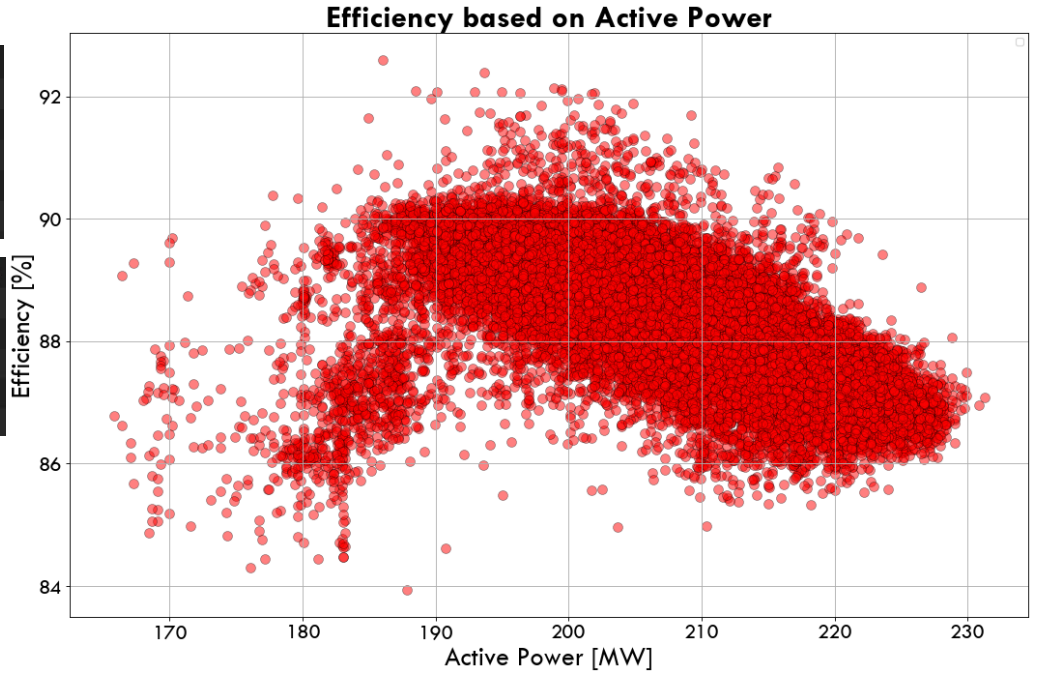
# Research

Using Python with Pandas, and data coming from PI Data Archive all efficiency values were calculated for the year 2018 and expressed according to the Active Power of the GT:

| Tiempo | Mes | Eficiencia | Potencia | DP_Filtro | P1 | P2_a | P2_b | P2_c | T1 | T2 | vIGV_Pos |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018-01-02 20:00:00 | 1.0 | 89.0732 | 166.406 | 1.20116 | 1000.83 | 12.9684 | 13.2496 | 13.1689 | 28.5409 | 386.2 | 45.3627 |
| 2018-01-02 20:05:00 | 1.0 | 90.5333 | 186.198 | 1.32044 | 1000.88 | 14.0311 | 14.3148 | 14.2222 | 28.4834 | 395 | 71.4004 |
| 2018-01-02 20:10:00 | 1.0 | 90.6614 | 202.827 | 1.5629 | 1000.94 | 15.0291 | 15.3149 | 15.2067 | 28.426 | 407.2 | 102.199 |
| 2018-01-02 20:15:00 | 1.0 | 89.8419 | 201.953 | 1.55562 | 1000.99 | 14.974 | 15.2724 | 15.1702 | 28.3685 | 409.8 | 102.199 |
| 2018-01-02 20:20:00 | 1.0 | 89.7579 | 201.758 | 1.54833 | 1001.04 | 14.9839 | 15.2736 | 15.1891 | 28.2977 | 410.1 | 102.199 |

| Tiempo | Mes | Eficiencia | Potencia | DP_Filtro | P1 | P2_a | P2_b | P2_c | T1 | T2 | vIGV_Pos |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018-12-31 23:35:00 | 12.0 | 88.9698 | 205.215 | 1.93068 | 1008.25 | 15.0581 | 15.3673 | 15.3053 | 21.3287 | 397.737 | 85.3375 |
| 2018-12-31 23:40:00 | 12.0 | 89.0031 | 205.273 | 1.92566 | 1008.27 | 15.0684 | 15.3785 | 15.3094 | 21.2966 | 397.632 | 85.7728 |
| 2018-12-31 23:45:00 | 12.0 | 88.9579 | 206.771 | 1.92064 | 1008.3 | 15.0852 | 15.3835 | 15.3509 | 21.2645 | 398 | 86.4689 |
| 2018-12-31 23:50:00 | 12.0 | 89.0986 | 206.699 | 1.91562 | 1008.32 | 15.1173 | 15.4248 | 15.3528 | 21.2324 | 397.665 | 87.6462 |
| 2018-12-31 23:55:00 | 12.0 | 89.2341 | 207.533 | 1.91059 | 1008.34 | 15.1584 | 15.4622 | 15.4168 | 21.2003 | 397.627 | 89.1577 |

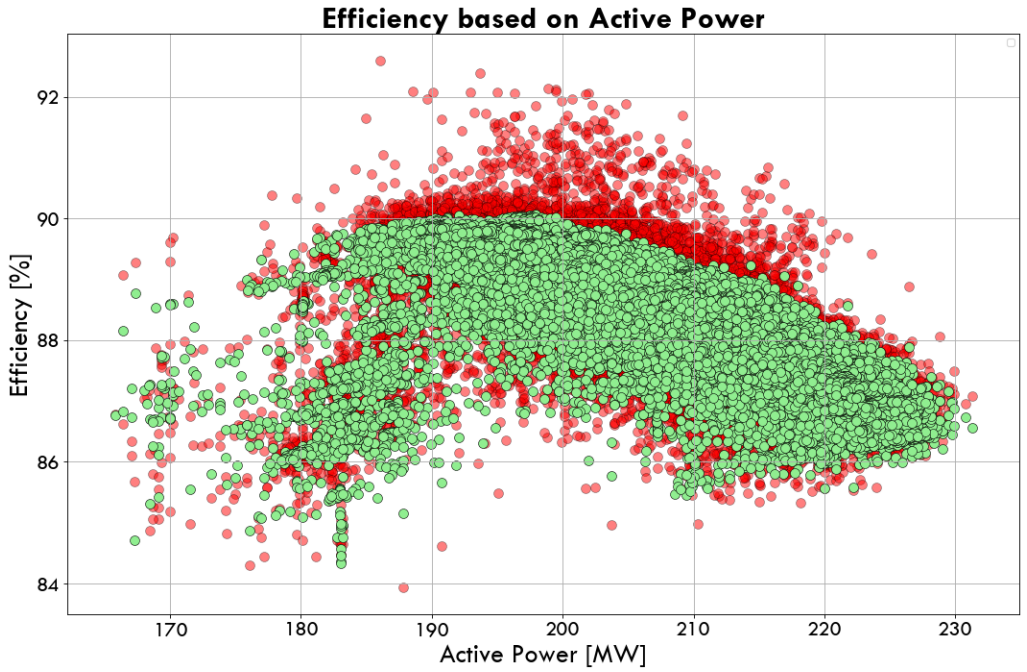
105.119 Samples
Ts = 5 min



# Research

Using Polynomial Features and Multivariable Linear Regression models, efficiency can be expressed as a function of Active Power, Compressor Inlet Temperature and Inlet Pressure [degree=2].

```
from sklearn.preprocessing import PolynomialFeatures
from sklearn import linear_model
from sklearn.model_selection import train_test_split

X = df_sin_falla[['Potencia','T1','P1']].values.reshape(-1,3)
Y = df_sin_falla.iloc[:, 2].values.reshape(-1, 1)

poly = PolynomialFeatures(degree=2)
poly_variables = poly.fit_transform(X)

poly_var_train,poly_var_test,res_train,res_test = train_test_split(
    poly_variables, Y, test_size = 0.3, random_state = 4)

regression = linear_model.LinearRegression()

model = regression.fit(poly_var_train, res_train)
score = model.score(poly_var_test, res_test)

print('Intercept: \n', regression.intercept_)
print('Coefficients: \n', regression.coef_)
print('R: \n', score)
```

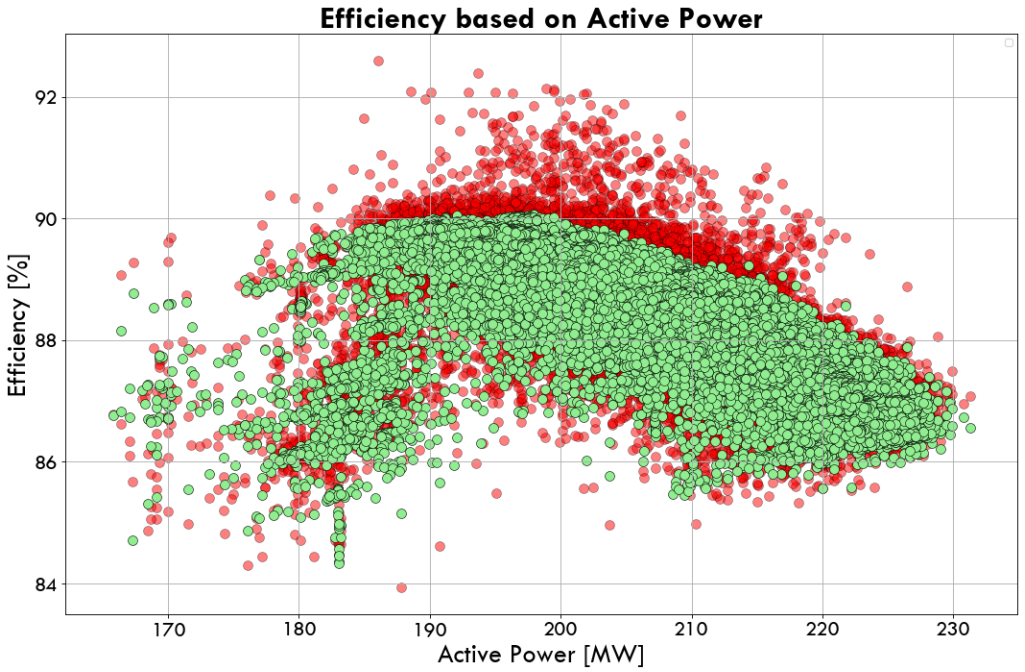


# Research

Using Polynomial Features and Multivariable Linear Regression models, efficiency can be expressed as a function of Active Power, Compressor Inlet Temperature and Inlet Pressure [degree=2].

```
*** Model Results: ***

----------------------

Intercept:
 [-304.69383815]

Coefficients:
 [[ 0.00000000e+00]
 [ 8.46390982e-01]
 [ 1.98102215e+00]
 [ 5.62823653e-01]
 [-1.26449258e-04]
 [-9.01145032e-04]
 [-7.28169703e-04]
 [-3.92654105e-03]
 [-1.47317064e-03]
 [-1.93179675e-04]]

Score (R):
 0.8689726078725302
```

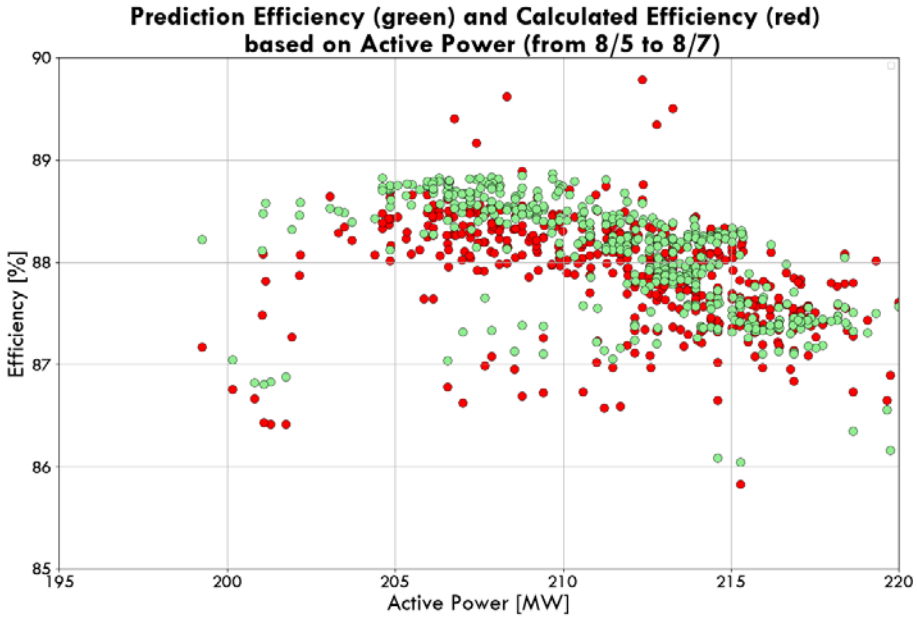
- 70% of the data were used to calculate the model and 30% to evaluate it.
- The green dots show the predictions for the year 2018.
- Approximation of first order was tested, but it was discarded since they failed in Active Powers around of 190 MW.
- The score of the model is 87 %



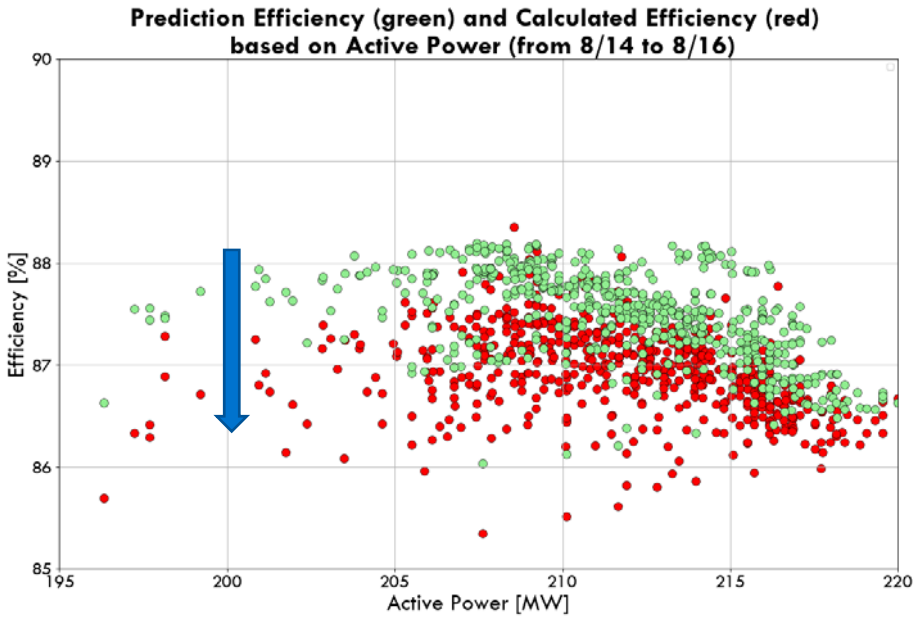
# Research

As can be seen, in the days before the failure, the model coincided with the calculations (left image). Since 14/08, the calculated efficiency decreases, departing from the efficiency of the model (right image).

Before Failure



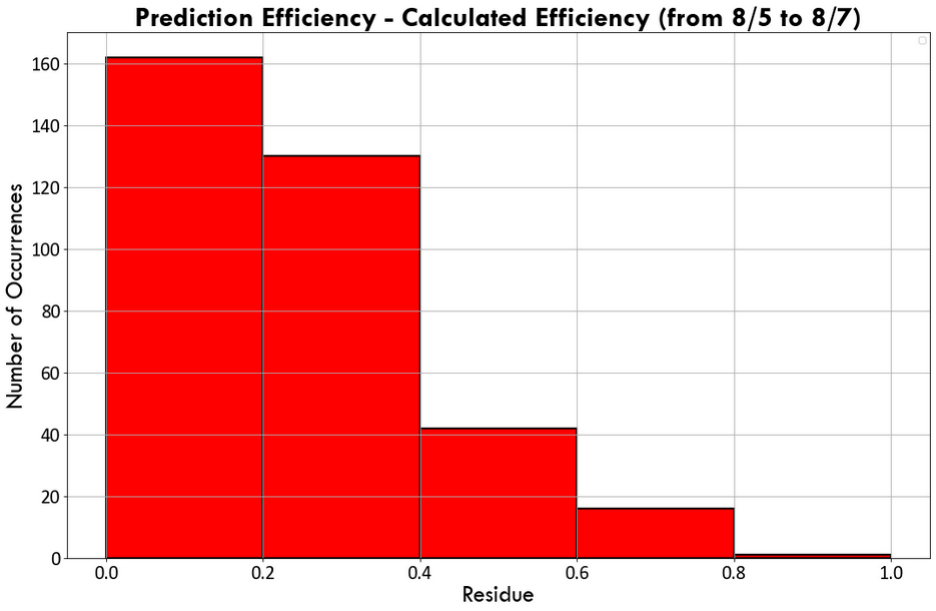

After Failure



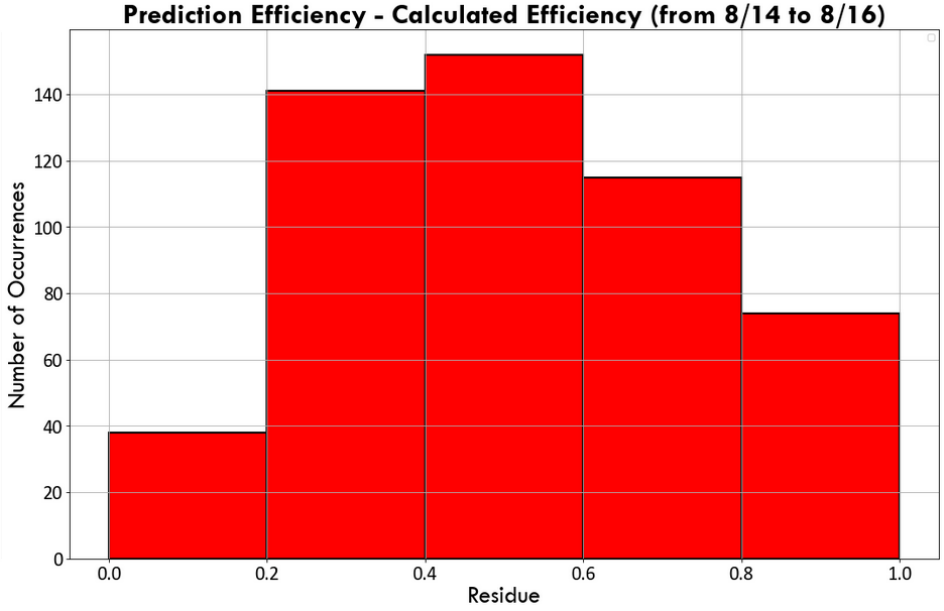
# Research

Calculating the histograms for the two situations mentioned above, a shift to the right is observed (more points exceeding a 0.4% difference between Prediction Efficiency - Calculated Efficiency)

Before Failure




After Failure



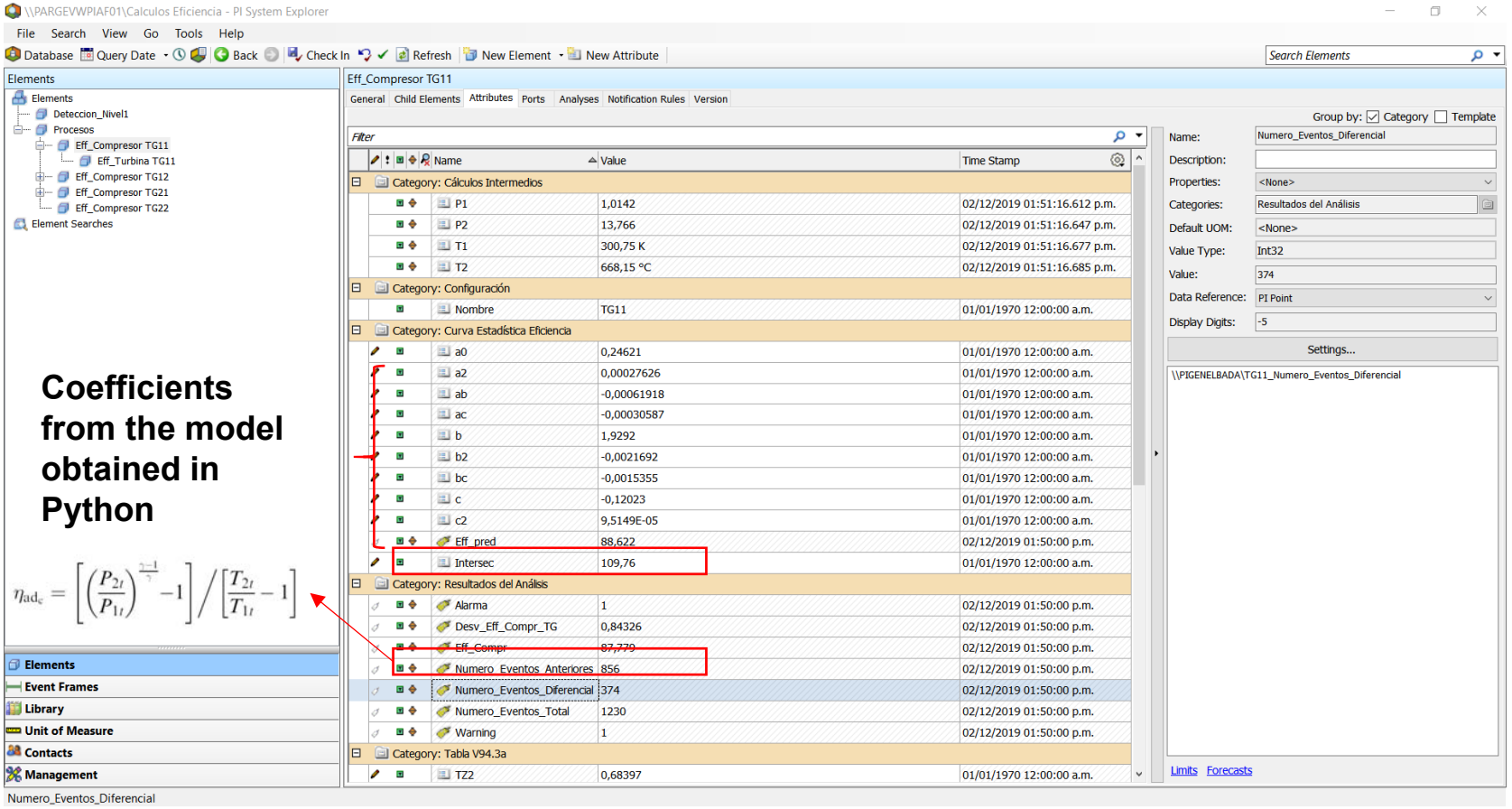
# Applications and Use Case / How the PI System was Applied

**The next questions are:**

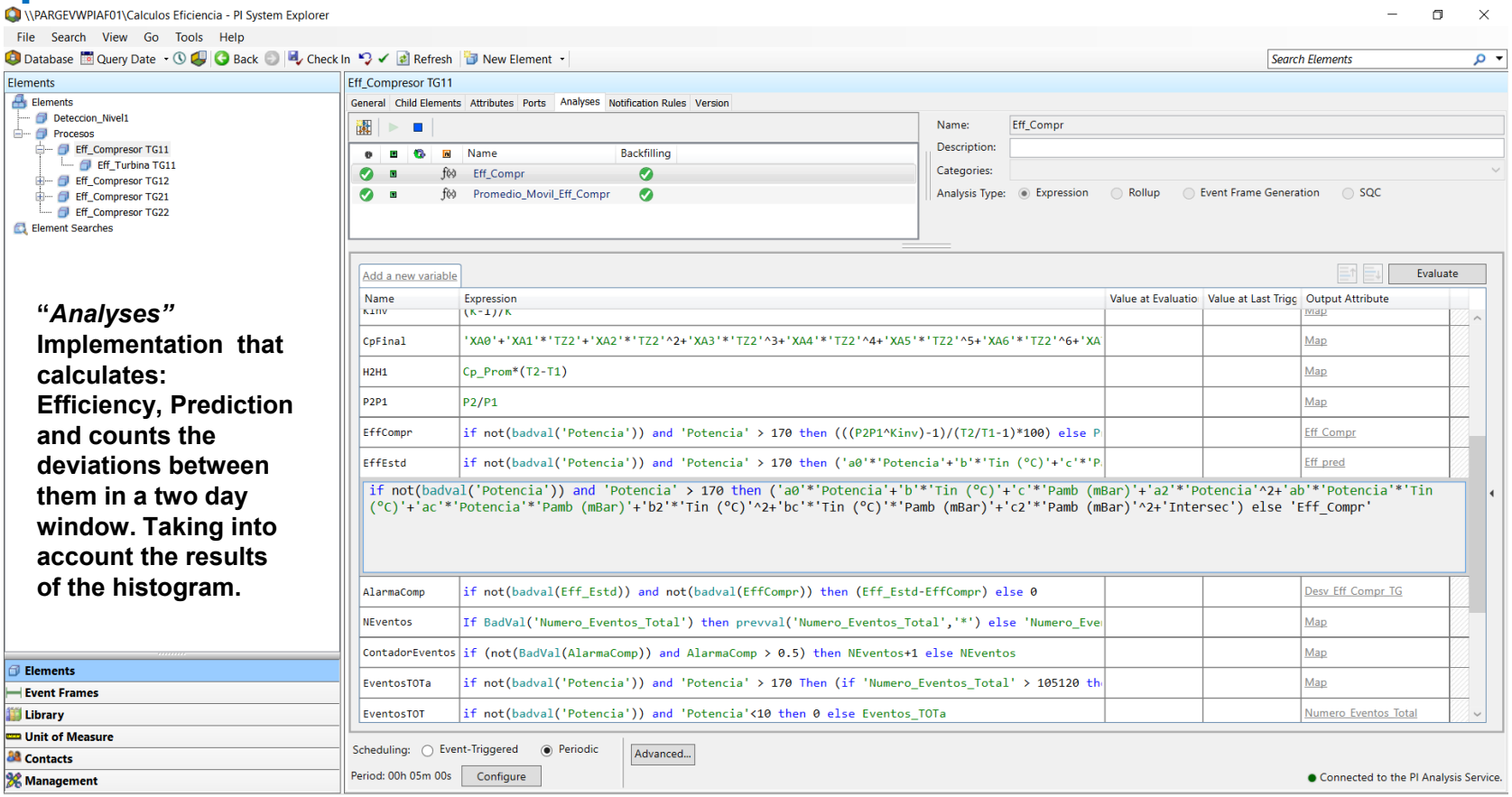
How can we capitalize on what we have learned?
What can we do so that a failure of this type does not happen again?

**The answer:**

# Implementation Details



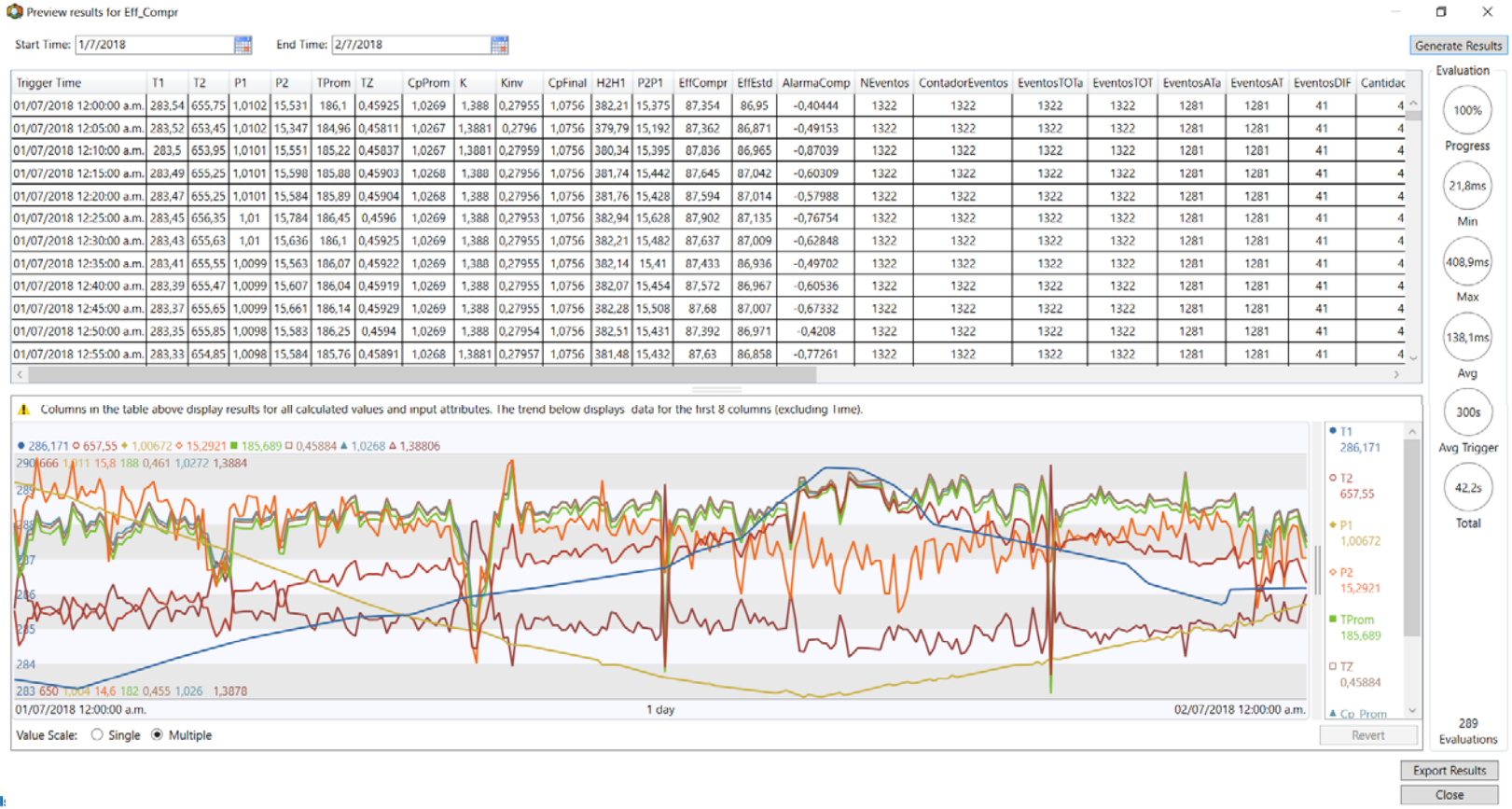
# Implementation Details



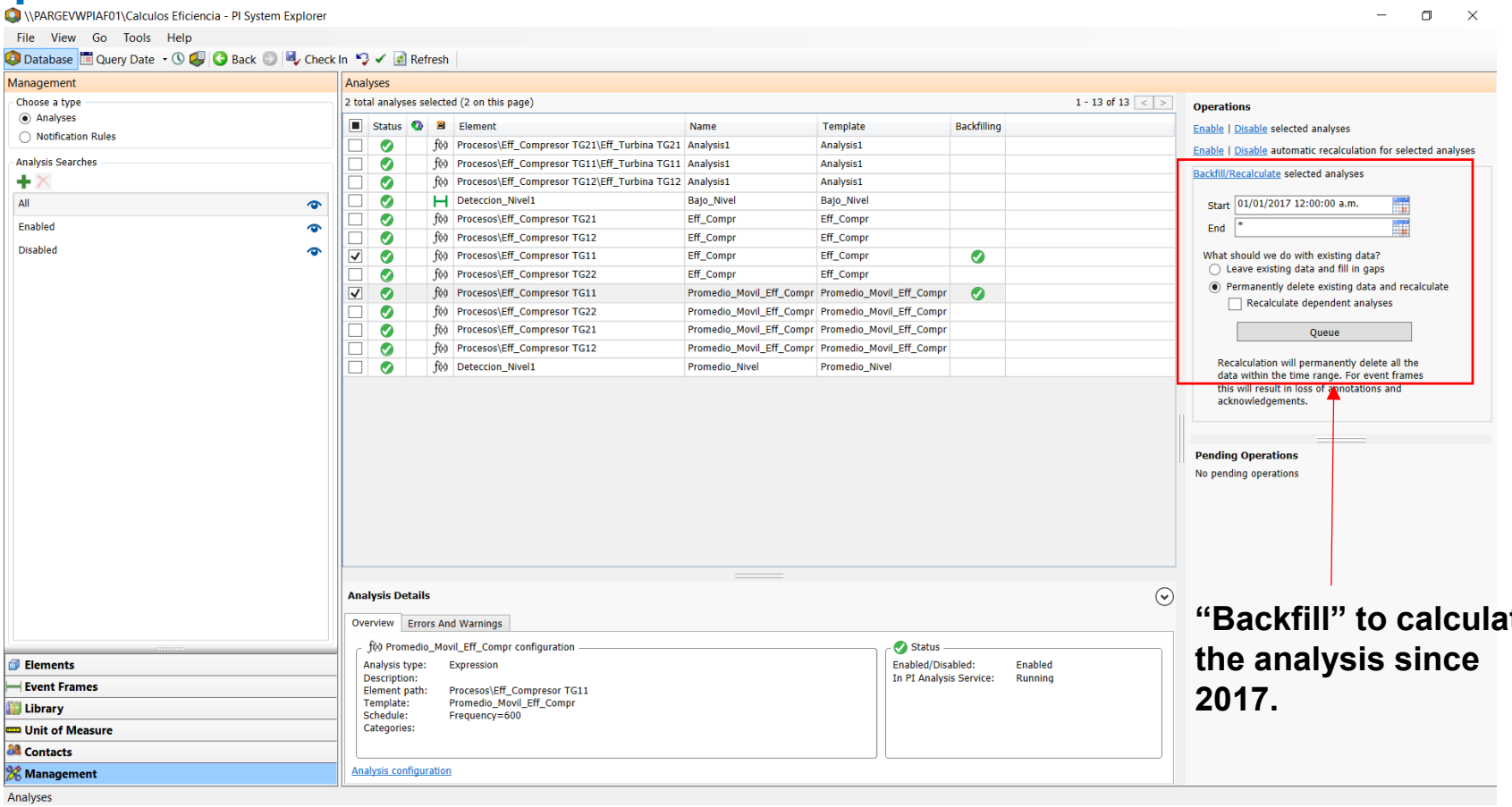

**"*Analyses*" Implementation that calculates: Efficiency, Prediction and counts the deviations between them in a two day window. Taking into account the results of the histogram.**

# Implementation Details

**“Preview Results”: It allows us to evaluate the behavior of the analysis developed.**

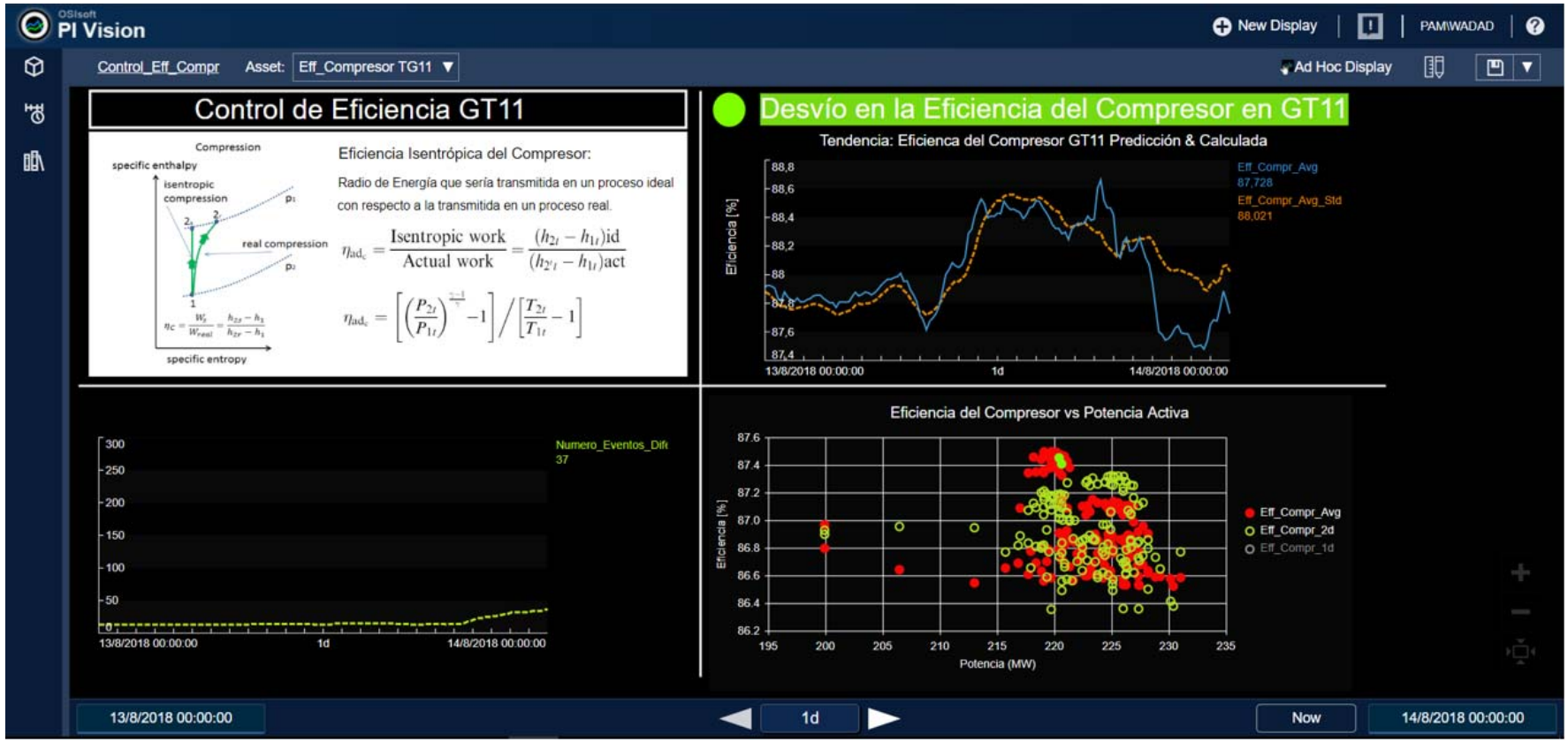


# Implementation Details

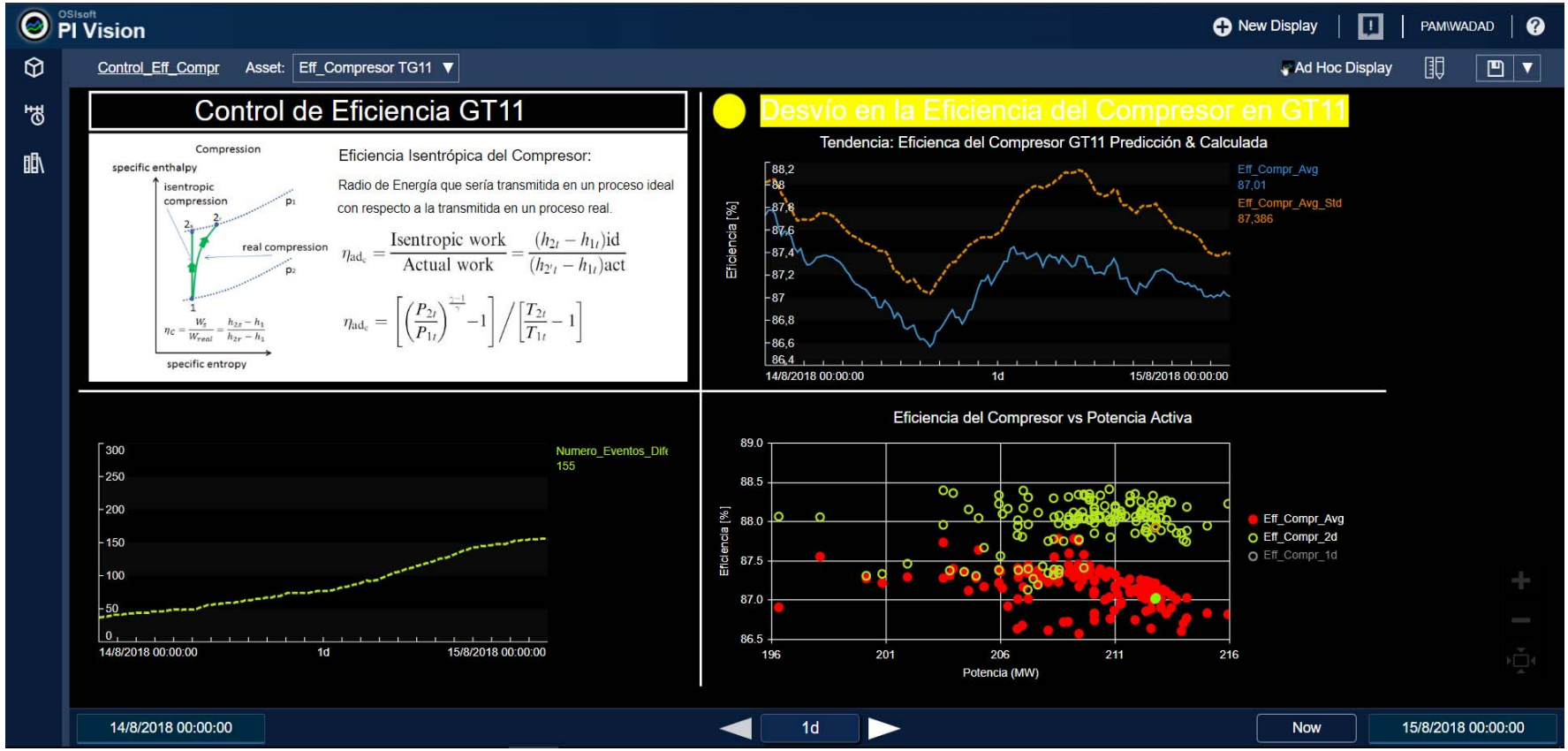



**“Backfill” to calculate the analysis since 2017.**

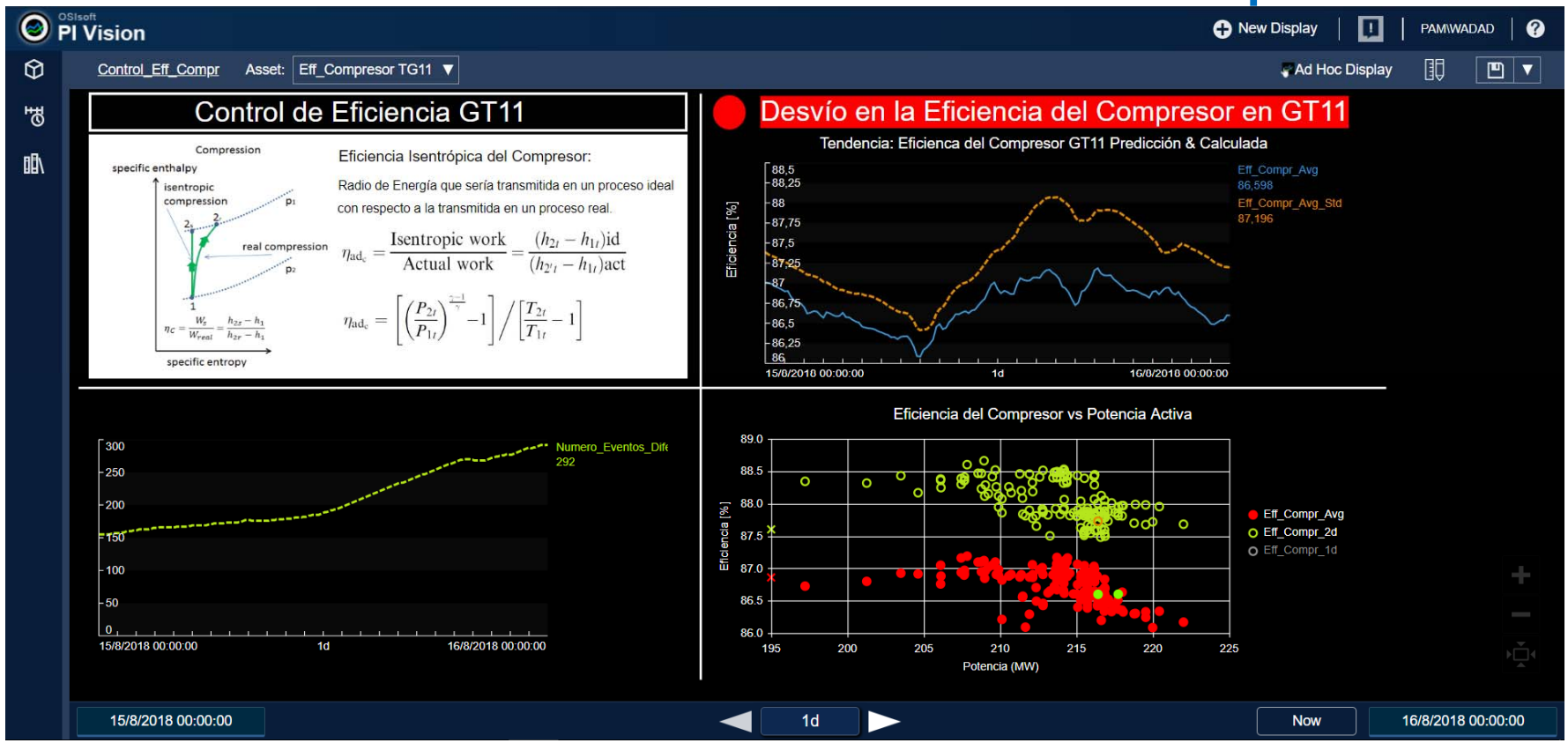
# Results Obtained and Business Impact



# Results Obtained and Business Impact



# Results Obtained and Business Impact



# Conclusions

Throughout this work, the technologist's experience could be capitalized, implementing a predictive algorithm that allows us to:

- Provide the Operations sector with a tool that complements the control system and helps them to make better decisions.
- Detect failures in the turbine compressor in advance.
- **Avoid losses of MM$,** due to catastrophic failures.

# PdM on Gas Turbine Compressor

Pampa energía

## CHALLENGES

- Avoid catastrophic failures in the compressors of outs Gas Turbines.

## SOLUTION

- Using PI AF and PI Vision we could implement a predictive maintenance algorithm that allows early detection of a failure in the compressors of the Gas Turbines.

## BENEFITS

- Provide the Operations sector with a tool that complements the control system and helps them to make better decisions.
- Detect failures in the turbine compressor in advance.
- **Avoid losses of MM$,** due to catastrophic failures.

> We developed an algorithm that allows us to detect failures in advance in our gas turbines, anticipating catastrophic situations. We are working on extending this solution to the rest of our company's assets.

# Contact Information



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# Questions?

Please wait for
the **microphone**

State your
**name & company**

## Save the Date...


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October 26-29, 2020

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