



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

Transmission

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

Distribution

Control of **edenor**
19% market share

OIL & GAS



Upstream

Leading producer
6% market share












Midstream

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

Petrochemicals

80-100% market share

Other affiliates

	Thermal	3,607 MW + 471 MW expansions ⁽¹⁾
	Hydro	938 MW
	Wind farms	206 MW ⁽²⁾
	HV Lines	20,933 km of lines
	Stations	160 transformer stations
	Concession area	3.1 million end users 20 TWh of sales
	Blocks Production	11 Productive + 7 Exploratory 50 kboepd, 90% gas
	Pipelines	9,231 km for natural gas
	NGL	1 million ton per year
	Plants	Styrene (160k ton/year) S. Rubber (55k ton/year) Polystyrene (65k ton/year)
	refinor ⁽³⁾	25.8 kbpd of refining capacity, 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

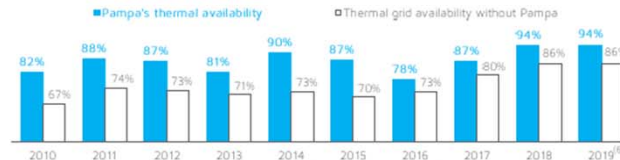
- 3 hydro plants, 938 MW
- 3 wind farms, 206 MW²
- 9 thermal plants, 3,607 MW³

4,751 MW installed capacity
+ 471 MW under construction³

5,222 MW total capacity

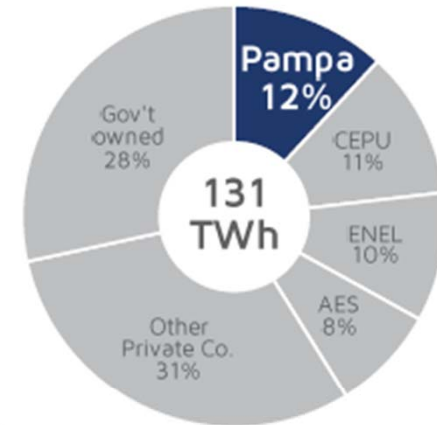


Pampa's Historical Availability v. Peers, in %



Note: (1) Source: Cammesa, genco/trusts such as FONNIVEMEM 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. (5) Under PPAs or contracts. (6) As of August 2019.

Argentina's Power Generation Market Share¹

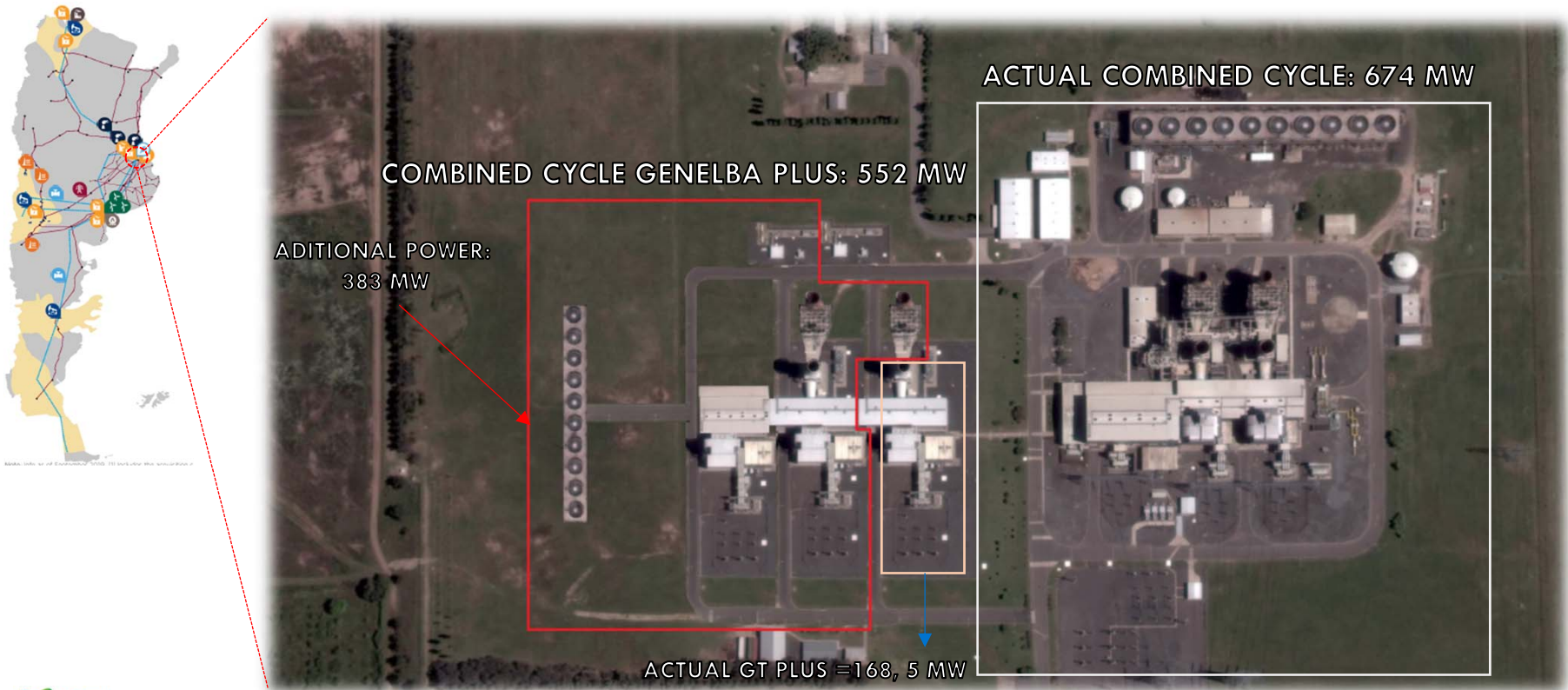


Working together: IT&OT

- 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.

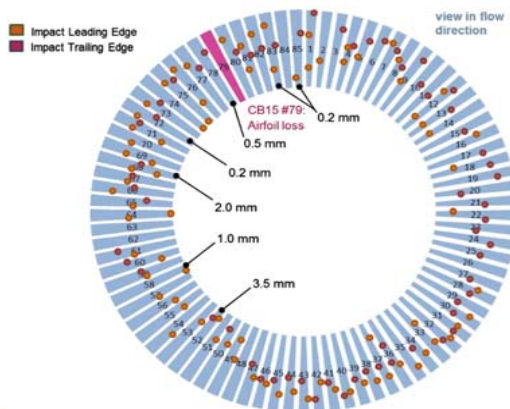
Background

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

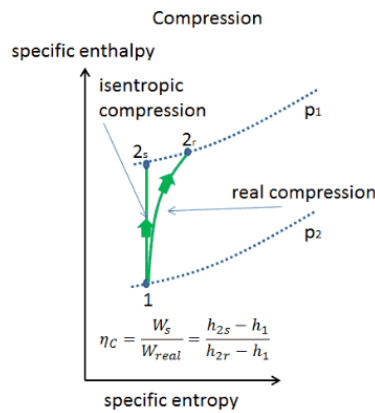


Research

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



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

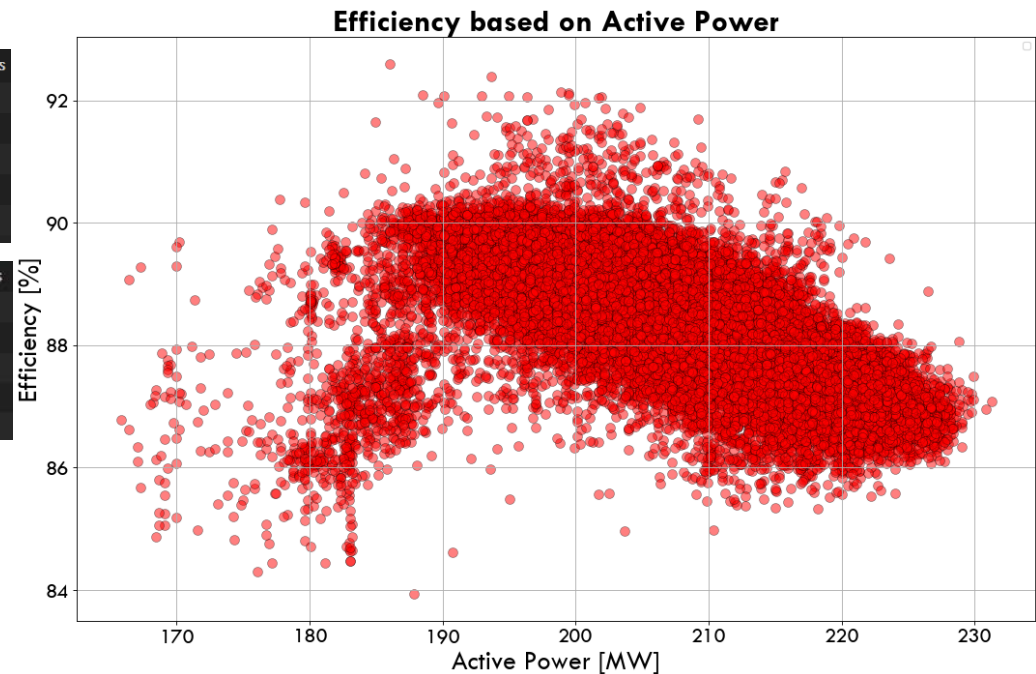
$$\eta_{ad_c} = \left[\left(\frac{P_{2t}}{P_{1t}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] / \left[\frac{T_{2t}}{T_{1t}} - 1 \right]$$

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
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)

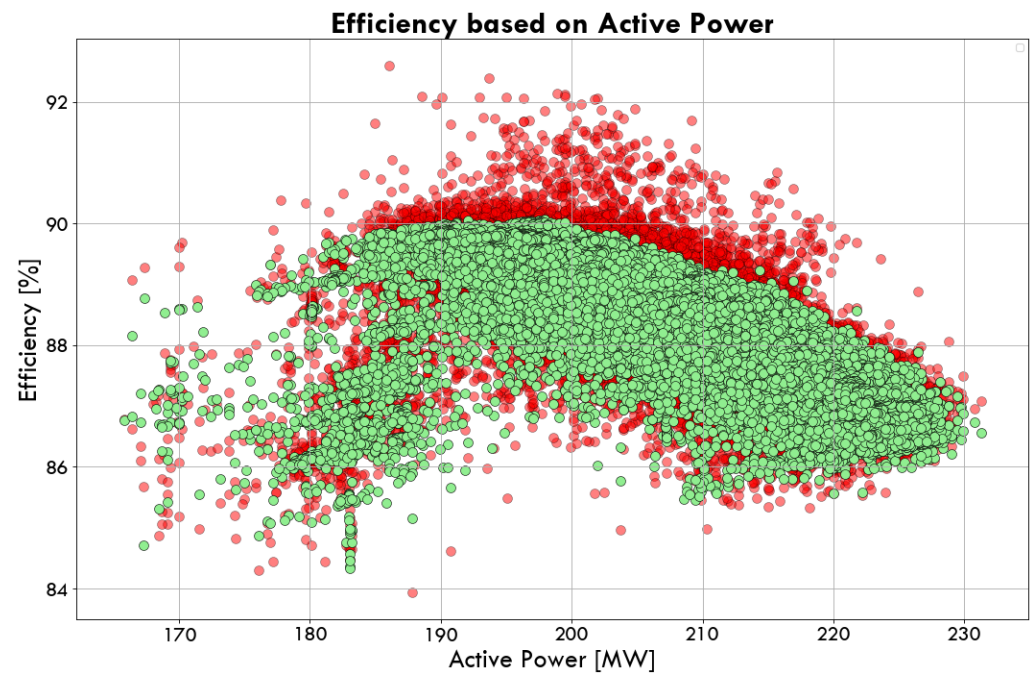
poly = PolynomialFeatures(degree=2)
poly_variables = poly.fit_transform(X)

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].

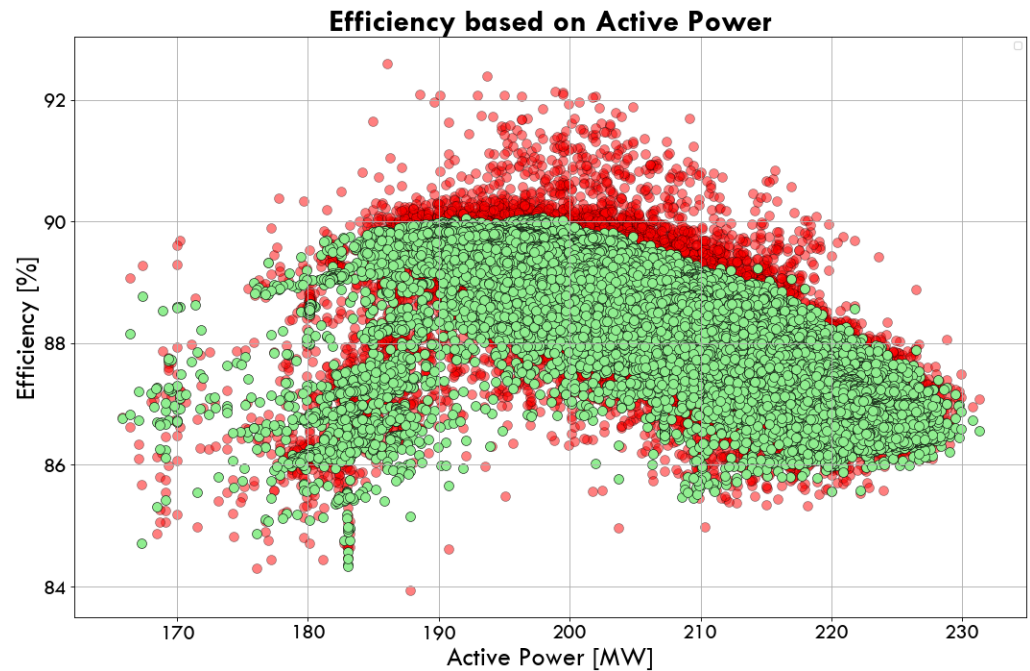
```
*** Model Results: ***
-----

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
```

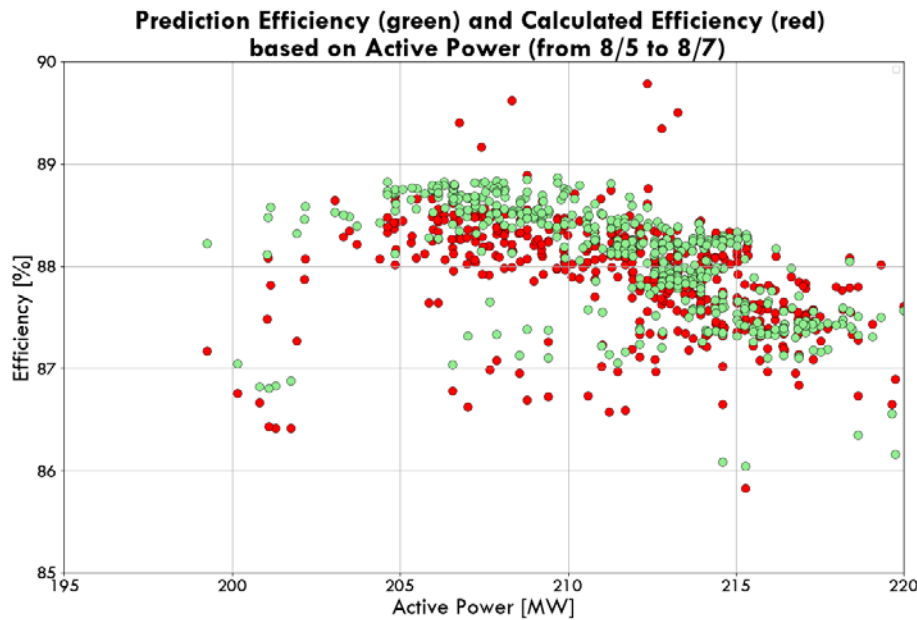
- 70% of the data were used to calculate the model and 30% to evaluate it.
- The green dots show the predictions for the year 2018.
- Approximation of first order was tested, but it was discarded since they failed in Active Powers around of 190 MW.
- The score of the model is 87 %



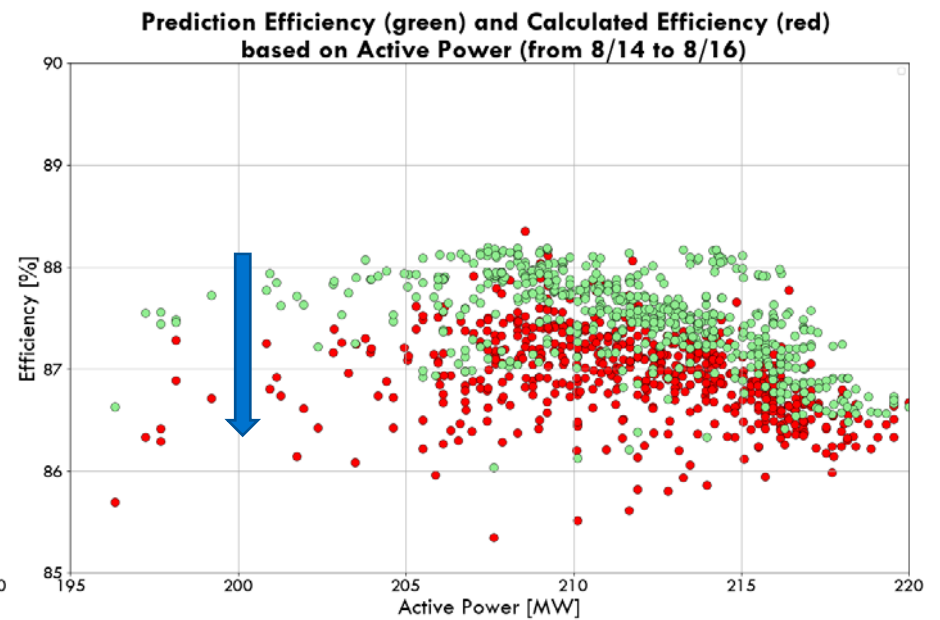
Research

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

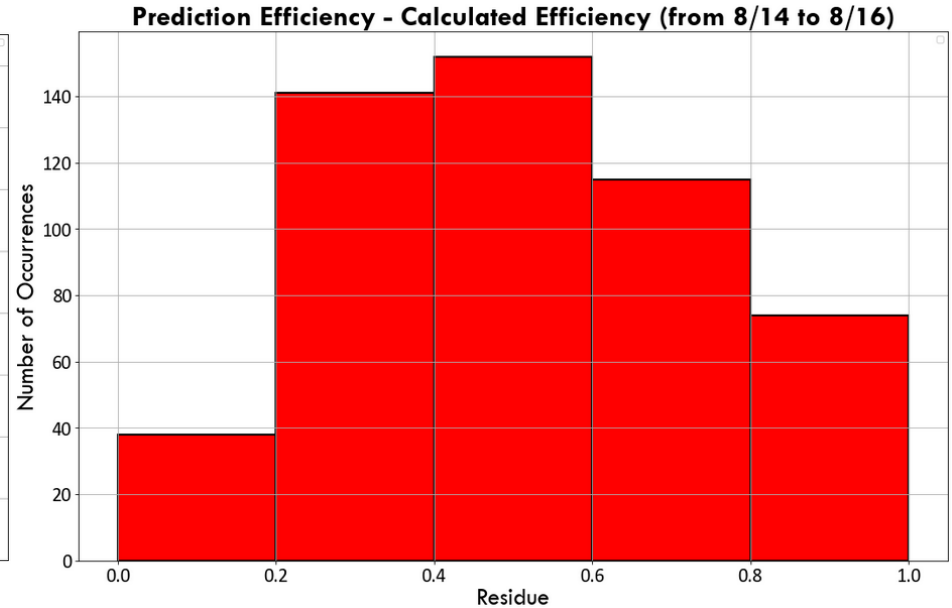
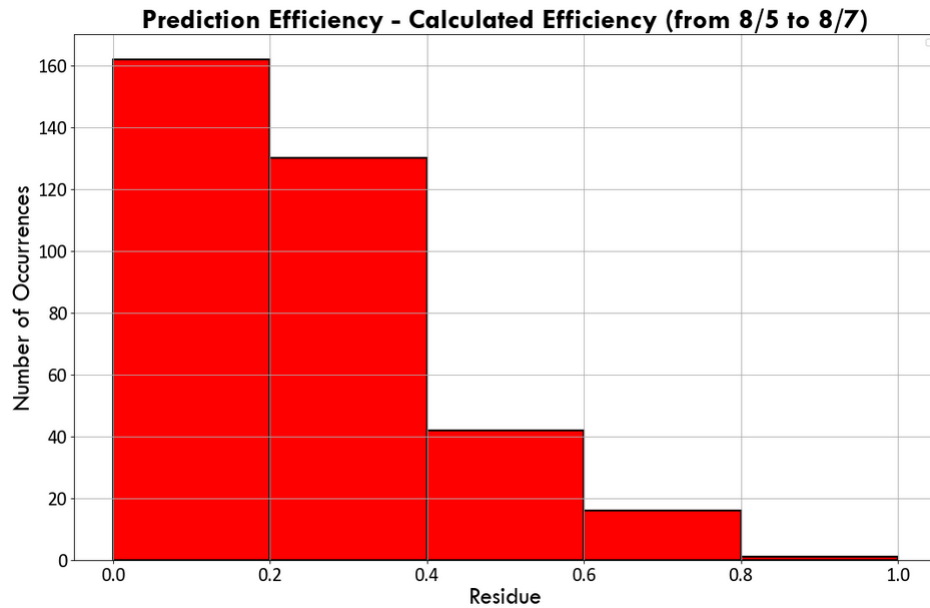


Research

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

\\PARGEVWPIAF01\Cálculos Eficiencia - PI System Explorer

File Search View Go Tools Help
Database Query Date Back Refresh New Element New Attribute Search Elements

Elements

- Elements
 - Deteccion_Nivel1
 - Procesos
 - Eff_Compresor TG11
 - Eff_Turbina TG11
 - Eff_Compresor TG12
 - Eff_Compresor TG21
 - Eff_Compresor TG22
 - Element Searches

Coefficients from the model obtained in Python

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

Eff_Compresor TG11

General Child Elements Attributes Ports Analyses Notification Rules Version

Filter

Name	Value	Time Stamp
Category: Cálculos Intermedios		
P1	1,0142	02/12/2019 01:51:16.612 p.m.
P2	13,766	02/12/2019 01:51:16.647 p.m.
T1	300,75 K	02/12/2019 01:51:16.677 p.m.
T2	668,15 °C	02/12/2019 01:51:16.685 p.m.
Category: Configuración		
Nombre	TG11	01/01/1970 12:00:00 a.m.
Category: Curva Estadística Eficiencia		
a0	0,24621	01/01/1970 12:00:00 a.m.
a2	0,00027626	01/01/1970 12:00:00 a.m.
ab	-0,00061918	01/01/1970 12:00:00 a.m.
ac	-0,00030587	01/01/1970 12:00:00 a.m.
b	1,9292	01/01/1970 12:00:00 a.m.
b2	-0,0021692	01/01/1970 12:00:00 a.m.
bc	-0,0015355	01/01/1970 12:00:00 a.m.
c	-0,12023	01/01/1970 12:00:00 a.m.
c2	9,5149E-05	01/01/1970 12:00:00 a.m.
Eff_pred	88,622	02/12/2019 01:50:00 p.m.
Intersec	109,76	01/01/1970 12:00:00 a.m.
Category: Resultados del Análisis		
Alarma	1	02/12/2019 01:50:00 p.m.
Desv_Eff_Compr_TG	0,84326	02/12/2019 01:50:00 p.m.
Eff_Compr	87,779	02/12/2019 01:50:00 p.m.
Numero_Eventos_Anteriores	856	02/12/2019 01:50:00 p.m.
Numero_Eventos_Diferencial	374	02/12/2019 01:50:00 p.m.
Numero_Eventos_Total	1230	02/12/2019 01:50:00 p.m.
Warning	1	02/12/2019 01:50:00 p.m.
Category: Tabla V94.3a		
T22	0,68397	01/01/1970 12:00:00 a.m.

Properties: Numero_Eventos_Diferencial

Settings...
\\PIGENLBADA\TG11_Numero_Eventos_Diferencial

Numero_Eventos_Diferencial

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.

The screenshot shows the PI System Explorer interface for the element 'Eff_Compr TG11'. The 'Analyses' tab is active, displaying a table of variables and their corresponding expressions. The 'Name' column lists variables like 'K_inv', 'Cp_Final', 'H2H1', 'P2P1', 'EffCompr', 'EffEstd', 'AlarmaComp', 'NEventos', 'ContadorEventos', 'EventosTOTa', and 'EventosTOT'. The 'Expression' column contains the logic for each variable, such as $\frac{1}{K-1}$ for K_inv and a complex formula for EffCompr involving 'Potencia' and 'T2-T1'. The 'Output Attribute' column shows the mapped output for each variable, such as 'Map' or 'Desv. Eff. Compr. TG'. The interface also includes a 'Scheduling' section with 'Event-Triggered' and 'Periodic' options, and a 'Configuration' button.

Name	Expression	Value at Evaluation	Value at Last Trigg	Output Attribute
K_inv	$\frac{1}{K-1}$			Map
Cp_Final	'XA0'+ 'XA1'*'T22'+ 'XA2'*'T22'^2+ 'XA3'*'T22'^3+ 'XA4'*'T22'^4+ 'XA5'*'T22'^5+ 'XA6'*'T22'^6+ 'XA			Map
H2H1	Cp_Prom*(T2-T1)			Map
P2P1	P2/P1			Map
EffCompr	if not(badval('Potencia')) and 'Potencia' > 170 then (((P2P1^K_inv)-1)/(T2/T1-1)*100) else P			Eff_Compr
EffEstd	if not(badval('Potencia')) and 'Potencia' > 170 then ('a0'*Potencia+'b'*Tin (°C)+'c'*P. (°C)+'ac'*Potencia*'Pamb (mBar)+'b2'*Tin (°C)^2+bc'*Tin (°C)*'Pamb (mBar)+'c2'*Pamb (mBar)^2+Intersec') else 'Eff_Compr'			Eff_pred
AlarmaComp	if not(badval(Eff_Estd)) and not(badval(EffCompr)) then (Eff_Estd-EffCompr) else 0			Desv. Eff. Compr. TG
NEventos	If BadVal('Numero_Eventos_Total') then prevval('Numero_Eventos_Total','*') else 'Numero_Eve			Map
ContadorEventos	if (not(BadVal(AlarmaComp)) and AlarmaComp > 0.5) then NEventos+1 else NEventos			Map
EventosTOTa	if not(badval('Potencia')) and 'Potencia' > 170 Then (if 'Numero_Eventos_Total' > 105120 th			Map
EventosTOT	if not(badval('Potencia')) and 'Potencia' < 10 then 0 else Eventos_TOTa			Numero_Eventos_Total

Implementation Details

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



Implementation Details

\\PARGEVWPIAF01\Calculos Eficiencia - PI System Explorer

File View Go Tools Help

Database Query Date Back Check In Refresh

Management

Choose a type

- Analyses
- Notification Rules

Analysis Searches

All

Enabled

Disabled

Analyses

2 total analyses selected (2 on this page) 1 - 13 of 13

Status	Element	Name	Template	Backfilling
<input type="checkbox"/>	Procesos\Eff_Compresor TG21\Eff_Turbina TG21	Analysis1	Analysis1	
<input type="checkbox"/>	Procesos\Eff_Compresor TG11\Eff_Turbina TG11	Analysis1	Analysis1	
<input type="checkbox"/>	Procesos\Eff_Compresor TG12\Eff_Turbina TG12	Analysis1	Analysis1	
<input type="checkbox"/>	Deteccion_Nivel1	Bajo_Nivel	Bajo_Nivel	
<input type="checkbox"/>	Procesos\Eff_Compresor TG21	Eff_Cmpr	Eff_Cmpr	
<input type="checkbox"/>	Procesos\Eff_Compresor TG12	Eff_Cmpr	Eff_Cmpr	
<input checked="" type="checkbox"/>	Procesos\Eff_Compresor TG11	Eff_Cmpr	Eff_Cmpr	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Procesos\Eff_Compresor TG22	Eff_Cmpr	Eff_Cmpr	
<input checked="" type="checkbox"/>	Procesos\Eff_Compresor TG11	Promedio_Movil_Eff_Cmpr	Promedio_Movil_Eff_Cmpr	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Procesos\Eff_Compresor TG22	Promedio_Movil_Eff_Cmpr	Promedio_Movil_Eff_Cmpr	
<input type="checkbox"/>	Procesos\Eff_Compresor TG21	Promedio_Movil_Eff_Cmpr	Promedio_Movil_Eff_Cmpr	
<input type="checkbox"/>	Procesos\Eff_Compresor TG12	Promedio_Movil_Eff_Cmpr	Promedio_Movil_Eff_Cmpr	
<input type="checkbox"/>	Deteccion_Nivel1	Promedio_Nivel	Promedio_Nivel	

Operations

Enable | Disable selected analyses

Enable | Disable automatic recalculation for selected analyses

Backfill/Recalculate selected analyses

Start: 01/01/2017 12:00:00 a.m.

End: *

What should we do with existing data?

- Leave existing data and fill in gaps
- Permanently delete existing data and recalculate
- Recalculate dependent analyses

Queue

Recalculation will permanently delete all the data within the time range. For event frames this will result in loss of annotations and acknowledgements.

Pending Operations

No pending operations

Analysis Details

Overview Errors And Warnings

Promedio_Movil_Eff_Cmpr configuration

Analysis type: Expression

Description:

Element path: Procesos\Eff_Compresor TG11

Template: Promedio_Movil_Eff_Cmpr

Schedule: Frequency=600

Categories:

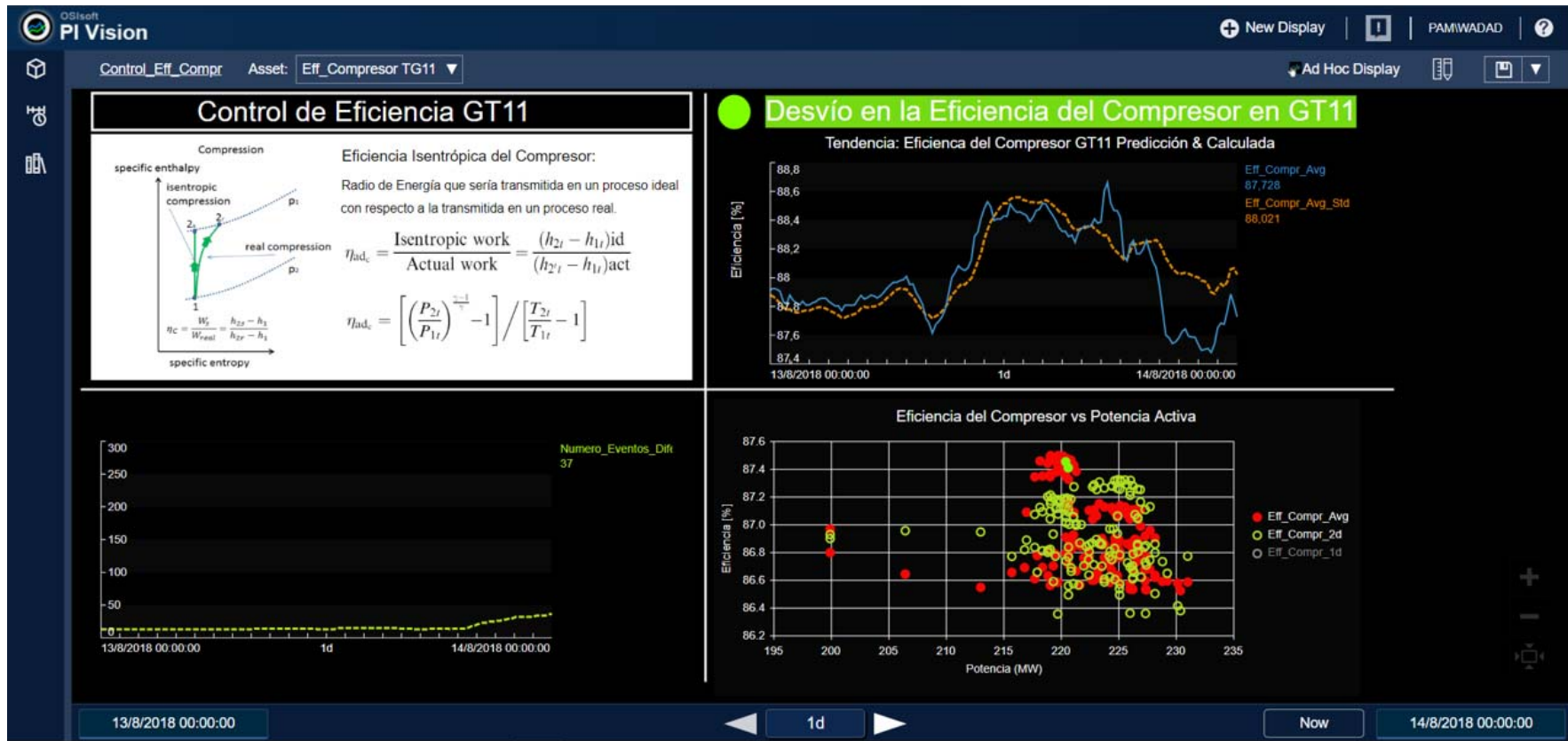
Status

Enabled/Disabled: Enabled

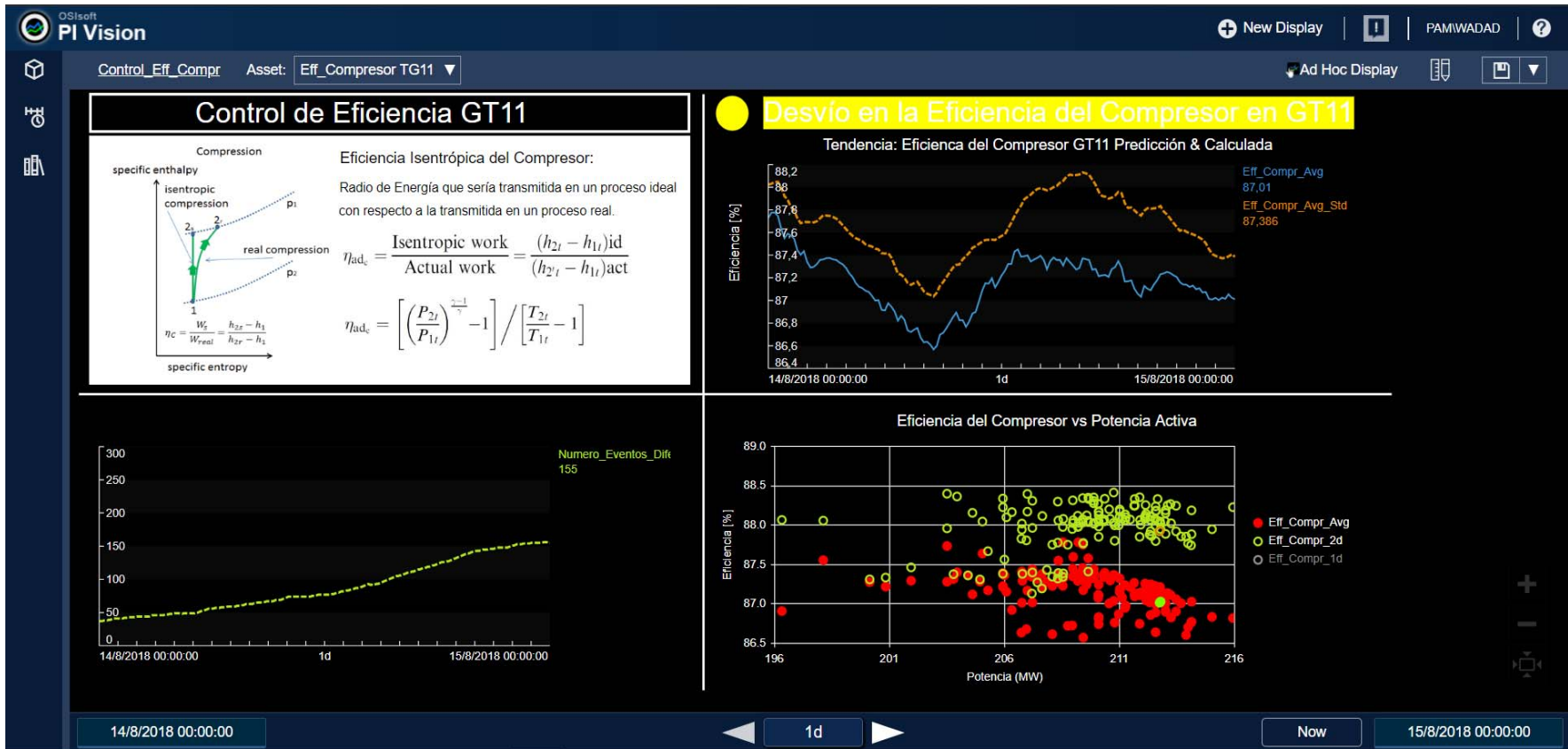
In PI Analysis Service: Running

“Backfill” to calculate the analysis since 2017.

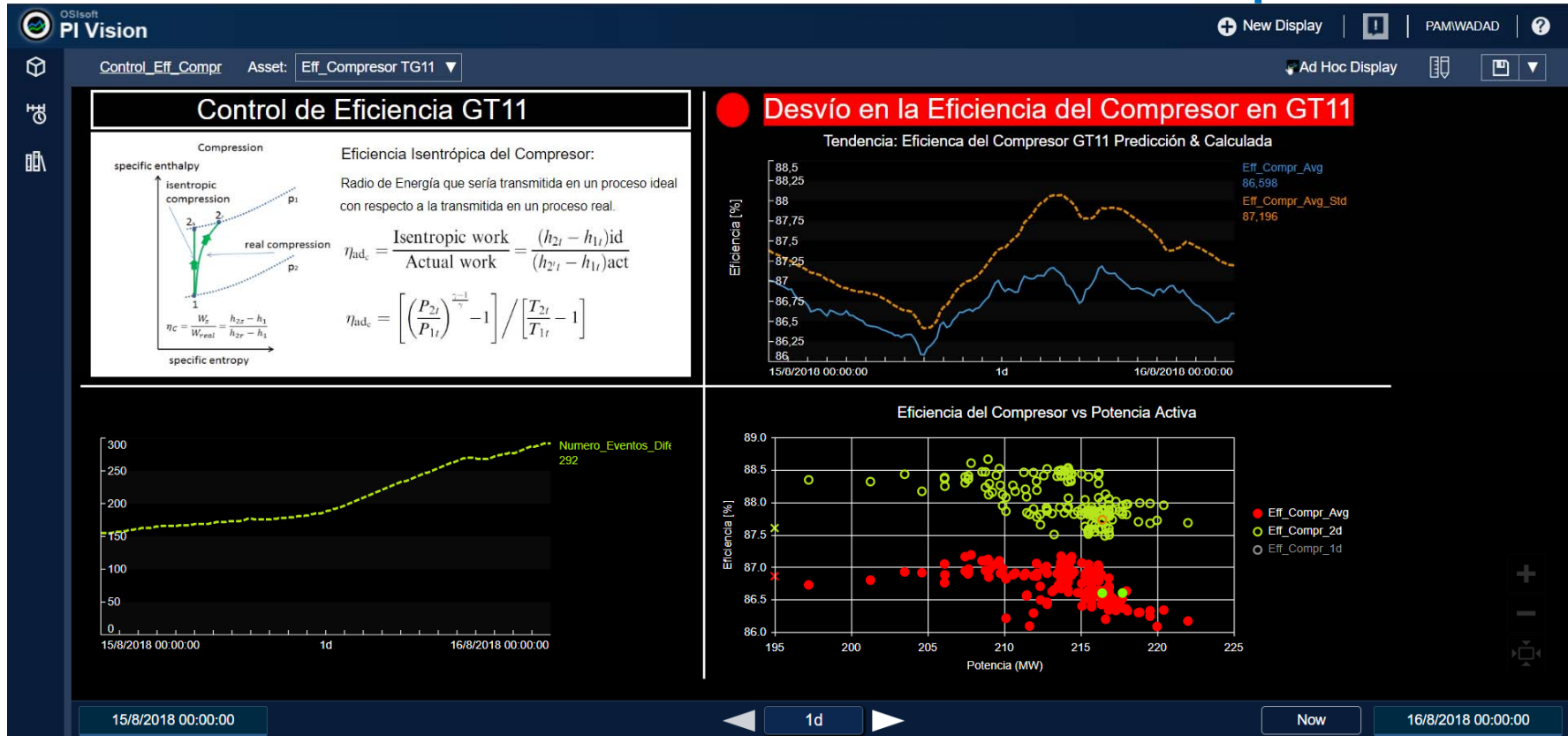
Results Obtained and Business Impact



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

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...



AMSTERDAM
October 26-29, 2020



