From on-site performance testing to digital twin performance monitoring. EDF's experience.

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Abstract. In this article a digital energy performance twin of hydraulic power plants is presented and the manner of how it is used to create a monitoring of the energy performance on EDF's French hydro power plants is detailed. Examples of incident detection are also presented.

1. Introduction

Since its creation, EDF has carried out energy performance tests on its hydroelectric power plants.

These measurements of unit's efficiency and of head losses in the tunnels & penstocks make it possible the construction of a digital energy twin of each power plant for different uses, including the optimization of the production. This twin called "Optimiz" exists for 10 years in EDF. 165 plants have now been modelled and cover 85% of the EDF total installed hydro power.

It was decided to create a new strategic use for this twin by propagating it on the monitored EDF hydraulic data base. It allows to compare the performances calculated by the twin with the data directly monitored on the facilities (or elaborated from these data).

This comparison made it possible to build a new monitoring of energy performance:

- In absolute terms, it is possible to detect, at incipient point, a large number of deoptimizations which need to be treated.
- In relative, it is possible to easily detect a drift of the monitored data compared to the data of the twin which makes it possible to trigger an alert and warn an existing remote monitoring center.

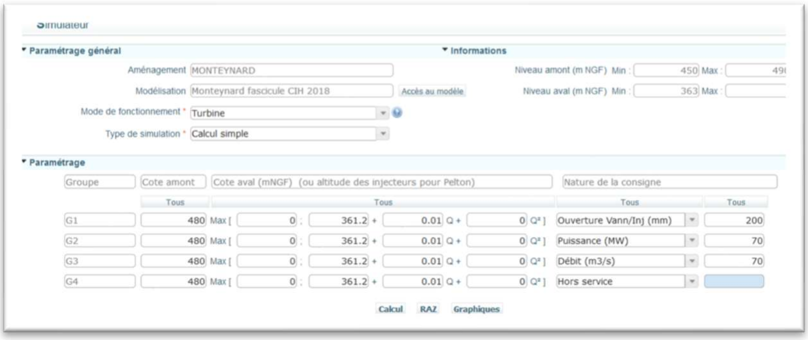
This article outlines this new monitoring of performance and shows some examples of the detection of abnormal operation of the machines.

2. The Digital Twin Optimiz

Principles of the tool were the subject of a previous presentation at IGHEM 2012 [1].

Optimiz is a digital energy twin of hydraulic plants. It is an Intranet tool available on DTG e-monitoring platform since 2012. It allows easy manipulation of Electrical power (MW), Flowrate (m3/s), Head losses (mWC), Energy coefficients (kWh/m3), Efficiency (%), Levels (Upstream, downstream) and heads (net and gross), Openings (Wicket gate/injector, blades) (mm or %).

It is a universal tool suited for all types of turbines (Kaplan, Bulb, Francis, Pelton …), all types of operation regimes (Turbine, pump, Pumped storage power station), complex water ways including intermediate water intakes and complex pressure losses.



Résultat 1 (Calcul simple / Turbine)

Enregistrer | Exporter | RAZ

N°	Groupe	Cote Amont (m)	Cond. Aval	Hb (m)	Hn (m)	Pdc (m)	Ouverture	P (MW)	Q (m^3/s)	η (%)	CE (Kwh/m^3)
1	Aménagement	480.00	363.26	116.75				210.539	205.381	89.56	0.2848
1	G1	480.00	363.26	116.75	115.64	1.11	200.00	68.872	67.113	90.51	0.2851
1	G2	480.00	363.26	116.75	115.60	1.15	203.98	70.000	68.268	90.47	0.2848
1	G3	480.00	363.26	116.75	115.54	1.21	210.18	71.667	70.000	90.38	0.2844

Illustration of the simulator ergonomics

Optimiz is the referent EDF tool to define the use strategy of each plant. In addition to this, it has various uses:

- Define input data for studies and simulations (speed control, …)
- Source for the control system's charts
- Economic evaluation of new projects
- Cam curve reference
- Analysis of Flow inconsistencies

Modeling is based on on-site performance measurement & Pressure loss measurement. A monitoring module allows the comparison between the model and partial but actual data (Power-Openings-Head)

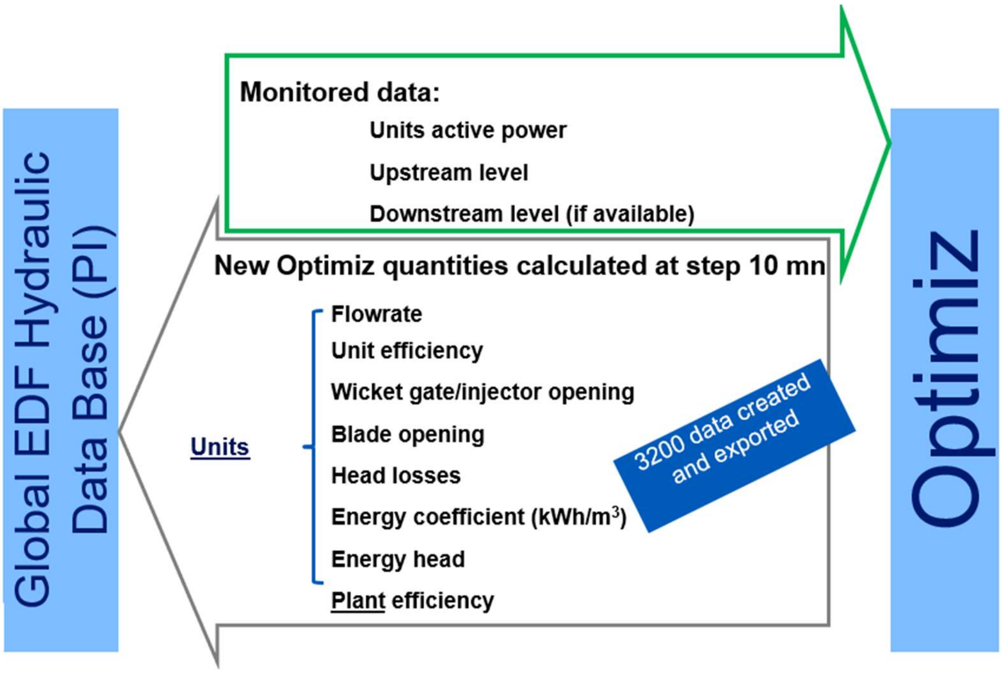
The computing core is constituted of a Newton Raphson matrix iteration.

3. Large-scale implementation of the twin within the Inhouse Data Base

It was decided to propagate the twin data in the global hydraulic data base (PI System) for several reasons:

1. Make available in the global data base the best flowrate data.
2. Make available new types of data: Efficiency and head losses.
3. Create continuous performance monitoring

The technical principle of this implementation is summarized in the diagram below and it is running and calculated every 10mn:



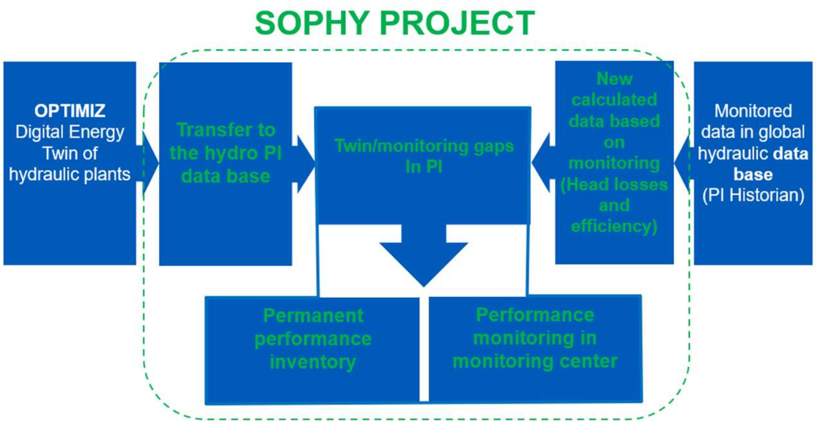
Monitored data used for the Optimiz calculations and for the comparison with the twin's data are averaged on a 10 minutes time span.

As we can see, the electrical power is the monitored data, which makes possible the computation of the other quantities of the twin.

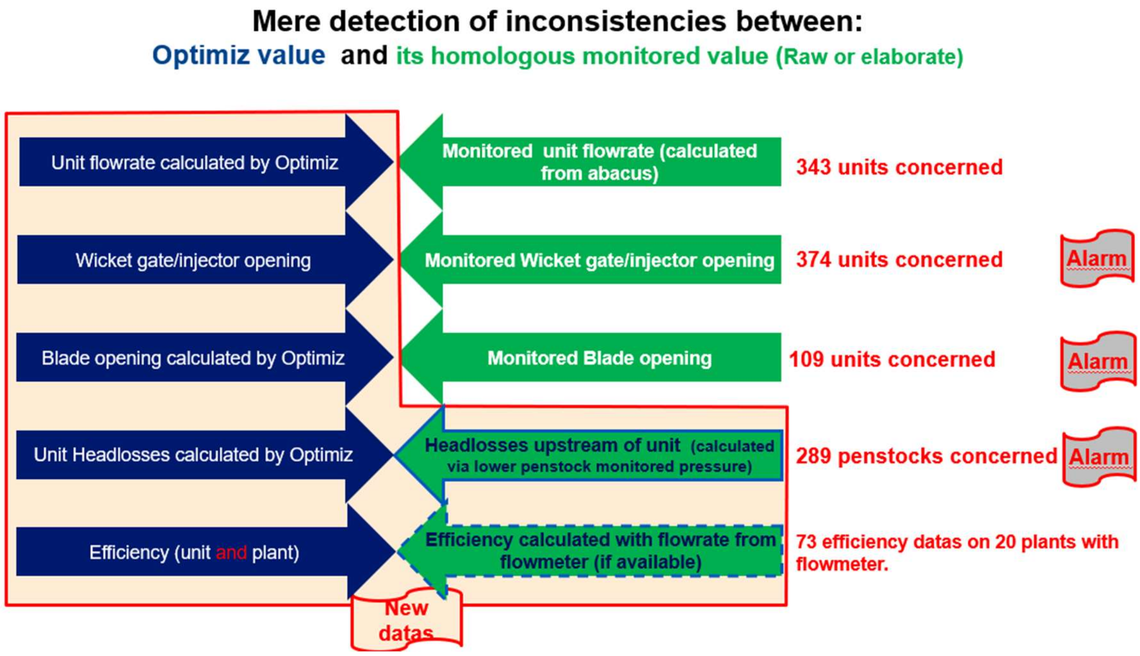
Once the twin data is present in the inhouse monitored data base, it is possible to compare it with their peer monitored data.

4. Comparison between monitored and twin data

The graph below shows the perimeter of Sophy Project:



The graph below shows which monitored and twin data are compared with each other.



As can be seen, some of the data monitored were already available in the global data base (flowrate, openings) and 2 others have been calculated in PI system independently from Optimiz (head losses, efficiency).

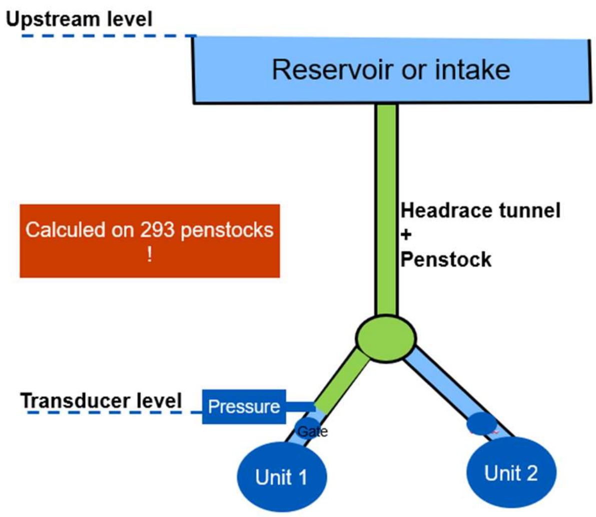
5. Evaluation of new “elaborated” monitored data

5.1. Head losses

A pressure sensor is installed in the lower part of all penstocks operated by EDF Hydro.

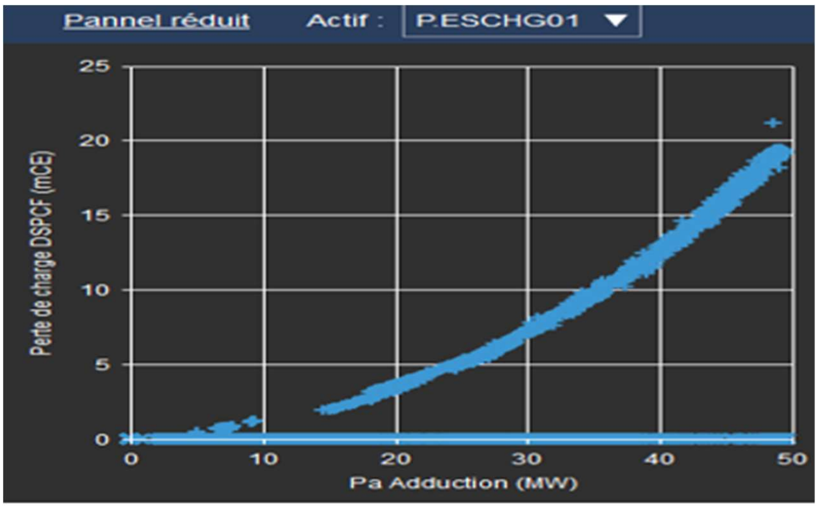
The goal of these sensors was primitively to detect transient pressure surges for safety concern. The Sophy project has given another valuable use to these monitored data: calculation of head losses.

This calculation is done in the PI system.



On this example, head loss is relative to one unit and consists of the global head loss between intake and inlet valve. Calculation is inhibited in transient conditions (Criteria of stability of power and pressure).

At each shut down of the plant, comparison is done between piezometric level calculated from the pressure transducer and reservoir level (monitored by the Upstream Level transducer). It creates a corrective term for calculation of head losses when units are running.



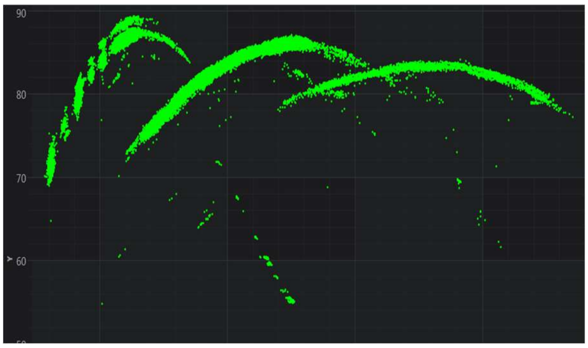
Example of monitored head losses function of plant active power

5.2. Efficiency

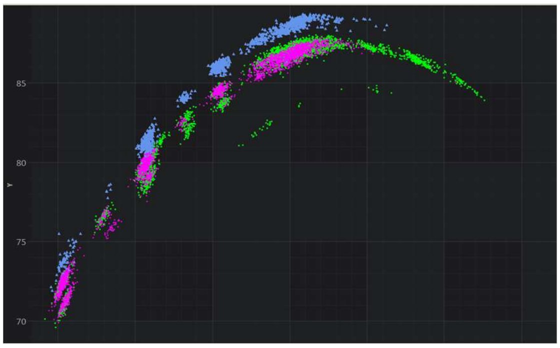
20 EDF hydraulic plants have flowrates monitored thanks to US flowmeter. Most of flowmeters have been bought to dispose of a good flowrate reference which is particularly important for successive power plants located on a river or a canal.

We have used the flowrate signal in addition to active power, upstream and downstream level in order to calculate:

- the efficiency of the whole plant
- The unit efficiency of each unit in gross head when the unit is running alone



Monitored plant efficiency function of the plant turbined flowrate



Monitored unit efficiency (gross head) function of the unit flowrate (one unit running for each point)

6. Example of surveillance detection

6.1. Descaling of a regulating device's opening sensor (wicket gate or blade)

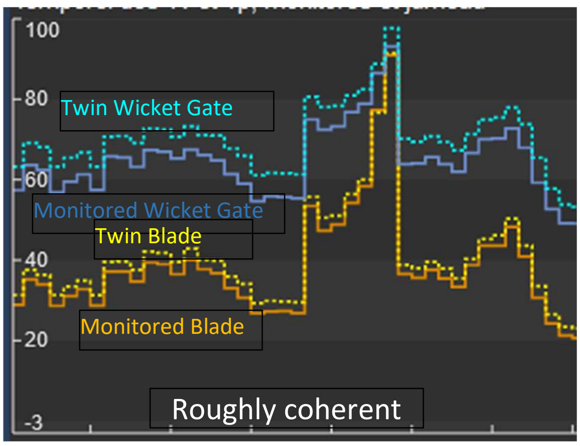
A defect of a blade opening sensor created a major cam curve deoptimization, a large gap on the calculated flowrate and a vibration crisis.

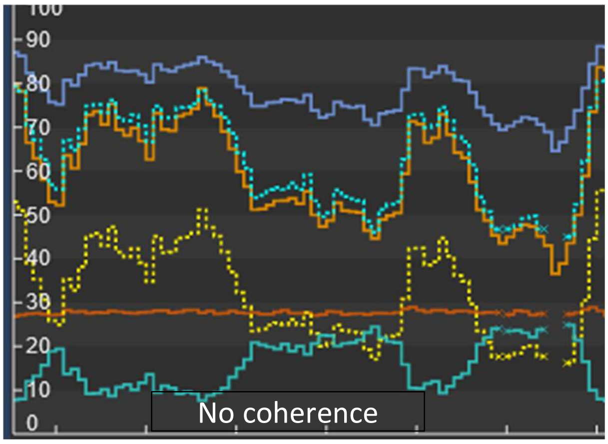
PI System calculates the gap between monitored value and Optimiz calculated one:

- For wicket gate opening:
- For blade opening,

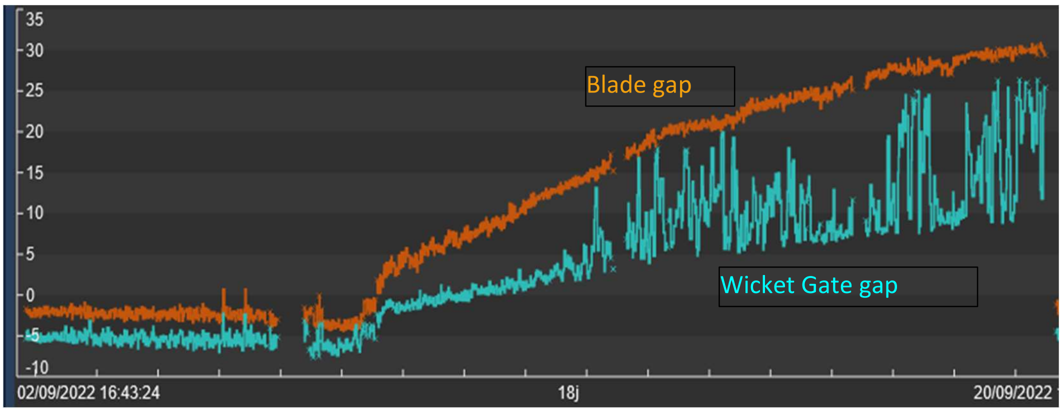
An alert is sent when the gap is over or below a threshold:

Before the defect **During the defect:**





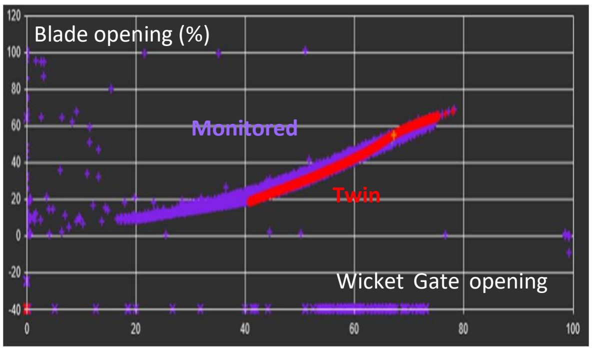
If we focus on the gap, the technical problem can be easily detected:

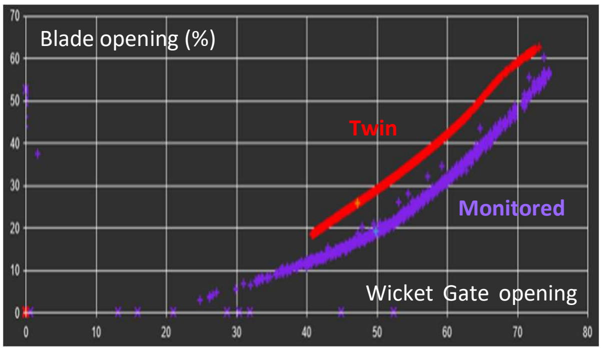


Deviation of gaps because of descaling of a blade opening sensor

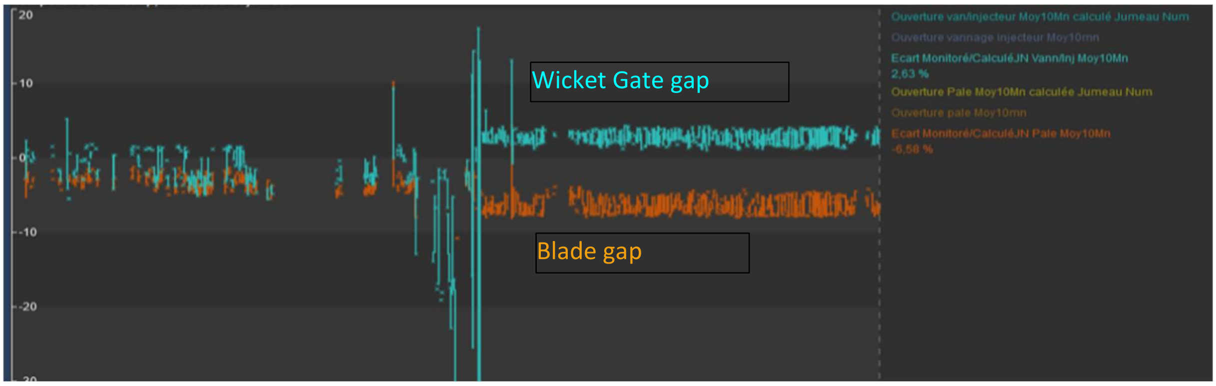
6.2. Erroneous modification of the cam curve in the governor.

Before the defect **During the defect:**





The defect is obvious on the gaps (below) and the system performs an automatic alert:

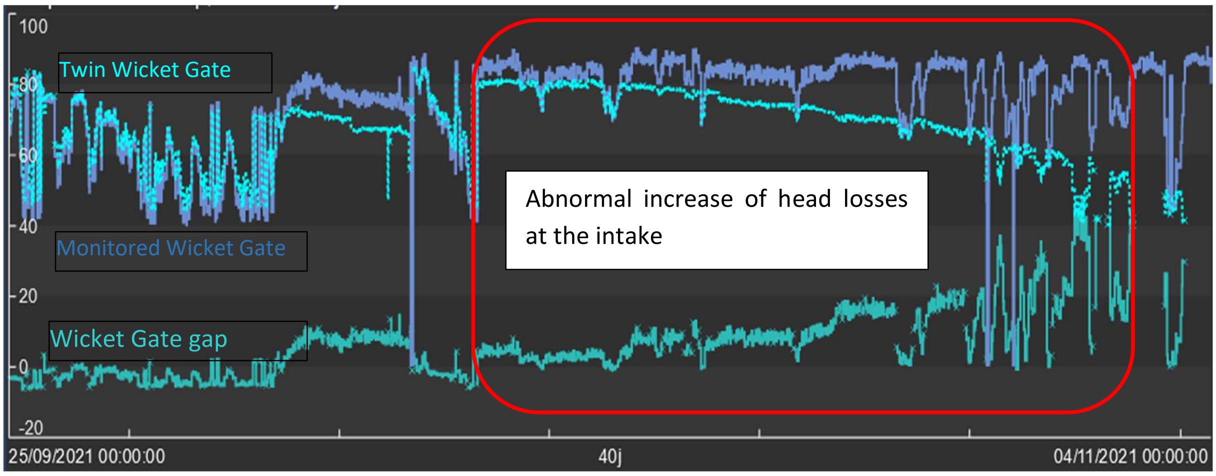


We notice that in this case, gaps have opposite signs.

6.3. Abnormal increase of head losses

In La Vanelle low head plant, there is no sensor to measure the head losses at the intake of the Kaplan unit.

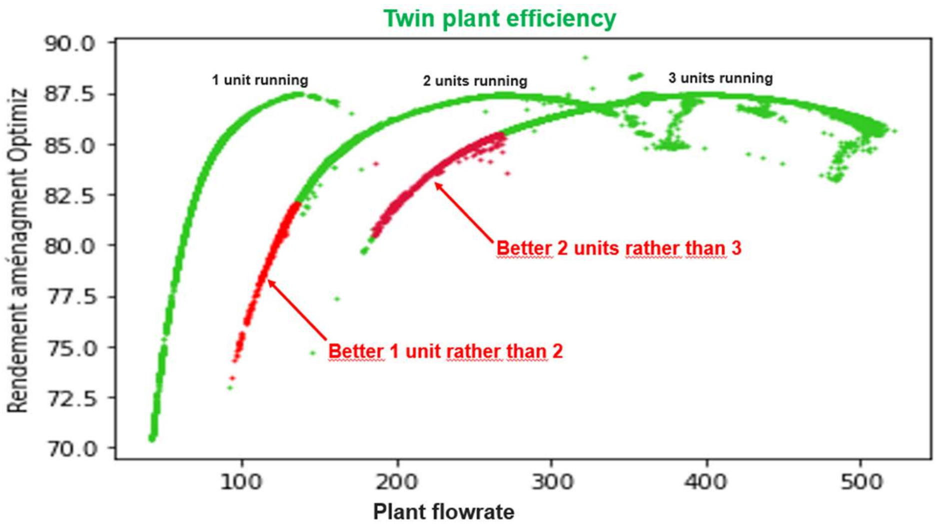
Abnormal increase of head losses at the intake trash racks, lowers net head and active power. Consequently, the Twin wicket gate opening calculated from monitored active power lowers equally.



Abnormal head loss can be detected by abnormal wicket gate opening gap

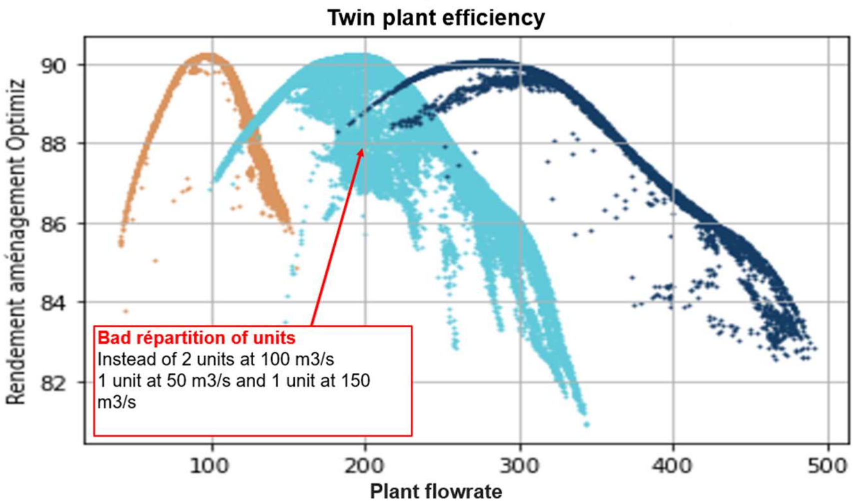
6.4. Poor power transition level from N to N+1 units running

Even without a flowmeter installed on the hydraulic circuit of the plant, it can be useful to look after plant efficiency calculated by the twin. These visuals allow easy awareness of deoptimizations.



Power transition deoptimization can be detected with plant efficiency from the twin

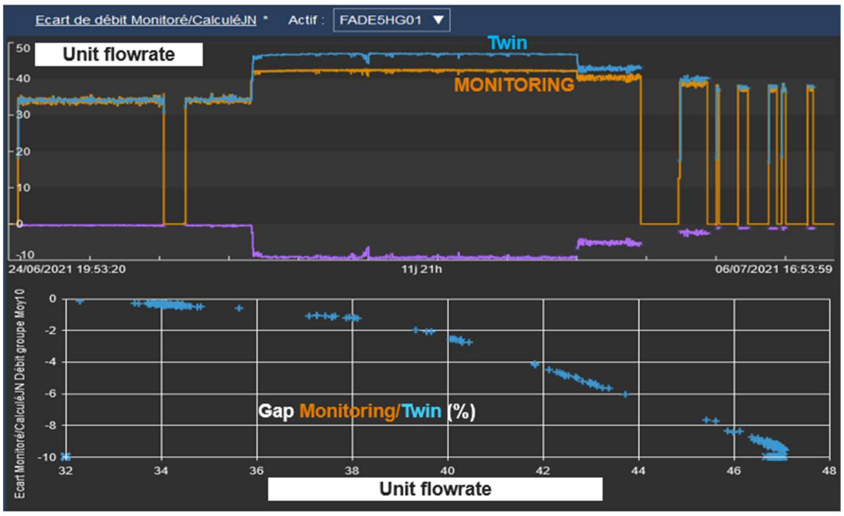
6.5. Problem of iso-repartition between units



Bad repartition of units within a given number of units running can be detected

6.6. Flowrate badly calculated by Plant supervisory & control system

Error on the turbinated flows announced by the plant of 10%. Correction requested.



At high load, bad flowrate coherence between twin flowrate and monitored one (deriving from control system Flow charts)

7. Conclusions and outlook

Recent years have shown that it is relevant for various uses to have a digital energy twin for every significant plant. In addition to initial explicit needs, many implicit needs are continuously discovered.

The creating of a plant twin is a rather demanding job and is carried out, on opportunity, whenever a need for a twin is identified on a plant. It is obviously necessary to dispose of on-site performance measurement reports.

Once the twin exists, and if a global inhouse data base is available, performance monitoring becomes a by-product of the twin at a reasonable cost. We are only at the beginning of the exploration of this new monitoring field, but the first detections suggest that this surveillance is to be continued and expanded.

8. Bibliography

[1] Héraud J 2012 *Optimiz Software. Features and global structure* IGHEM 2012

The authors:

Jean Héraud graduated as an aeronautical engineer in 1995 and joined EDF in 1997. During the last 15 years between 2005 and 2020 he has realized many hydraulic plant site measurements in the field of flow measurement, efficiency optimization, start-stop optimization and hydro mechanical diagnostic and troubleshooting. These years he focuses on digital twin performance monitoring.

Damien LE GOFF graduated as an hydraulic engineer in 2013 and joined EDF just after. He has worked during 6 years on over instrumentation project on hydraulic plants, to enable a new distant monitoring of hydraulic units. Last two years, he has realized several performance measurements on hydraulic plants and has contributed to the digital twin performance monitoring.