Power Transformer Simulation Laboratory for Proactive Maintenance

Presented by **Luc Vouligny, Ing, Ph.D.**

Hydro Québec
Institut de recherche

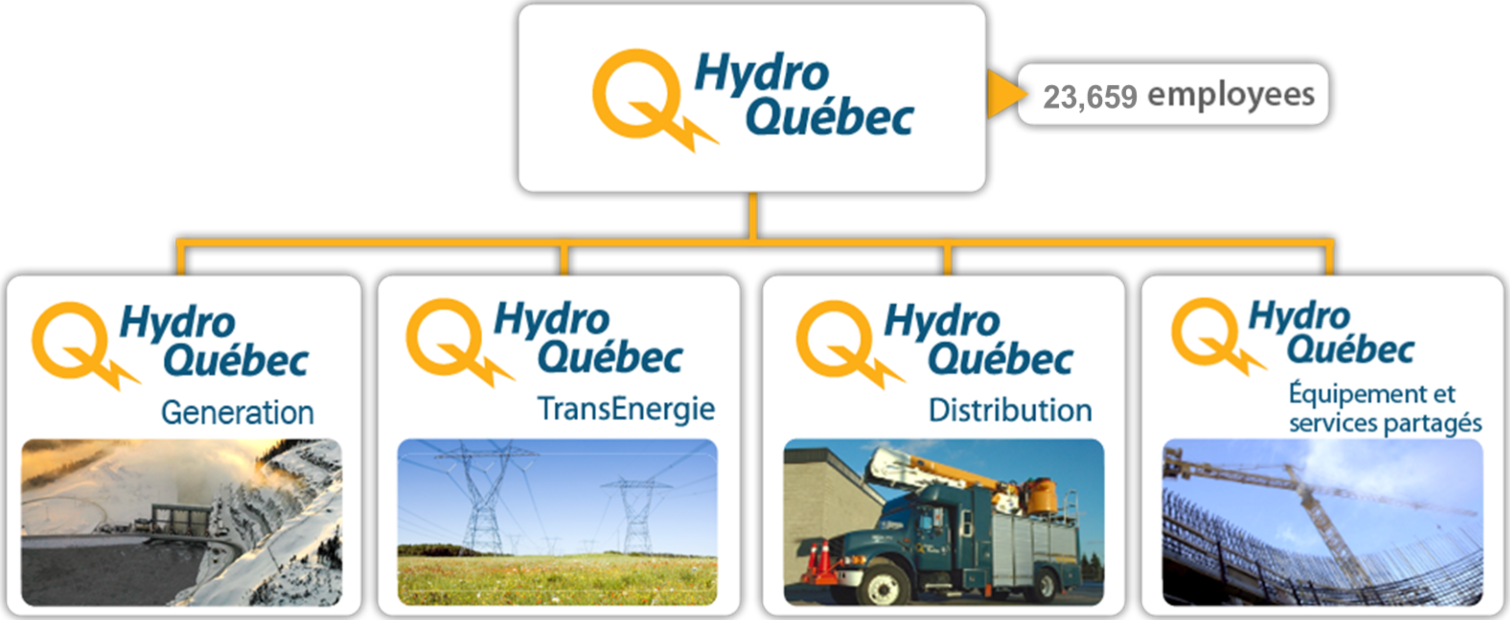
Agenda

- About Hydro-Québec & IREQ
- Context of the Research Project
- The Power Transformer Laboratory
- Experimental Results
- Conclusion and Future Work

About Hydro-Québec

- Hydro-Québec is the largest electric utility in Canada
  - 30% of electricity generation
    - Installed capacity of 36,671 MW
    - 98% renewable energy (hydro & wind power)
- Hydro-Québec is the largest power generator in North America
  - 15 interconnections with neighboring markets (> 5,000 MW)
  - Active in the following markets : Ontario, Maritimes, New-England, New-York, PJM and MISO
- Hydro-Québec is among the largest power transmission companies in North America
  - $17 B in transmission assets
- 4 M Customers
  - Residential (41%), Large-power corp. (31%), Commercial (25%) and Others (3%)

Corporate Structure



Hydro-Québec TransÉnergie

- Annual investment 2009-2013: $1B
- 21,000 miles of power transmission lines
  - Including 7,000 miles of 765 & 735 kV lines
  - First utility worldwide to use 735 kV lines
- 514 transmission substations
- 2200 power transformers

Hydro-Quebec's Research Institute (IREQ)

- Largest electrical utility research center in North America
  - 500 scientists, technicians, engineers & specialists
  - $100 M in innovation projects
- Specifics of the network
  - Generating facilities located up North, far from the load centers
  - Harsh climate
  - Very long transmission lines at high voltage levels
- Primarily involved in projects related to electricity Generation, Transmission & Distribution
  - Performance & Durability
  - Inspection & Maintenance
  - Inflow Forecasting & Electricity Production
  - Energy Efficiency
  - Land Transportation Electrification

Context of the MEET-PM research project

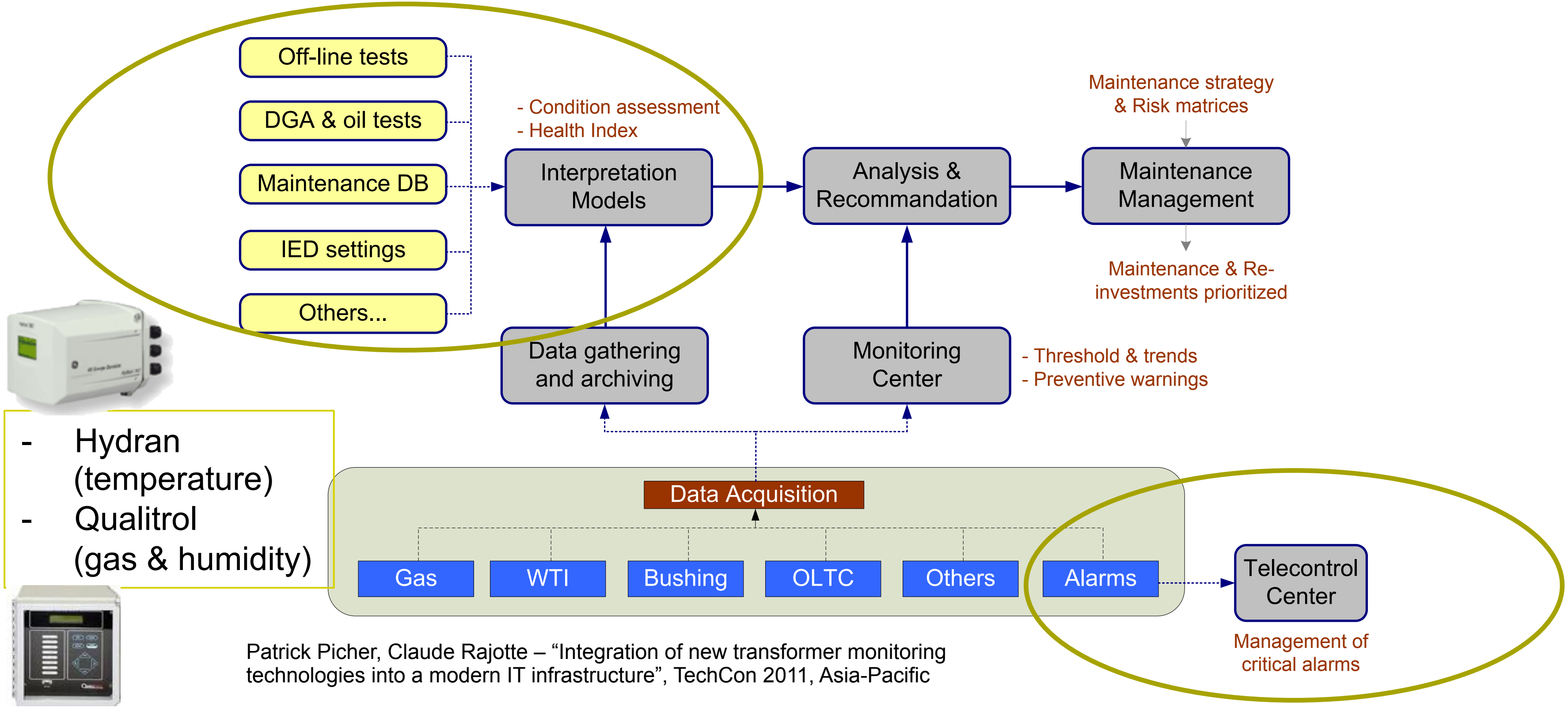
- *"Power Transformer State Evaluation Models for Sustainability and Maintenance"*
- Transformers are critical components of the network
  - Average age: 31 years old
  - Their life expectancy: 57 years
- Each of these power transformers cost from $1M to $6M
- It becomes important to have more actualized information on their health states to avoid costly outage due to their malfunctions
- Hydro-Quebec has started to install on-line monitoring capability
  - 90 power transformers are already linked with a SCADA system and the sensors data are gathered in a PI Server since August 2011

Goal of the research project

- To make use of the on-line diagnostic possibilities to allow for proactive maintenance
  - Maximization of asset life
  - Risk & Cost Reduction of unexpected failure
  - Maintenance and Inspection driven by asset condition

Research project's main goal with proactive maintenance…

Information model overview

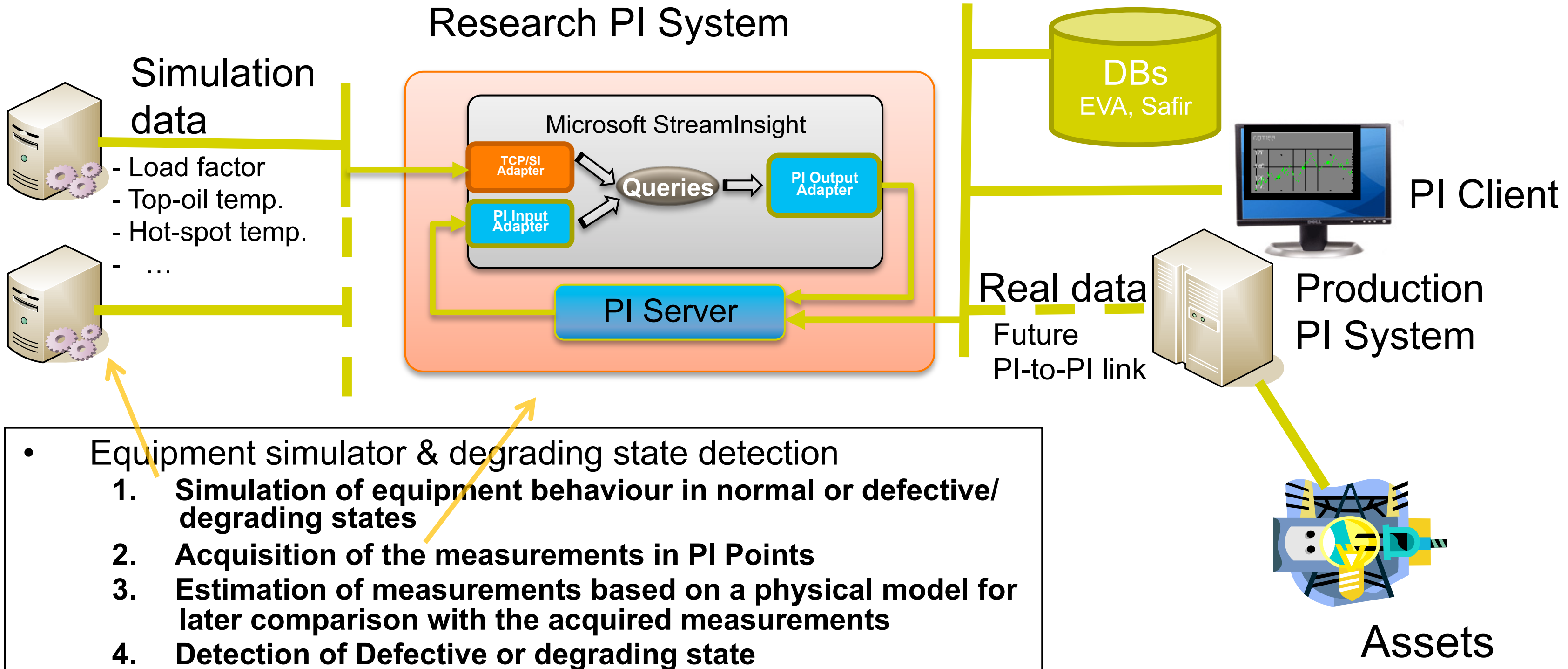


Patrick Picher, Claude Rajotte – “Integration of new transformer monitoring technologies into a modern IT infrastructure”, TechCon 2011, Asia-Pacific

Research Project History and Current Objective

- The project started a year ago (March 2011)
- The objective for the first stage of our research projects is to look for different options
- One of the options includes to test and use the OSIsoft PI System to see if it would be **sufficient** to help us implement our proactive maintenance concepts
  - Establish the dynamic state of the equipment taking into account the on-line sensors diagnostic data
  - Establish an expert system for the detection of early signs of state degradation

Power Transformer Laboratory



- Equipment simulator & degrading state detection
  1. **Simulation of equipment behaviour in normal or defective/ degrading states**
  2. **Acquisition of the measurements in PI Points**
  3. **Estimation of measurements based on a physical model for later comparison with the acquired measurements**
  4. **Detection of Defective or degrading state**

Simulation of Transformer Behaviour

- The performance of power transformer functions can be analysed with different models:
  - Load current model
  - Insulation model
  - Moisture (humidity) model
  - Cooling efficiency (thermal) model
  - …

    Flynn, B., "Case Studies regarding the integration of monitoring &diagnostic equipment on aging transformers with communications for SCADA and maintenance, DistribuTECH 2008, Jan 22-24, Tampa, FL
- If we have
  - the physical model of a given behaviour
  - the data from the sensors,
  - the characteristics of the asset,
  - its history and its operating conditions
  - then we could be able to correctly identify a degrading function
- To test our settings, we will take the established oil temperature model from the IEC 60076-7 International Standard to test our approach.

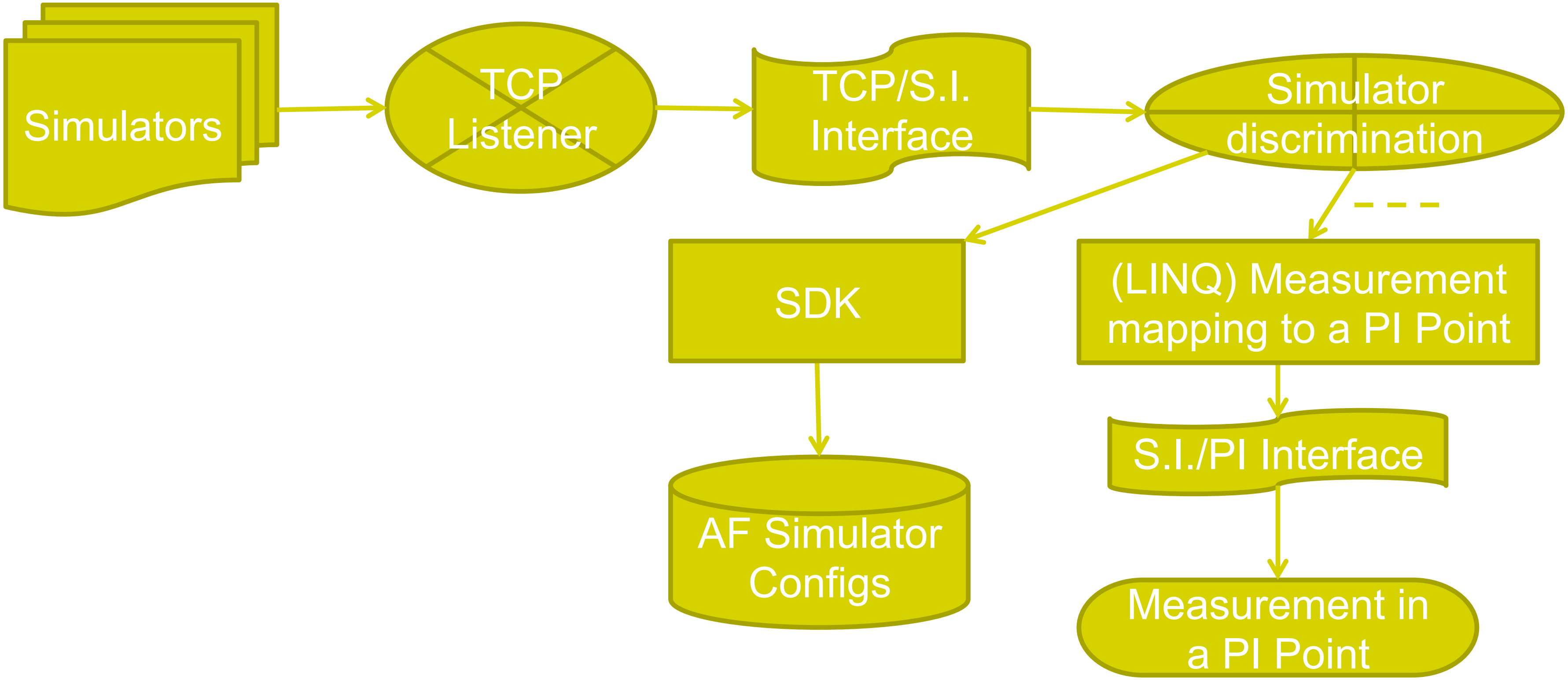
Thermal model

- Operational conditions
  - Ambient temperature (θ_a)
  - Initial top-oil temperature gradient ($\Delta\,\theta_{oi}$)
  - Initial hot-spot-to-top-oil temperature gradient ($\Delta\,\theta_{hi}$)
  - …
- Equipment characteristics
  - Winding time constant (τ_ω)
  - …
- Formula to get the oil temperature (θ_o) value for a given load factor (κ) setting at a given time t: exponential equations formulation of the IEC 60076-7 IS for increasing & decreasing state of the load factor κ

$$\theta_{\mathrm{o}}(t) = \theta_{\mathrm{a}} + \Delta\theta_{\mathrm{oi}} + \left\{\Delta\theta_{\mathrm{or}} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^x - \Delta\theta_{\mathrm{oi}}\right\} \times f_1(t)$$

$$\theta_{\mathrm{o}}(t) = \theta_{\mathrm{a}} + \Delta\theta_{\mathrm{or}} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^x + \left\{\Delta\theta_{\mathrm{oi}} - \Delta\theta_{\mathrm{or}} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^x\right\} \times f_3(t)$$

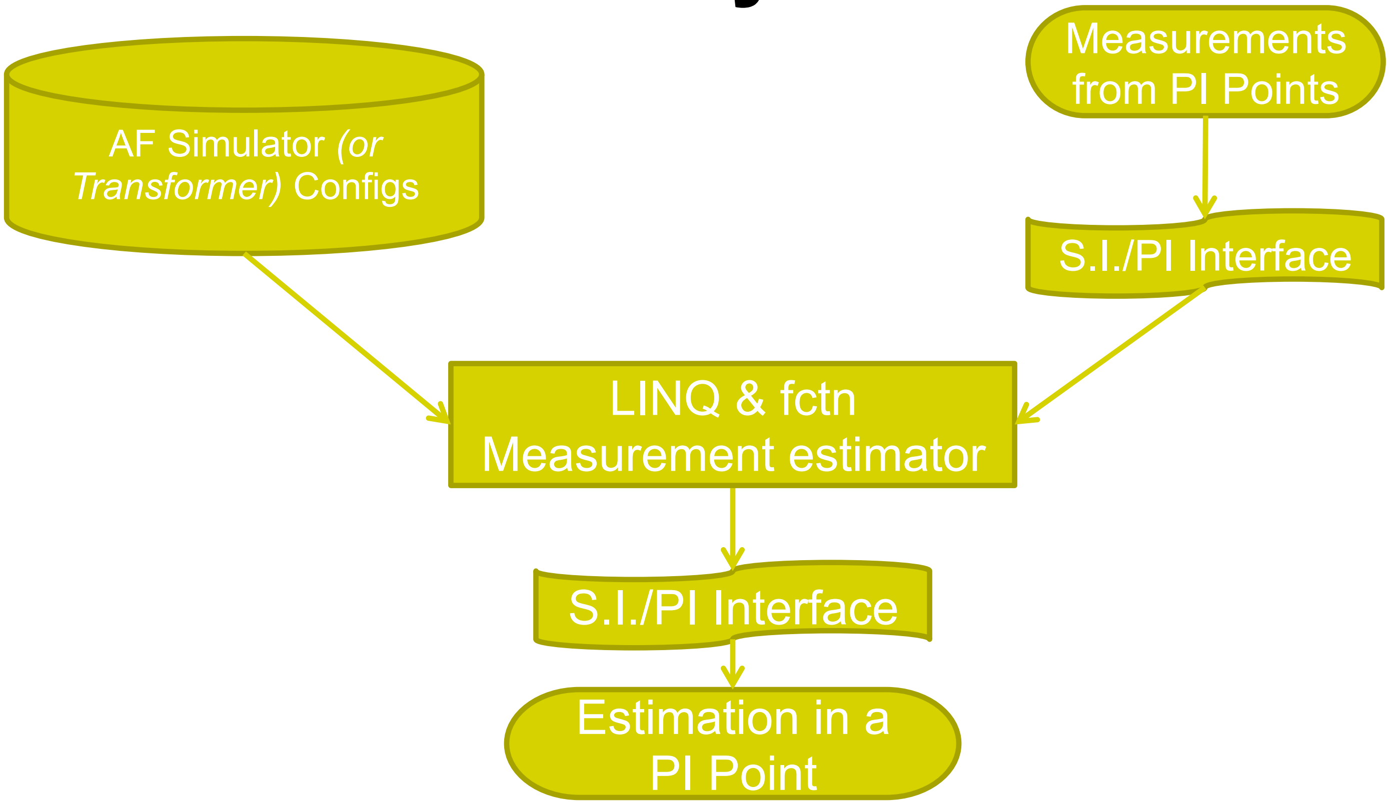
The acquisition system



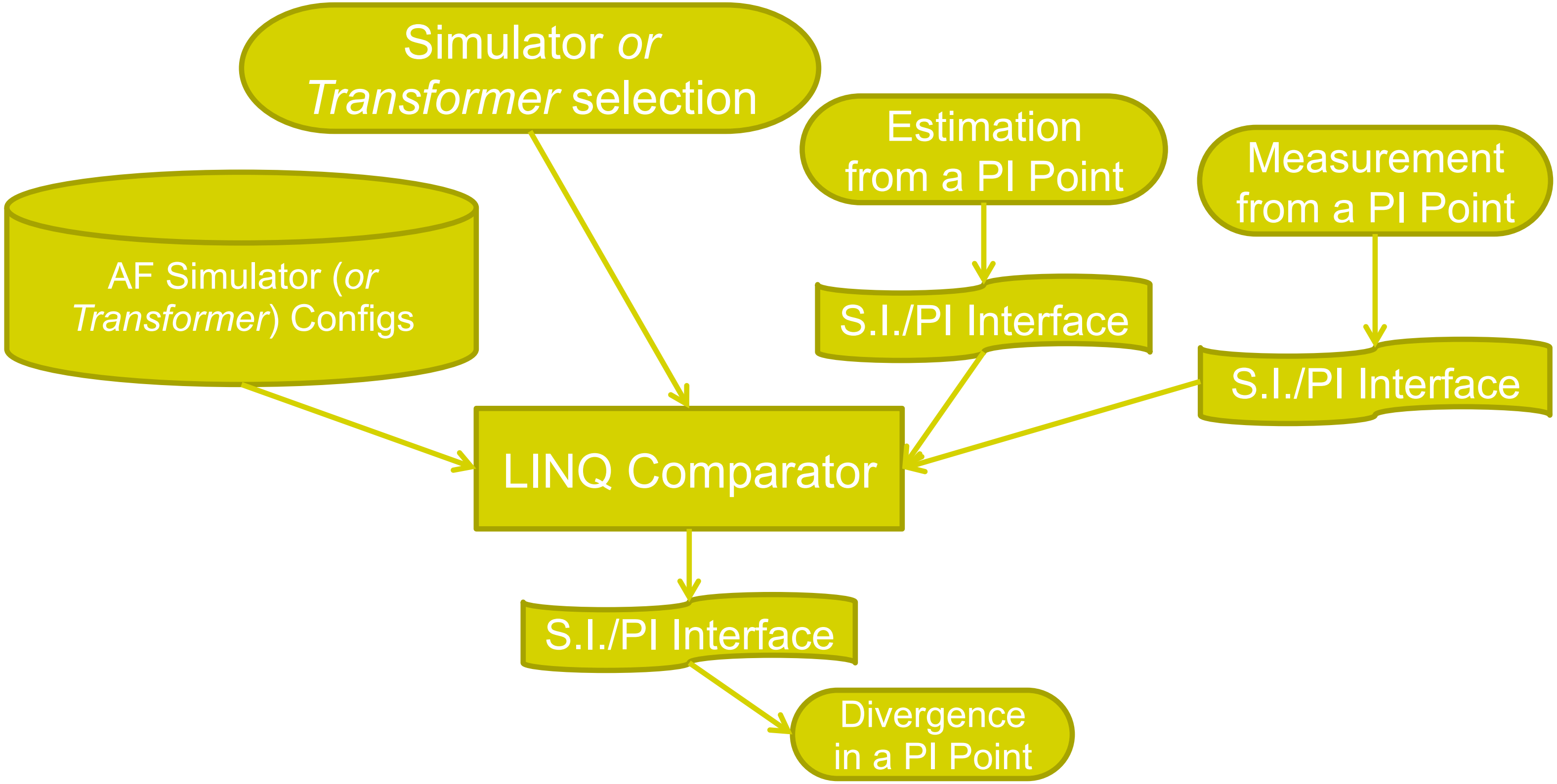
Why Microsoft StreamInsight

- Enables complex event processing (CEP), specifically suited for data streams
- Many maintenance situations such as degrading state recognition depend on temporal as well as causal relationships between events, which can be expressed in a CEP system
- StreamInsight is well integrated with PI ACE
  - Input/Output adaptors with PI System for StreamInsight
- Used for acquisition, estimation & detection

The estimation system



Defective & degrading state detection system



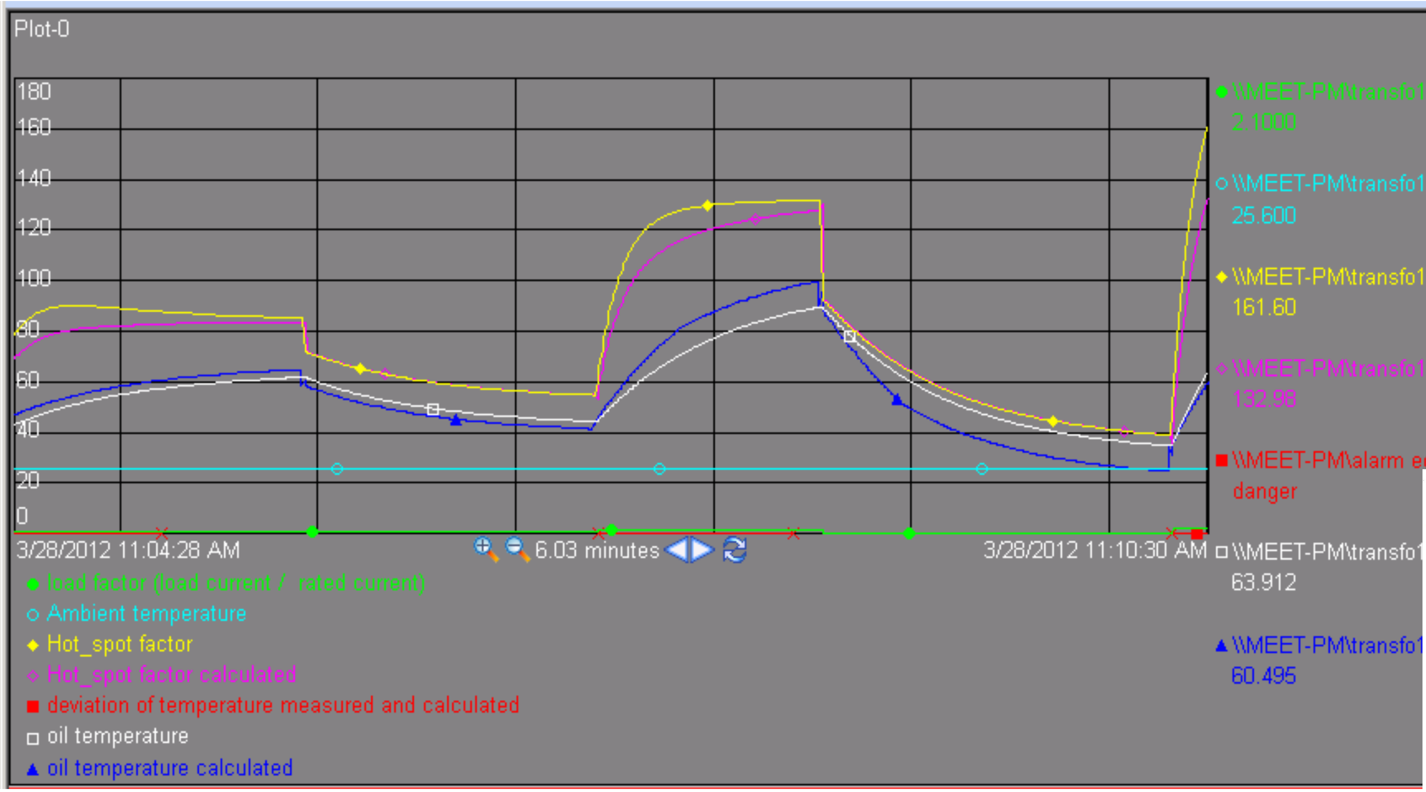
Defective & degrading state detection

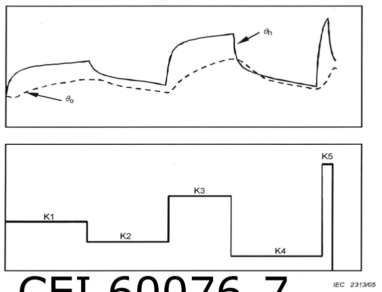
- PI/StreamInsight input adapter is used to get the data from the PI points referring to the different signals (measured & estimated)
- A StreamInsight LINQ expression is used to notice an excessive divergence between the measured and the calculated events

```
 var query = from dataMesuree in donneeMesuree
                    join dataCalculee in donneeCalculee on dataMesuree.Path.Substring(0, 5) equals
dataCalculee.Path.Substring(0, 5)
                    select new PIDataSingle()
                    {
                            Path = alarmDifference,
                            Status = (abs(dataMesuree.Value - dataCalculee.Value) > TempVar ? 0 : -1),
                            Value  = (abs(dataMesuree.Value - dataCalculee.Value) > TempVar ? "danger" : "normal")

                    };
```

Simulation result sample

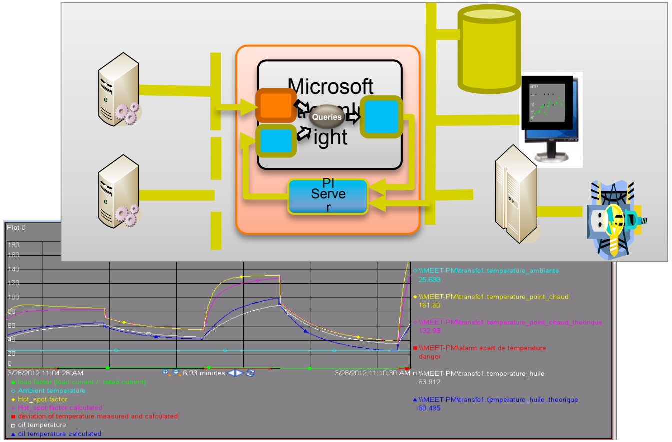




CEI 60076-7

Power Transformer Simulation Laboratory for Proactive Maintenance

« Now that we have on-line monitoring possibilities for maintenance purposes on power transformers, our simulation laboratory will allow us to elaborate and test many possibilities of proactive maintenance models & technics before implementing them in the field. »



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Business Challenge

- Maximization of asset life
- Risk & Cost Reduction of unexpected failure
- Maintenance and Inspection driven by asset condition

Solution

Simulation laboratory

- Simulation of degrading state assets measurements
- Detection techniques using PI ACE & StreamInsight

Results and Benefits

Enables us to implement and test new degrading state detection algorithms from simulation data and physical models for proactive maintenance

Conclusion and Future Work

- First year with the OSIsoft PI System; very satisfied so far with the capacity of the system and the support we received (TechSupport & Training)
- Everything has been accomplished with a VCampus PI System
- Once tested, the idea is to progressively implement our detection algorithms in the enterprise maintenance system
- New models for degrading situation recognition will be considered and added to the detector
- A PI-to-PI link between our research facilities and the PI System used for on-line monitoring of the enterprise will be established in a near future
- This will allow us to use historical data when no physical models are available

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Patrick Picher, the MEET-PM Project Leader
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Many people have participated so far on the establishment of this laboratory and I would like to thank them all, especially:

Fouad Liq, Gilmer Prada-Velasque, Jonathan Simard, Clément Étienne; university students I supervised

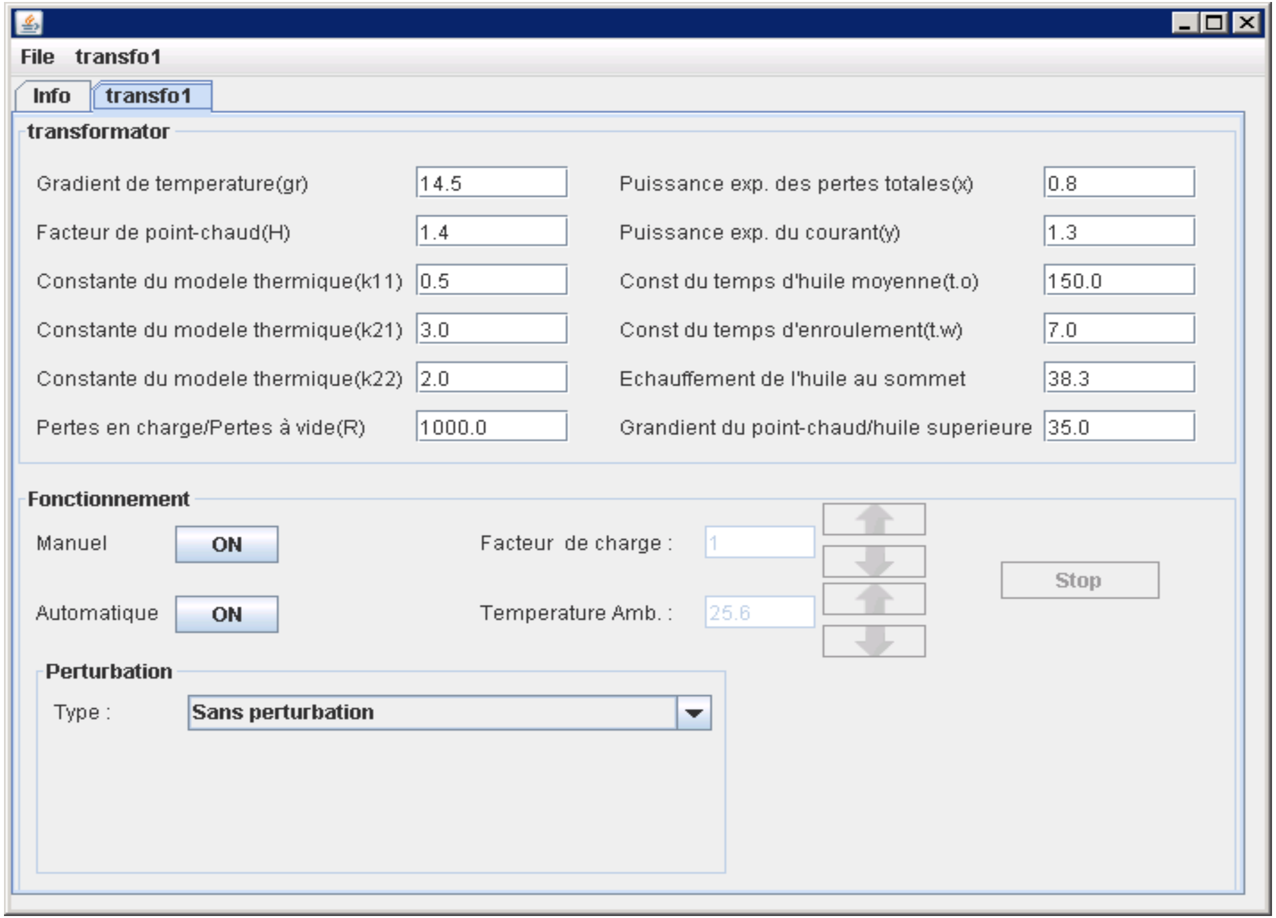
Mathieu Viau, Luc Cauchon, Arnaud Zinflou & Alexandre Bouffard, coworkers of my department.

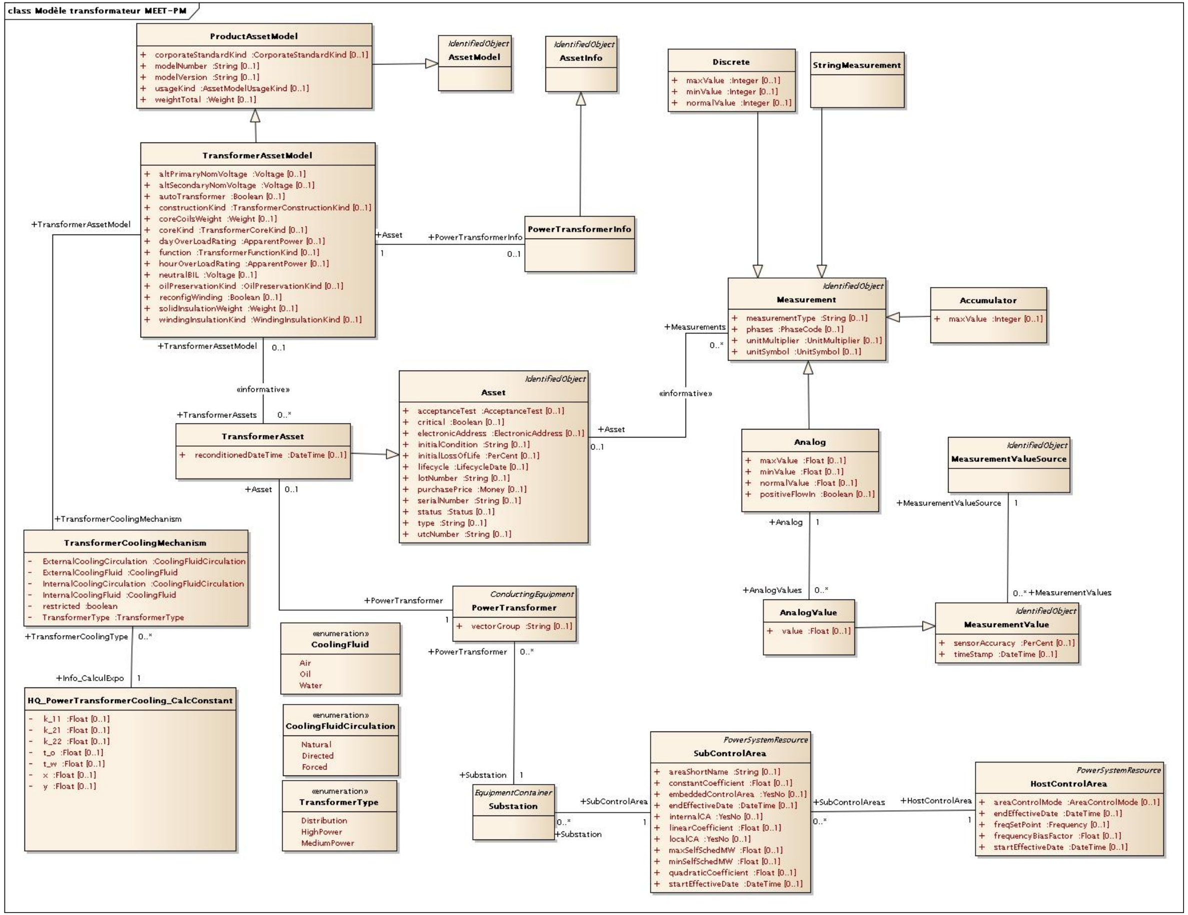
THANK YOU

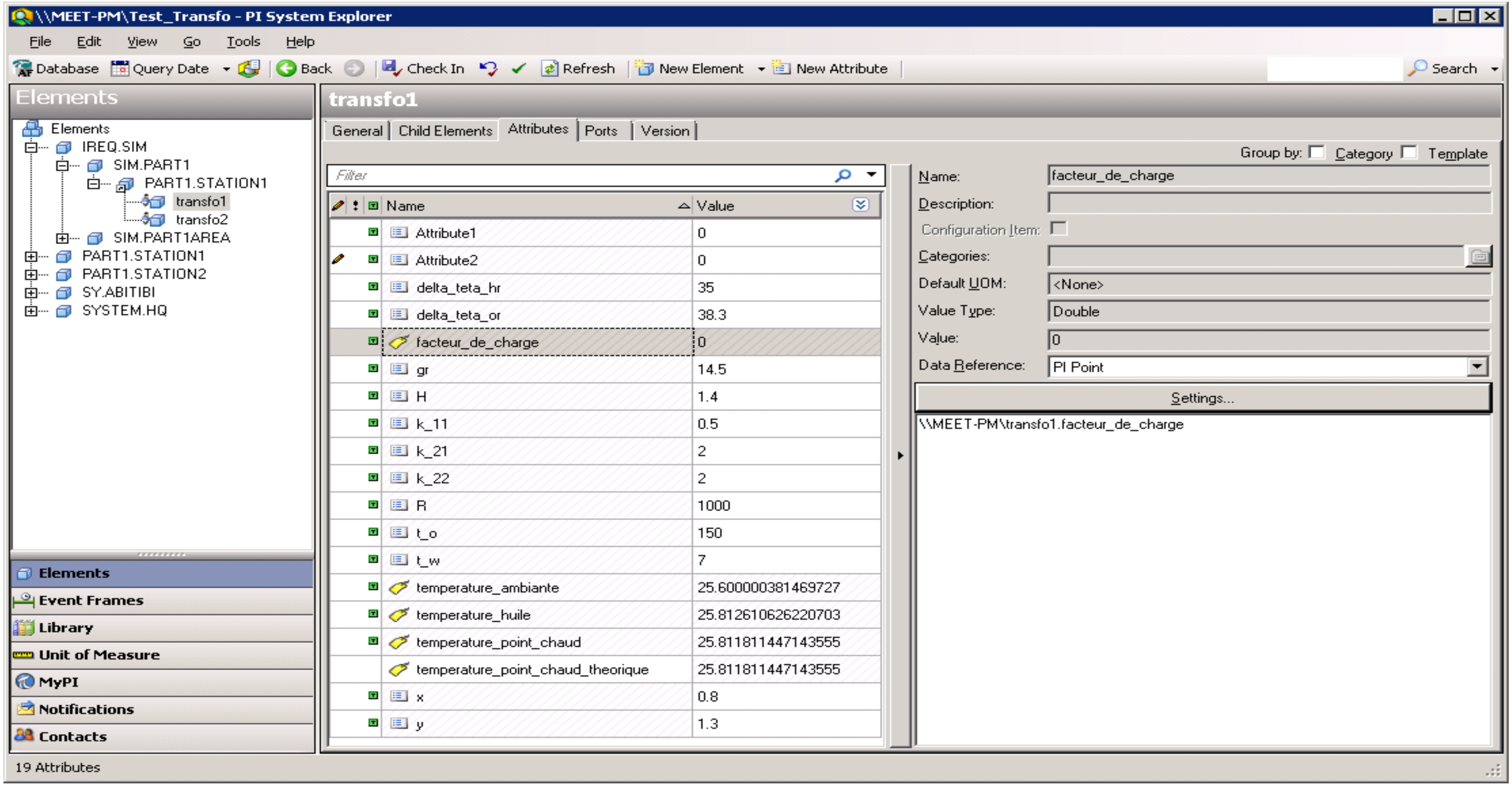
Brought to you by OSIsoft.

Appendix

- Transformer simulation user interface
- CIM model
- AF transformer model


File transfo1
Info
transfo1
transformator
Gradient de temperature(gr)
14.5
Facteur de point-chaud(H)
1.4
Constante du modele thermique(k11)
0.5
Constante du modele thermique(k21)
3.0
Constante du modele thermique(k22)
2.0
Pertes en charge/Pertes à vide(R)
1000.0
Puissance exp. des pertes totales(x)
0.8
Puissance exp. du courant(y)
1.3
Const du temps d'huile moyenne(t.o)
150.0
Const du temps d'enroulement(t.w)
7.0
Echauffement de l'huile au sommet
38.3
Grandient du point-chaud/huile superieure
35.0
Fonctionnement
Manuel
ON
Automatique
ON
Facteur de charge :
1
Temperature Amb. :
25.6
Stop
Perturbation
Type :
Sans perturbation


class Modèle transformateur MEET-PM
ProductAssetModel
+ corporateStandardKind :CorporateStandardKind [0..1]
+ modelNumber :String [0..1]
+ modelVersion :String [0..1]
+ usageKind :AssetModelUsageKind [0..1]
+ weightTotal :Weight [0..1]
IdentifiedObject
AssetModel
IdentifiedObject
AssetInfo
Discrete
+ maxValue :Integer [0..1]
+ minValue :Integer [0..1]
+ normalValue :Integer [0..1]
StringMeasurement
TransformerAssetModel
+ altPrimaryNomVoltage :Voltage [0..1]
+ altSecondaryNomVoltage :Voltage [0..1]
+ autoTransformer :Boolean [0..1]
+ constructionKind :TransformerConstructionKind [0..1]
+ coreCoilsWeight :Weight [0..1]
+ coreKind :TransformerCoreKind [0..1]
+ dayOverLoadRating :ApparentPower [0..1]
+ function :TransformerFunctionKind [0..1]
+ hourOverLoadRating :ApparentPower [0..1]
+ neutralBIL :Voltage [0..1]
+ oilPreservationKind :OilPreservationKind [0..1]
+ reconfigWinding :Boolean [0..1]
+ solidInsulationWeight :Weight [0..1]
+ windingInsulationKind :WindingInsulationKind [0..1]
+TransformerAssetModel
+Asset
1
+PowerTransformerInfo
0..1
PowerTransformerInfo
IdentifiedObject
Measurement
+ measurementType :String [0..1]
+ phases :PhaseCode [0..1]
+ unitMultiplier :UnitMultiplier [0..1]
+ unitSymbol :UnitSymbol [0..1]
Accumulator
+ maxValue :Integer [0..1]
+Measurements
0..*
+TransformerAssetModel
0..1
«informative»
+TransformerAssets
0..*
IdentifiedObject
Asset
+ acceptanceTest :AcceptanceTest [0..1]
+ critical :Boolean [0..1]
+ electronicAddress :ElectronicAddress [0..1]
+ initialCondition :String [0..1]
+ initialLossOfLife :PerCent [0..1]
+ lifecycle :LifecycleDate [0..1]
+ lotNumber :String [0..1]
+ purchasePrice :Money [0..1]
+ serialNumber :String [0..1]
+ status :Status [0..1]
+ type :String [0..1]
+ utcNumber :String [0..1]
«informative»
+Asset
0..1
TransformerAsset
+ reconditionedDateTime :DateTime [0..1]
+Asset
0..1
Analog
+ maxValue :Float [0..1]
+ minValue :Float [0..1]
+ normalValue :Float [0..1]
+ positiveFlowIn :Boolean [0..1]
IdentifiedObject
MeasurementValueSource
+MeasurementValueSource
1
+Analog
1
+TransformerCoolingMechanism
TransformerCoolingMechanism
- ExternalCoolingCirculation :CoolingFluidCirculation
- ExternalCoolingFluid :CoolingFluid
- InternalCoolingCirculation :CoolingFluidCirculation
- InternalCoolingFluid :CoolingFluid
- restricted :boolean
- TransformerType :TransformerType
+PowerTransformer
1
ConductingEquipment
PowerTransformer
+ vectorGroup :String [0..1]
+AnalogValues
0..*
0..*
+MeasurementValues
AnalogValue
+ value :Float [0..1]
IdentifiedObject
MeasurementValue
+ sensorAccuracy :PerCent [0..1]
+ timeStamp :DateTime [0..1]
+TransformerCoolingType
0..*
«enumeration»
CoolingFluid
Air
Oil
Water
+PowerTransformer
0..*
+Info_CalculExpo
1
HQ_PowerTransformerCooling_CalcConstant
- k_11 :Float [0..1]
- k_21 :Float [0..1]
- k_22 :Float [0..1]
- t_o :Float [0..1]
- t_w :Float [0..1]
- x :Float [0..1]
- y :Float [0..1]
«enumeration»
CoolingFluidCirculation
Natural
Directed
Forced
«enumeration»
TransformerType
Distribution
HighPower
MediumPower
+Substation
1
EquipmentContainer
Substation
+SubControlArea
0..*
1
+Substation
PowerSystemResource
SubControlArea
+ areaShortName :String [0..1]
+ constantCoefficient :Float [0..1]
+ embeddedControlArea :YesNo [0..1]
+ endEffectiveDate :DateTime [0..1]
+ internalCA :YesNo [0..1]
+ linearCoefficient :Float [0..1]
+ localCA :YesNo [0..1]
+ maxSelfSchedMW :Float [0..1]
+ minSelfSchedMW :Float [0..1]
+ quadraticCoefficient :Float [0..1]
+ startEffectiveDate :DateTime [0..1]
+SubControlAreas
0..*
+HostControlArea
1
PowerSystemResource
HostControlArea
+ areaControlMode :AreaControlMode [0..1]
+ endEffectiveDate :DateTime [0..1]
+ freqSetPoint :Frequency [0..1]
+ frequencyBiasFactor :Float [0..1]
+ startEffectiveDate :DateTime [0..1]


\\MEET-PM\Test_Transfo - PI System Explorer
File Edit View Go Tools Help
Database Query Date Back Check In Refresh New Element New Attribute Search
Elements
Elements
IREQ.SIM
SIM.PART1
PART1.STATION1
transfo1
transfo2
SIM.PART1AREA
PART1.STATION1
PART1.STATION2
SY.ABITIBI
SYSTEM.HQ
Elements
Event Frames
Library
Unit of Measure
MyPI
Notifications
Contacts
19 Attributes
transfo1
General Child Elements Attributes Ports Version
Group by: Category Template
Filter
Name Value
Attribute1 0
Attribute2 0
delta_teta_hr 35
delta_teta_or 38.3
facteur_de_charge 0
gr 14.5
H 1.4
k_11 0.5
k_21 2
k_22 2
R 1000
t_o 150
t_w 7
temperature_ambiante 25.600000381469727
temperature_huile 25.812610626220703
temperature_point_chaud 25.811811447143555
temperature_point_chaud_theorique 25.811811447143555
x 0.8
y 1.3
Name: facteur_de_charge
Description:
Configuration Item:
Categories:
Default UOM: <None>
Value Type: Double
Value: 0
Data Reference: PI Point
Settings...
\\MEET-PM\transfo1.facteur_de_charge