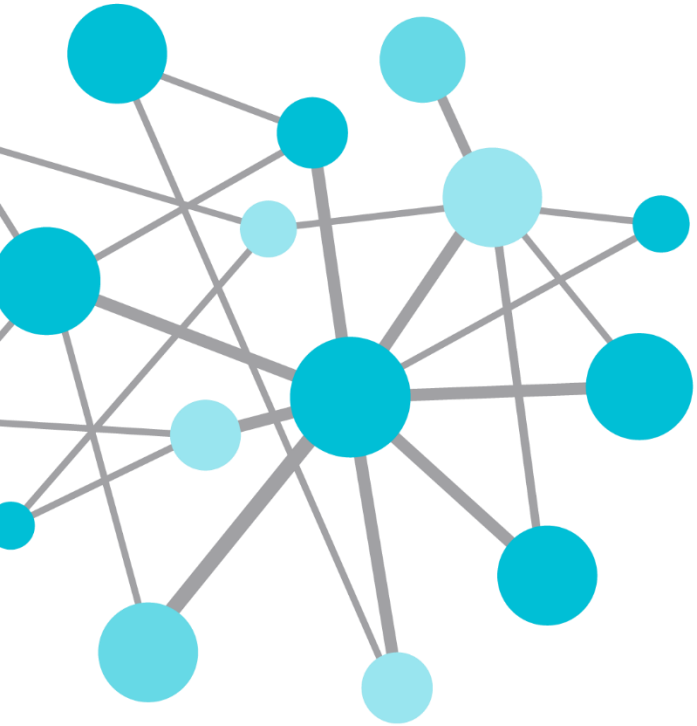


Power Transformer Simulation Laboratory for Proactive Maintenance II

Presented by **Nicolas Di Gaetano**
& Luc Vouligny

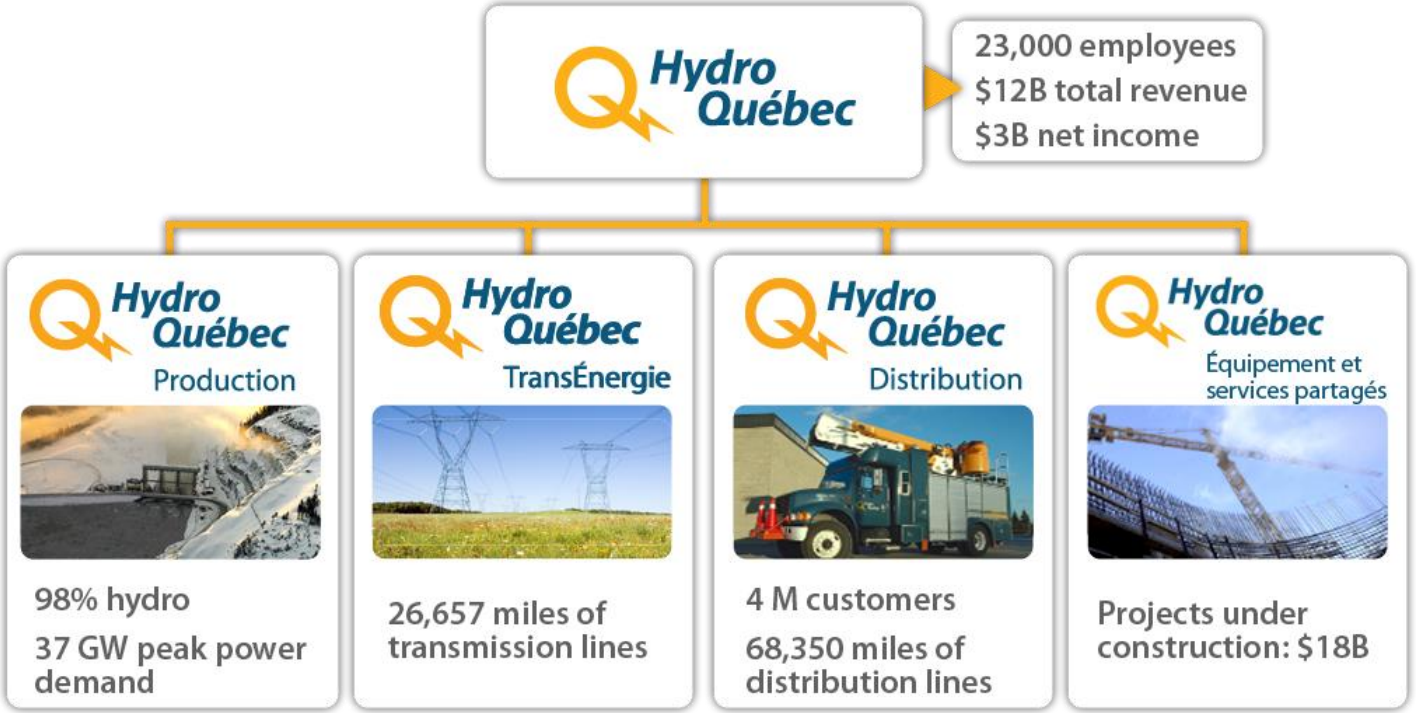
Agenda

- An overview of Hydro-Québec
- Context of the project
- Objectives of the project
- Transformer monitoring
- Conclusion & Future Work

Snapshot

- Hydro-Québec is among the largest power generator in North America
  - 98% renewable energy
- Hydro-Québec is among the largest power transmission companies in North America
- Hydro-Québec is the largest electric utility in Canada

About Hydro-Québec



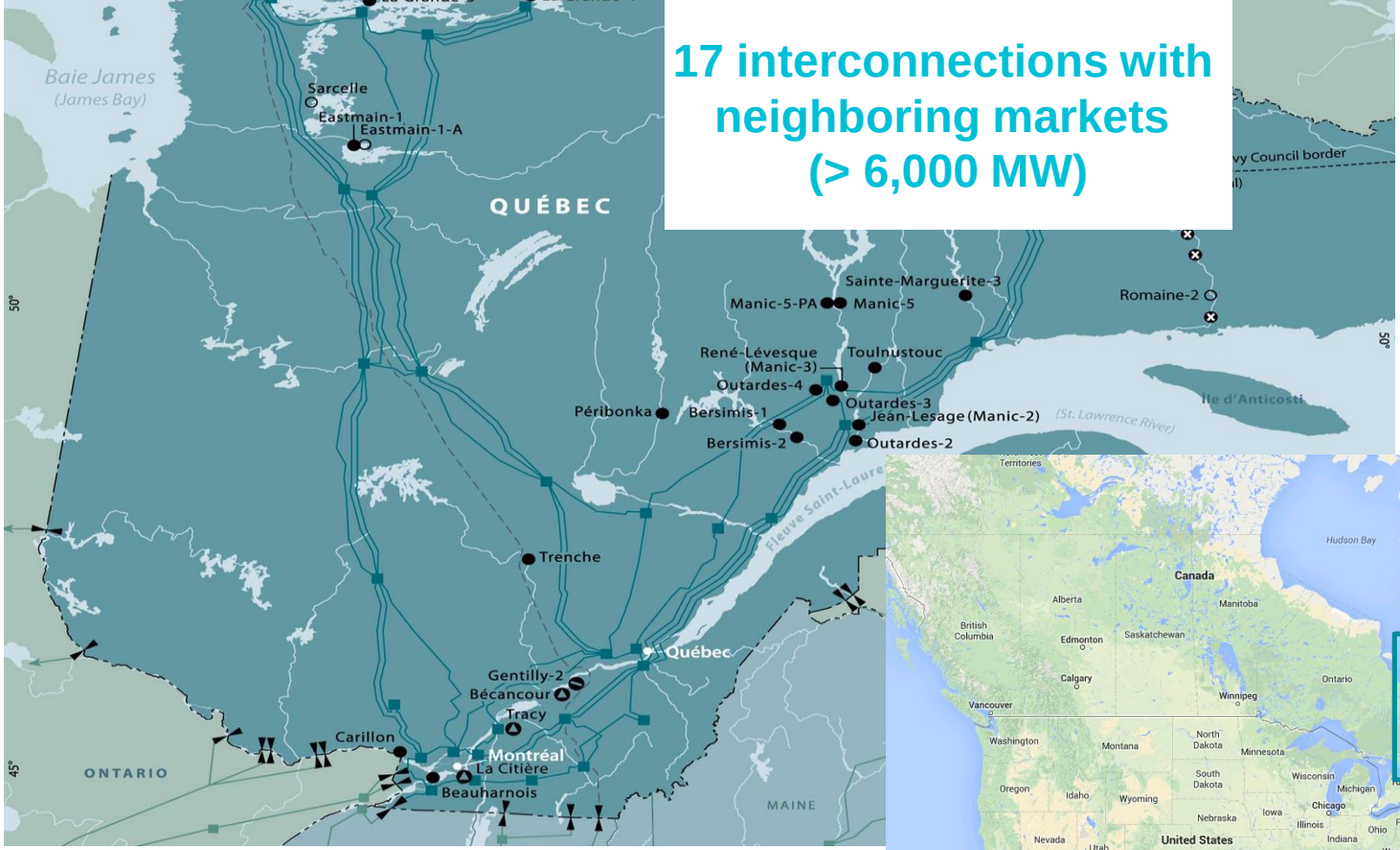
About Hydro-Québec's Research Institute (IREQ)

- **Largest electric utility research centre in North America**
  - 500 employees of which half are researchers
  - $100M invested each year on 100 projets
  - 1000 patents

Hydro-Québec TransÉnergie

- Transmission assets: $17.6 B
- 33,630 km of power transmission lines
  - Including 11,422 km of 735 kV lines
- 514 transmission substations
- Annual investment: $1,3 B

17 interconnections with neighboring markets (> 6,000 MW)



Context of the project

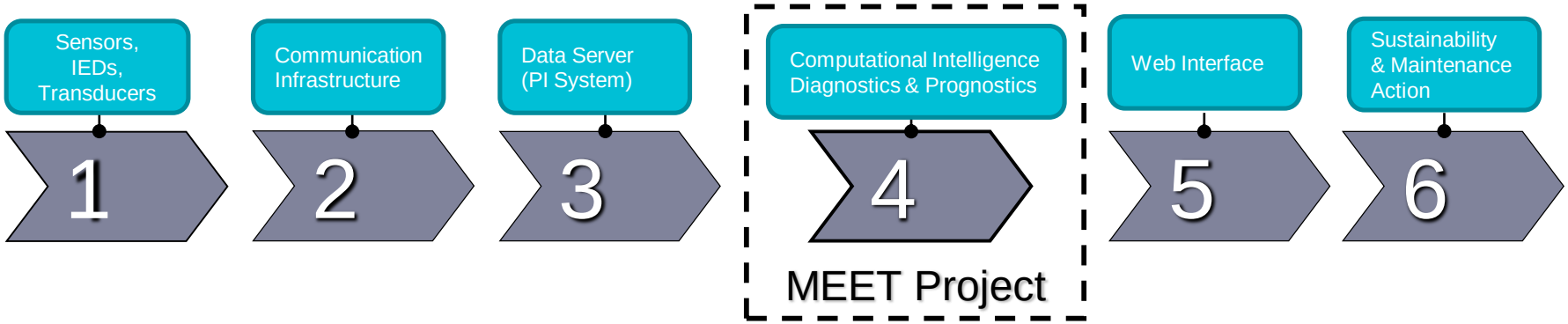
- Network: reliable and available
- Data: high-quality, value-added and just-in-time
- Decisions: appropriate, timely
- Power transformers are critical assets of the network
  - Average age: 33 years old
  - Their life expectancy: 40-50 years
- Transition from systematic to proactive maintenance

Objectives of the project

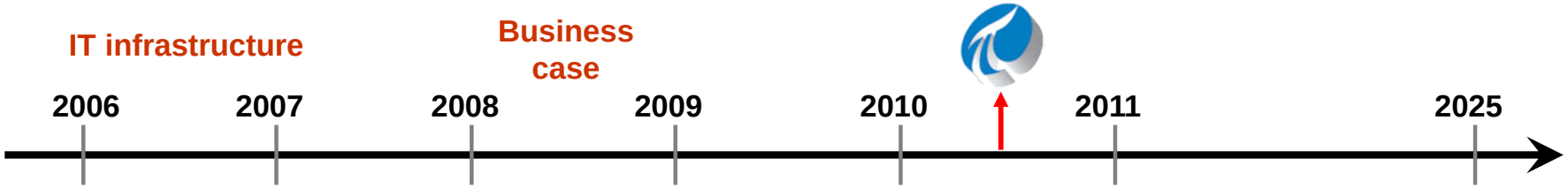
- Maximize asset life
- Reduce the Risk & Cost of unexpected failure
- Drive maintenance and inspection by asset condition
- Awareness of its condition and performance
- To maximize system availability

Transformer monitoring

Real-time monitoring



Transformer monitoring: From past to future



- Use remote monitoring for all growth and asset sustainment projects
  - More than 500 substations over a 15-year timeframe (2009–2025)
    - Objective: 30 to 40 substations a year
  - Monitoring of 240 strategic transformers by 2015
    - Gas and moisture
    - Temperature
    - Bushing and tap changer monitors (future deployment)
  - OSIsoft PI System
    - Automatic addition of points (PI APS, PI GenericCSV_APS connector)
    - Maximizes use of PI AF templates
    - PI AF SDK

PI Webparts: Displays

Avertissements en vigueur

Unité d'installation	Poste	Transfo	Etat
RICHELIEU	RICH_120	T2	Avertissement Hydran
LAURENTIDES	VEREN	T61-C	Avertissement Hydran

Arborescence

- AADT_DEFAUT
  - AADT_SycnhroMDB
  - NORD-EST
    - BAIE-JAMES
      - LG_2_P
      - LG_3_P
      - LG_4_P
      - NEMISCAU
      - RADISSON
      - SARCELL
      - TILLY
    - MANICOUAGAN_EST
    - MANICOUAGAN_OUEST
    - MATAPEDIA
    - MONTMORENCY_&_MAURICIE
    - SAGUENAY
  - SUD-OUEST
    - BEAUHARNOIS-GATINEAU-ABITIBI
    - ILE_DE_MONTREAL
    - LAURENTIDES
    - RICHELIEU

Informations poste

Description	Valeur
Nom du poste	La Suete
État du poste électrique	Normal

Transformateurs

NoExpl	Etat
T1	Normal
T2	Normal
T3	Normal
T4	Normal
T5	Normal
T6	Normal

Lignes

NoExpl	Etat
No Data	

USDI/Passerelles

Equipement
USDI

PI Webparts: Displays (continued)

Informations générales

Description	Valeur
Nom du poste	La Suete
Numéro d'exploitation	T2
État du transformateur	Normal
	Schéma unifilaire

Données ION

Description	Valeur	UM
Courant Phase A	1003	A
Courant Phase B	1031	A
Courant Phase C	997	A
Tension Phases AN	14,815	KV
Tension Phases BN	14,931	KV
Tension Phases CN	14,983	KV
Puissance active	45,179	MW
Puissance réactive	0,219	MVA
	Page ION	

Données inventaire

Description	Valeur	UM
Numéro d'exploitation	T2	
Numéro d'équipement	1U-1543	
Fabricant	FEDERAL PIONEER	
Date de fabrication	01/01/1978	
Puissance 1	40	MVA
Puissance 2	53	MVA
Puissance 3	66	MVA
Tension au primaire	225	KV
Tension au secondaire	26,4	KV

Arborescence

- TRANSFOS
  - T1
  - T2
  - T3
  - T4
  - T5
  - T6

Données Qualitrol

Description	Valeur	UM
Température ambiante	-12,38	°C
Température de l'huile	32,71	°C
Température enroulement basse tension	48,94	°C
Température enroulement haute tension	38,39	°C
	Page Qualitrol	

Données IÉTI

Description	Valeur	UM
Âge de l'équipement	25	yr
Âge apparent	32,135	yr
Cote de l'appareil	19	
	Page IÉTI	

Données Hydran

Description	Valeur	UM
Gaz dissous hydrogène	27	ppm
Taux d'humidité	5	ppm
	Page Hydran	

Données CPC

Description	Valeur
Fabricant du CPC	ABB
Modèle du CPC	UZERN
Date du dernier IC	27/09/2001
Position du changeur de prise	4
Compteur opérations changeur de prise	1154
	Page CPC

Données traversées

No datasets selected

Avertissements

Lien
Page Avertissements

PI Webparts: Displays (continued)

Qualitrol

Informations générales

Description	Valeur
Nom du poste	La Suete
Numéro d'exploitation	T2
État de la sonde	Normal

Températures

Mesures

Description	Date	Valeur	UM
Température ambiante	03/03/2014 13:55:00	-12,64	°C
Température de l'huile	03/03/2014 13:54:56	33,84	°C
Température enroulement basse tension	03/03/2014 13:54:29	50,6	°C
Température enroulement haute tension	03/03/2014 13:54:29	39,75	°C

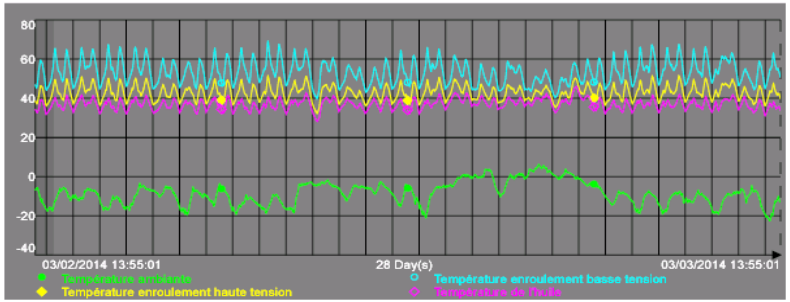
Alarmes

Description	Date	État
Température huile au sommet de la cuve (relais #3)	03/03/2014 13:24:23	
Point chaud, température d'enroulement (relais #4)	03/03/2014 13:24:23	
Supervision de contact du déclencheur (relais #6)	03/03/2014 13:24:23	

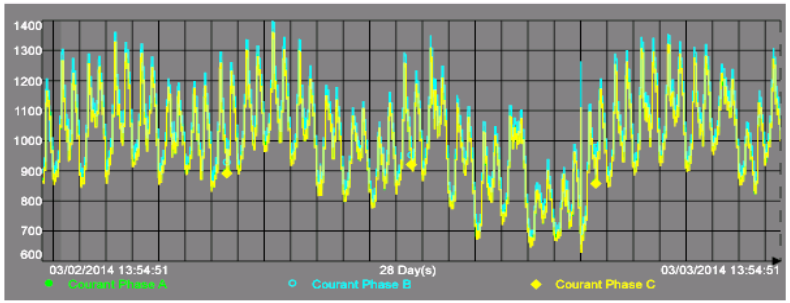
Plage de temps

Start Time *-1mo End Time * Apply

Courbes de tendances Qualitrol



Courbes courants ION



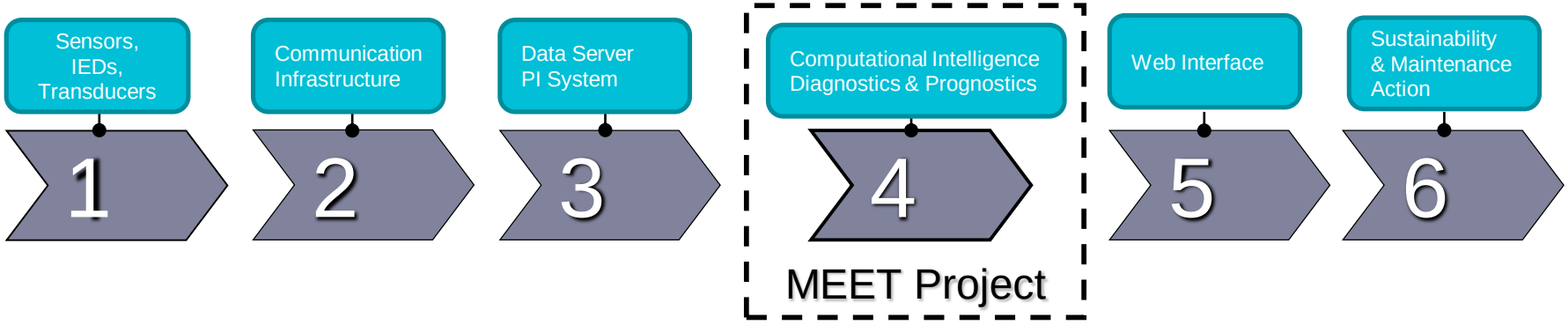
PI Notifications: Alerts

Remote Maintenance Centres

Technical Support

Managers

Transformer monitoring



Thermal Performance

Dissolved Gas

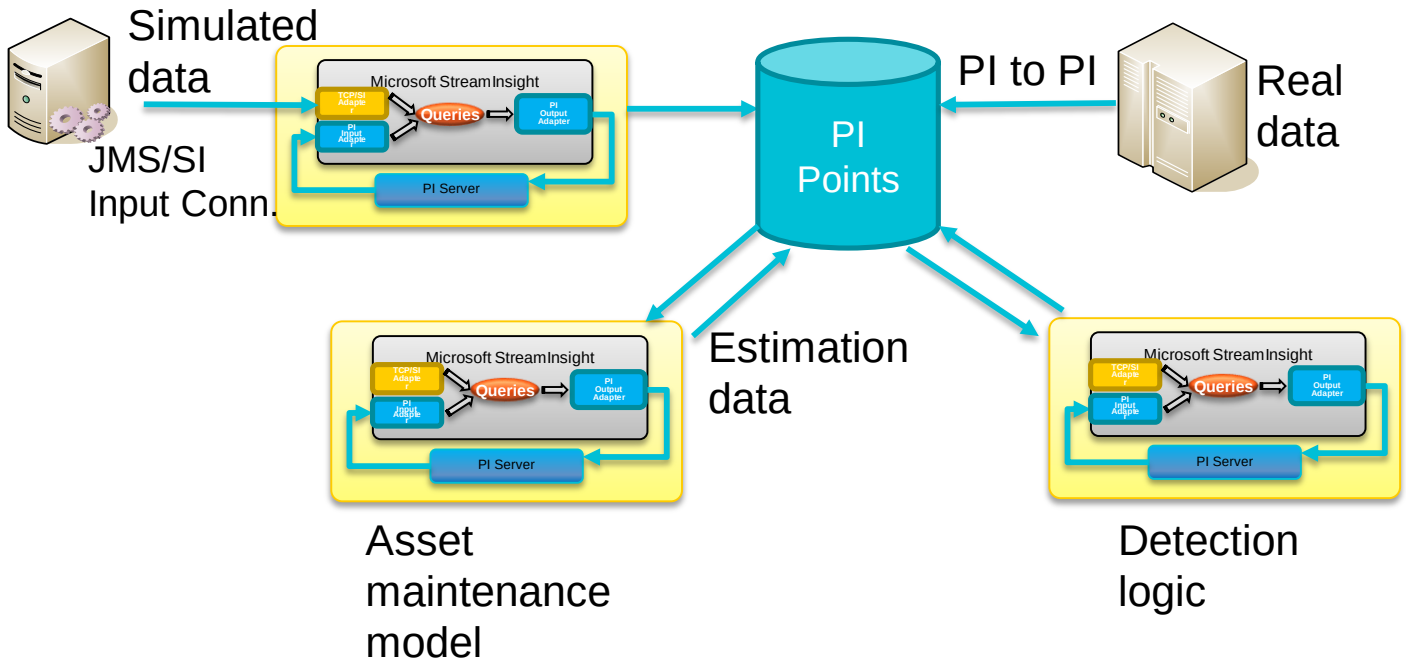
Moisture and Aging

Tap Changer

Bushing

Mechanical state

Acquisition, Estimation & Detection

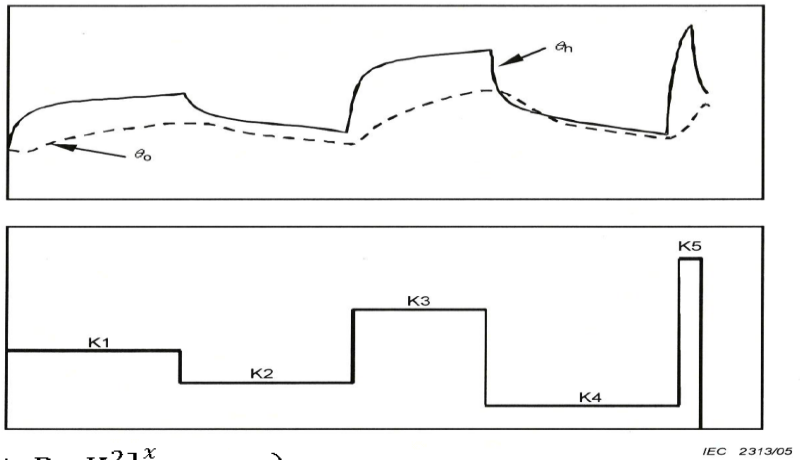


Thermal prediction with physical models

- IEC 60076-7 International Standard
  - Loading guide for oil-immersed power transformer
- IEEE Clause 7 Non-Linear
- IEEE Clause 7 Linear
- Swift
- Susa

IEC 60076-7 / Exponential Equations

- Load varies as a step function
- Used in the determination of heat transfer parameters
- Increasing load (κ)



$$\theta_o(t) = \theta_a + \Delta\theta_{oi} + \left\{\Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^{\chi} - \Delta\theta_{oi}\right\} \times f_1(t)$$

- Decreasing load (κ)

$$\theta_o(t) = \theta_a + \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^{\chi} + \left\{\Delta\theta_{oi} - \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R}\right]^{\chi}\right\} \times f_3(t)$$

IEC 60076-7 / Difference Equations

- Both the load and the ambient temperature are time-varying
- Adapted for monitoring purposes

$$\theta_{o(n)} = \theta_{o(n-1)} + D\theta_{o(n)}$$

$$D\theta_o = \frac{Dt}{k_{11}\tau_o}\left[\left[\frac{1+K^2R}{1+R}\right]^x \times (\Delta\theta_{or}) - [\theta_o - \theta_a]\right]$$

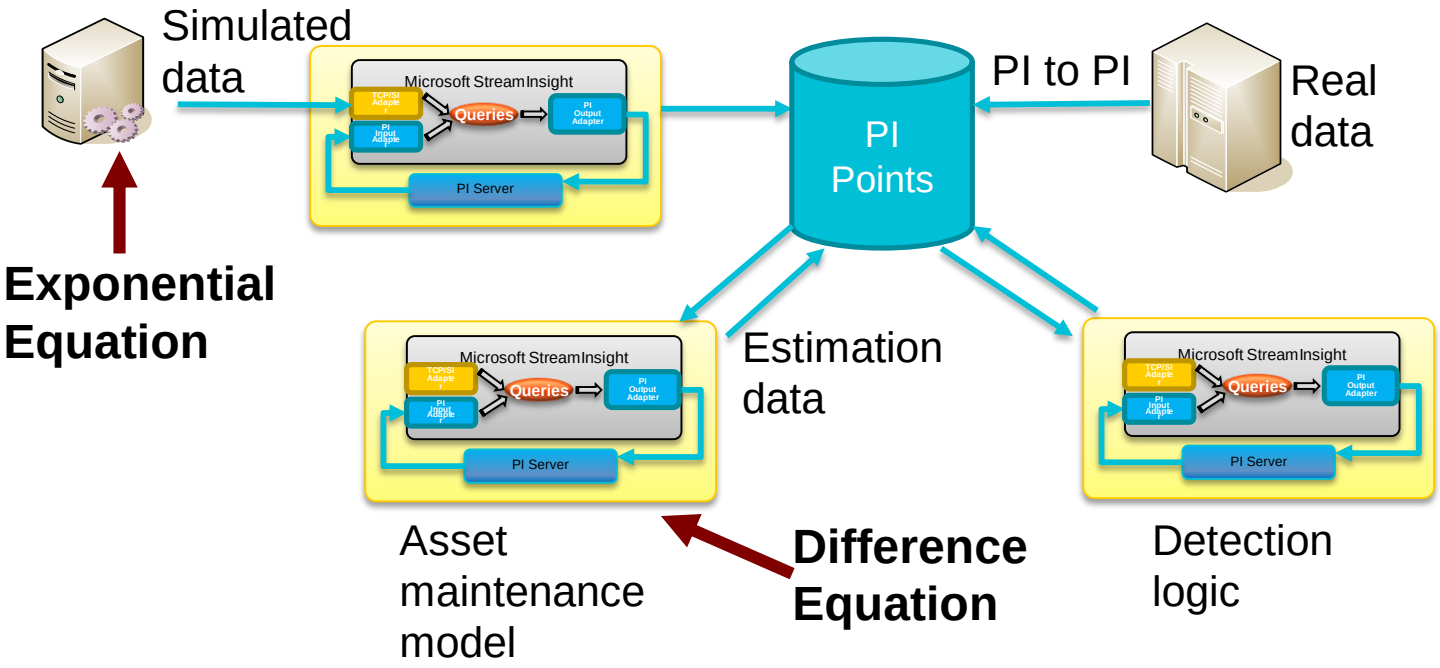
Temporal variables

- **κ : Load factor**
- **θo: Top-Oil temperature**
- **θ_a : Ambient temperature**
- **Dt: Time interval**
  - 1 minute

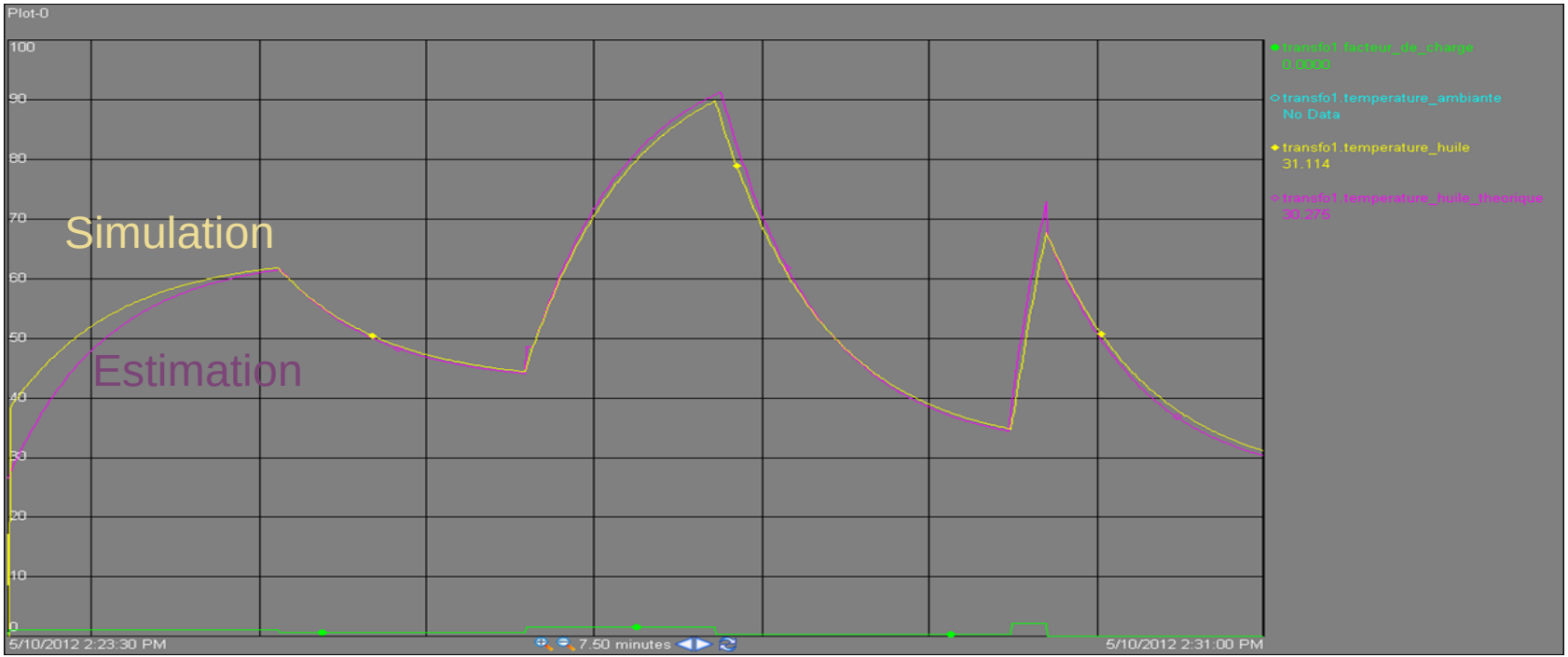
Constants:

- **k_{11} : Model constant**
  - 0,8
- **τ_O : Avg. oil time constant**
  - 150
- **Δ θ_{or} : Top oil rise constant**
  - 50
- ***R*: Load loss ratio**
  - 8,4
- ***x*: Exponential power of current vs top oil rise**
  - 0,8

Acquisition, Estimation & Detection



Difference equation performance



Real data

- 3 years of data

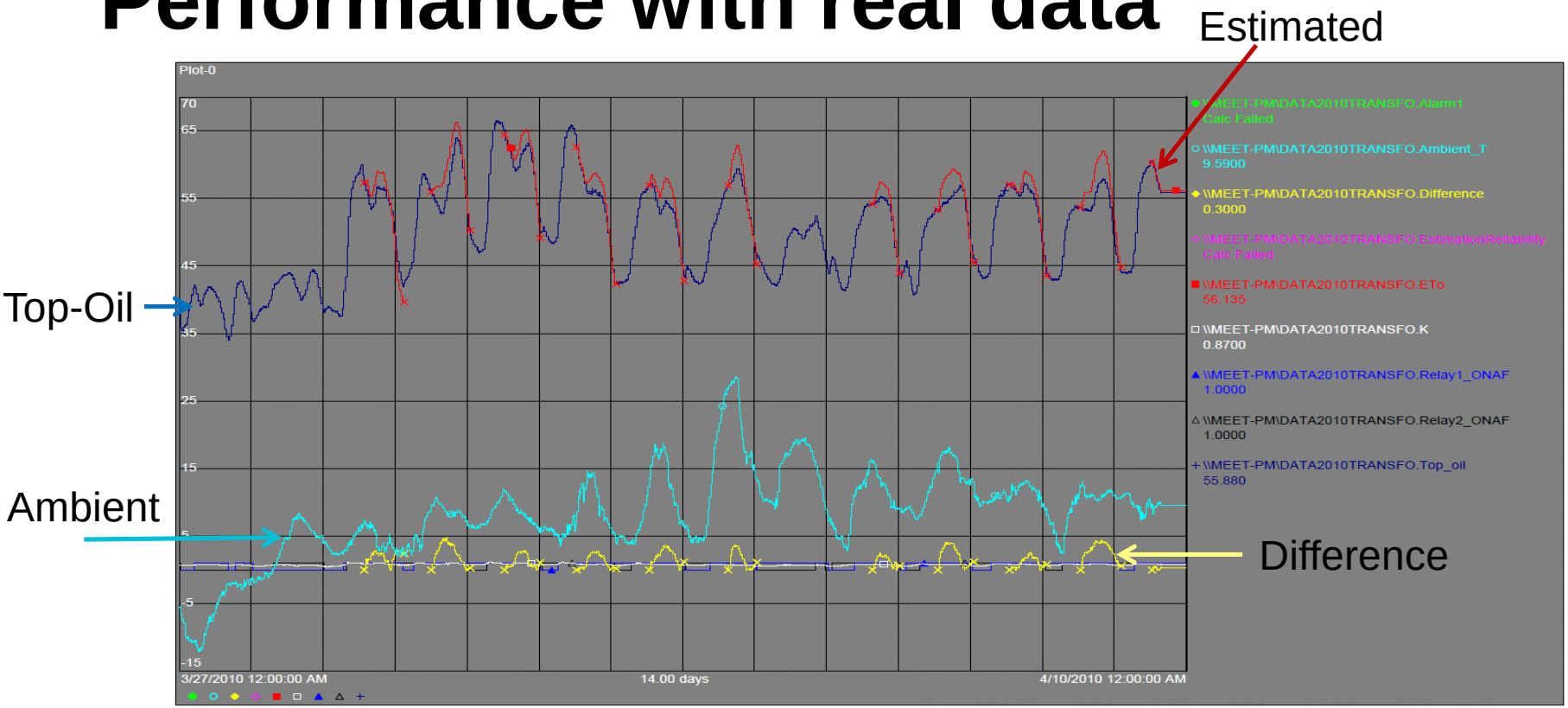
Load from 0 to 1.35 pu
Ambient Temp. from -31°C to 33°C

DATA2009.csv

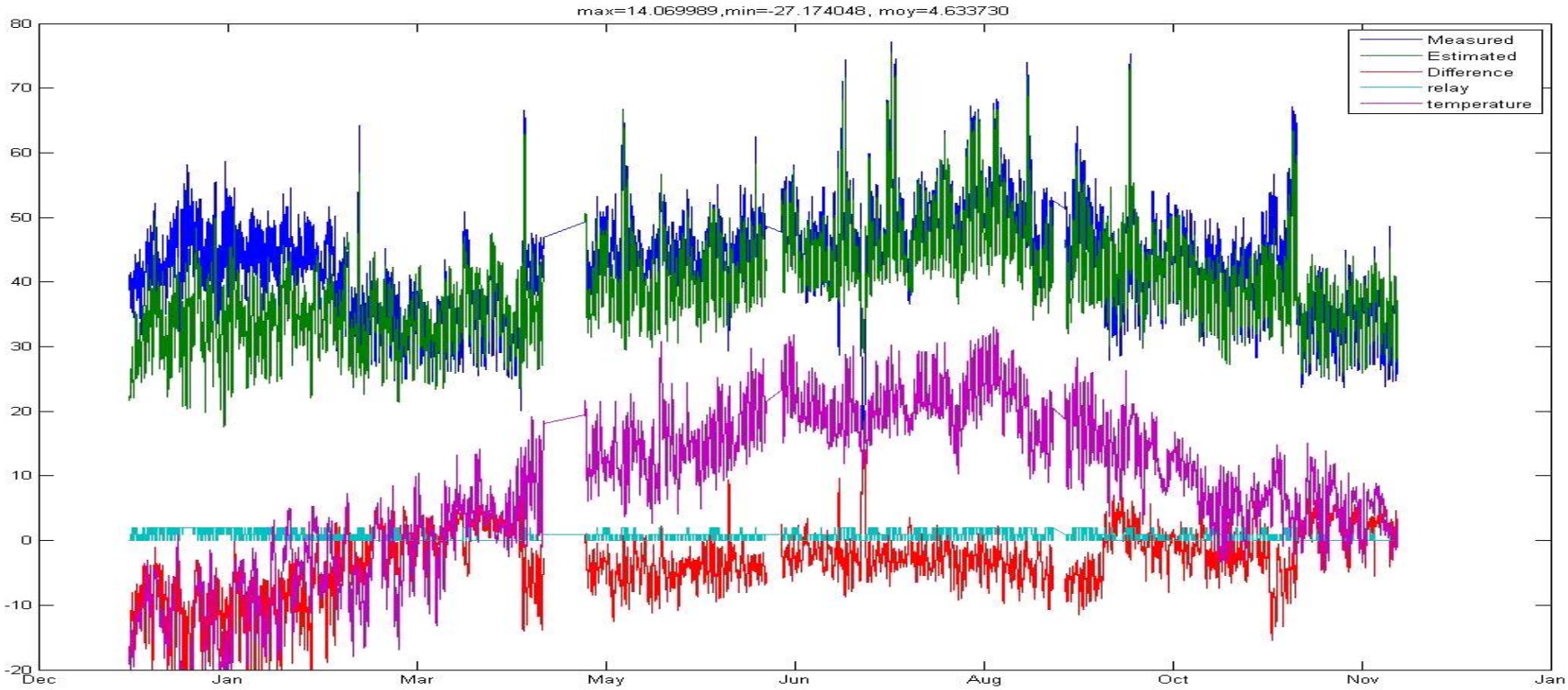
	A	B	C	D	E	F
1	TimeStamp	Ambient_T	LV_current	Relay1_ONAF	Relay2_ONAF	Top_oil
304375	8/15/2009 12:38	29.59	880.7922078	1	0	55.18
304376	8/15/2009 12:39	29.77	878.2367178	1	0	55.2
304377	8/15/2009 12:40	29.7	875.6812279	1	1	55.26
304378	8/15/2009 12:41	29.76	875.6812279	1	1	55.33
304379	8/15/2009 12:42	29.75	875.6812279	1	1	55.28
304380	8/15/2009 12:43	29.77	875.6812279	1	1	55.29
304381	8/15/2009 12:44	29.75	875.6812279	1	1	55.29
304382	8/15/2009 12:45	29.73	872.2739079	1	1	55.29
304383	8/15/2009 12:46	29.77	875.6812279	1	1	55.3
304384	8/15/2009 12:47	29.91	872.2739079	1	1	55.35
304385	8/15/2009 12:48	29.9	871.4220779	1	1	55.35

DATA2009

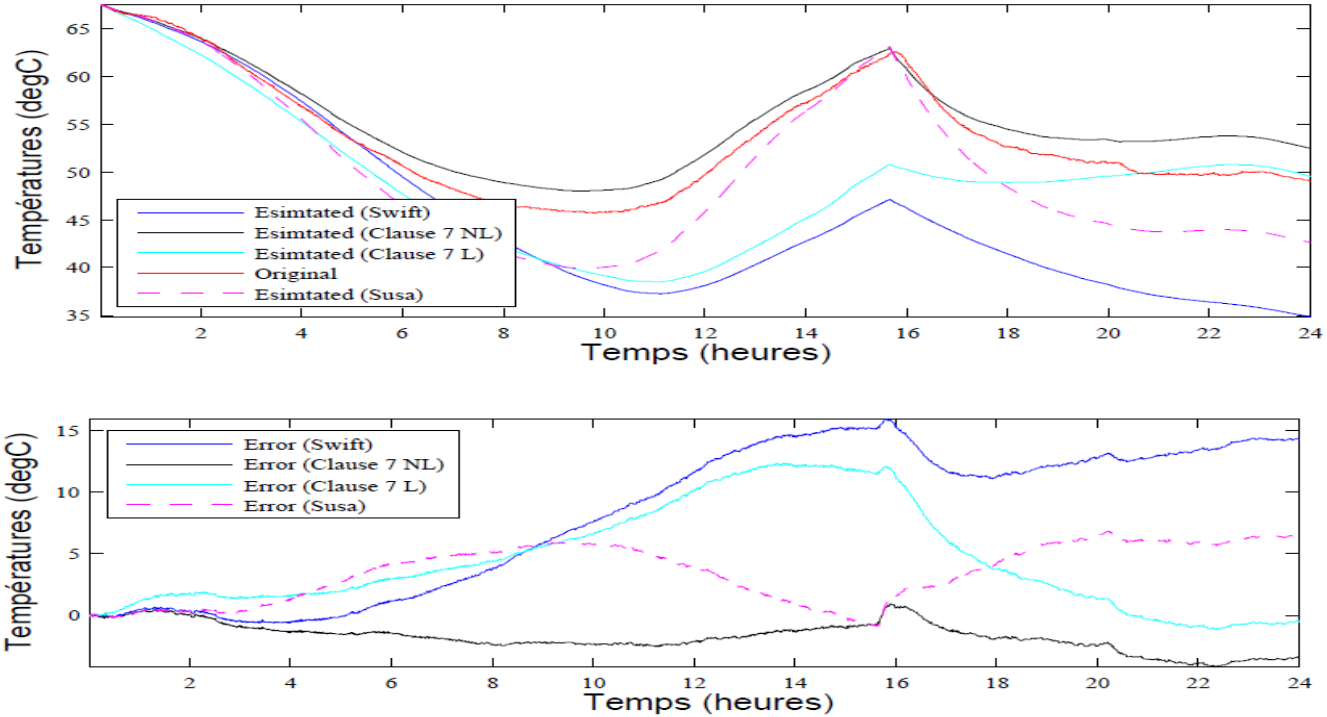
Performance with real data



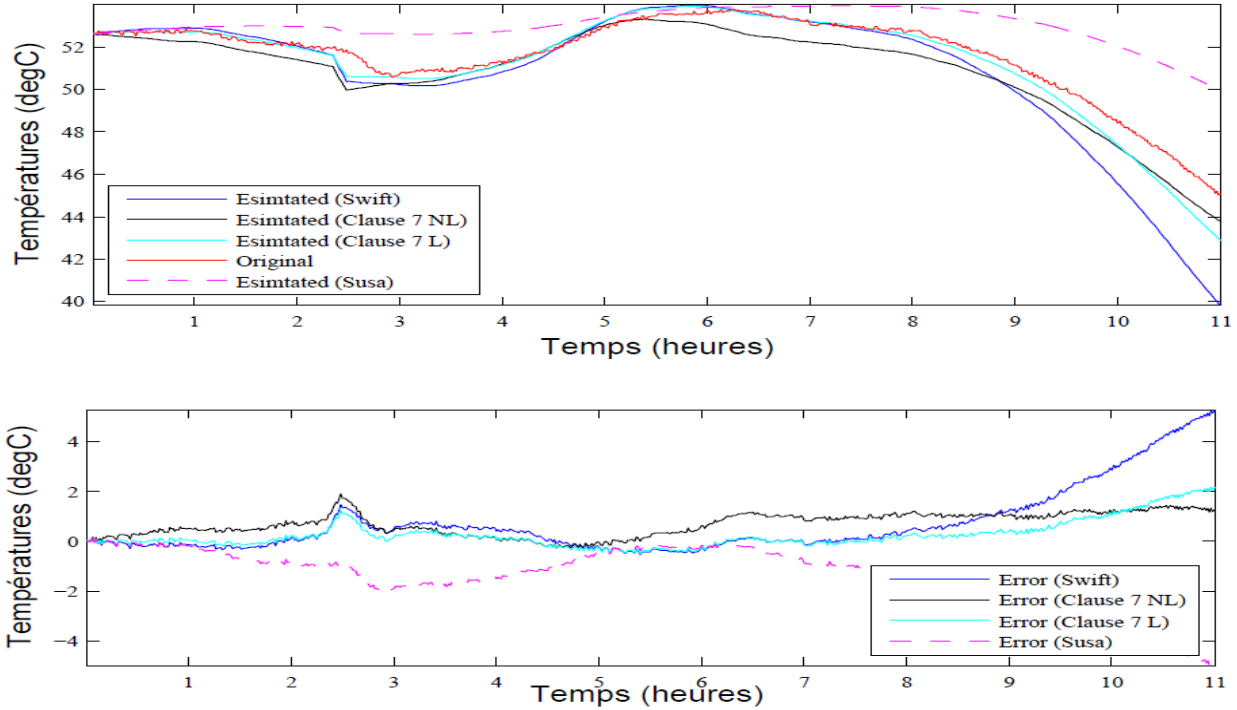
Performance over a year



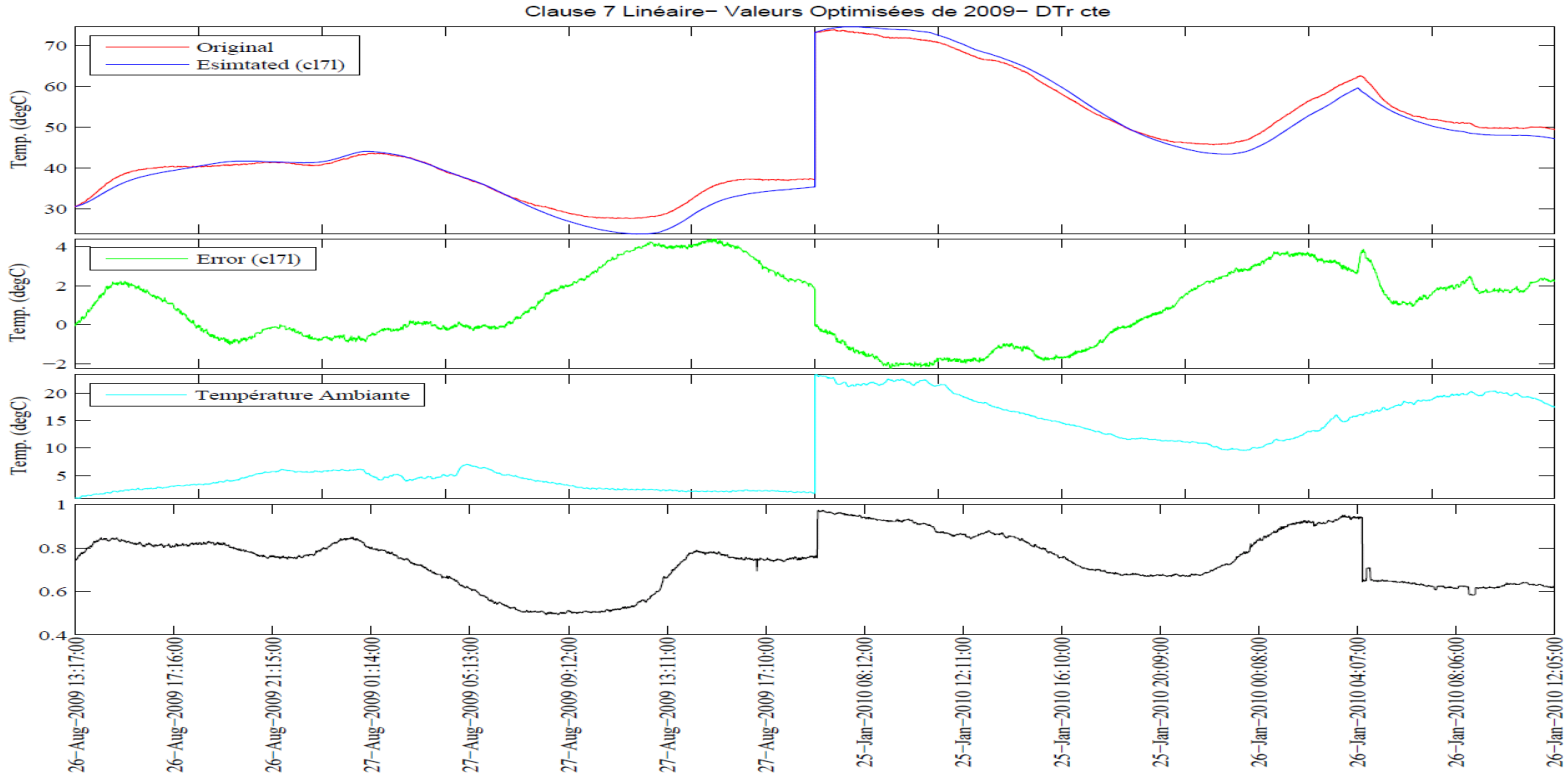
Results with physical models – 2009



Results with physical models – 2011



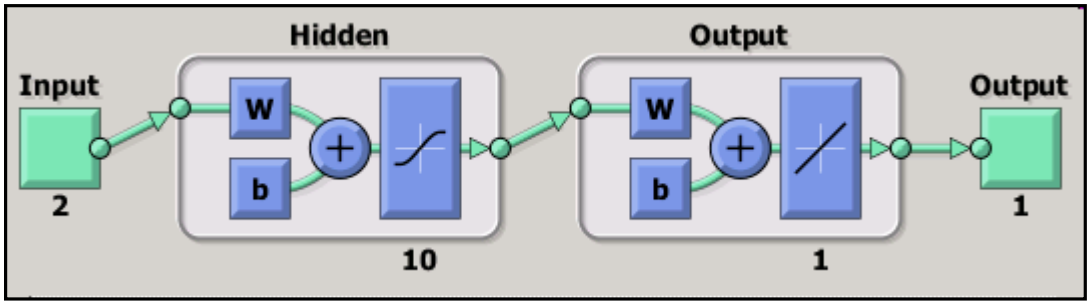
Results with clustering



Neural networks

- Neural networks are nonlinear black-box structures with “interesting” properties
  - general architecture
  - universal approximator
  - non-sensitive to over-parametrization
  - have learning algorithm to acquire knowledge from their environment, using examples
  - have recall algorithm to use the learned knowledge

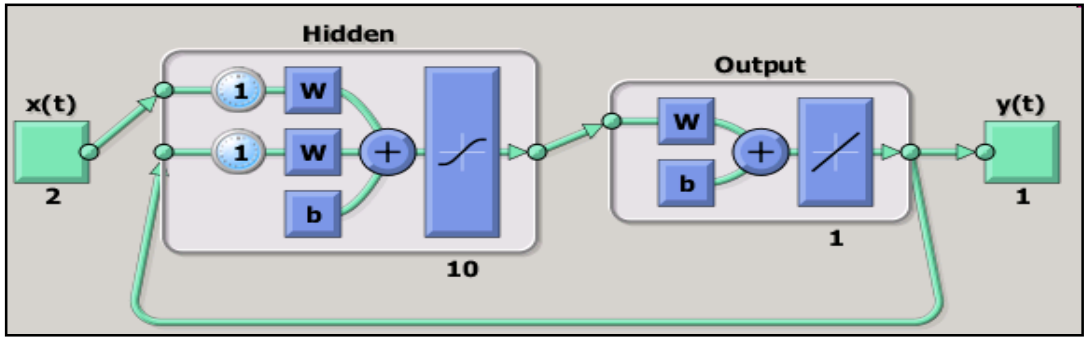
Basic Regressor Neural Networks



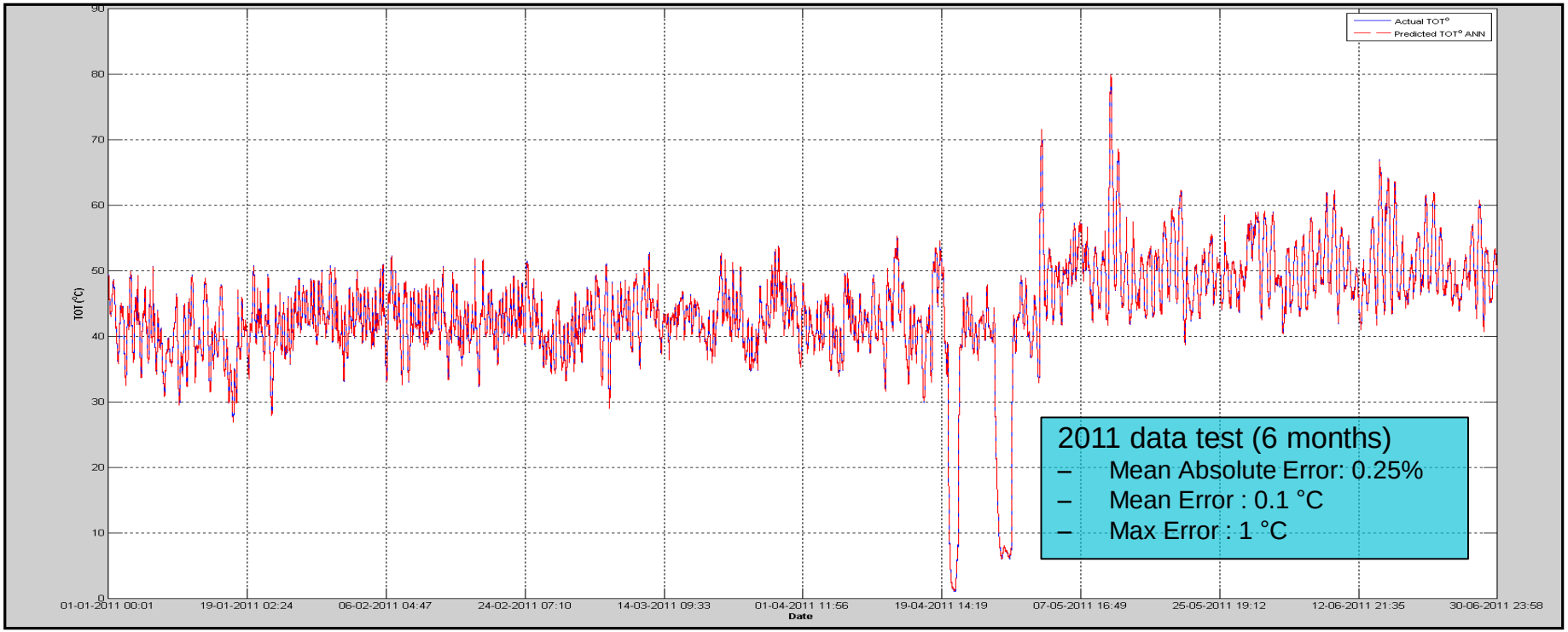
Current Inputs
(Static Networks)

Current Inputs
and Past Outputs
(Dynamic Networks)

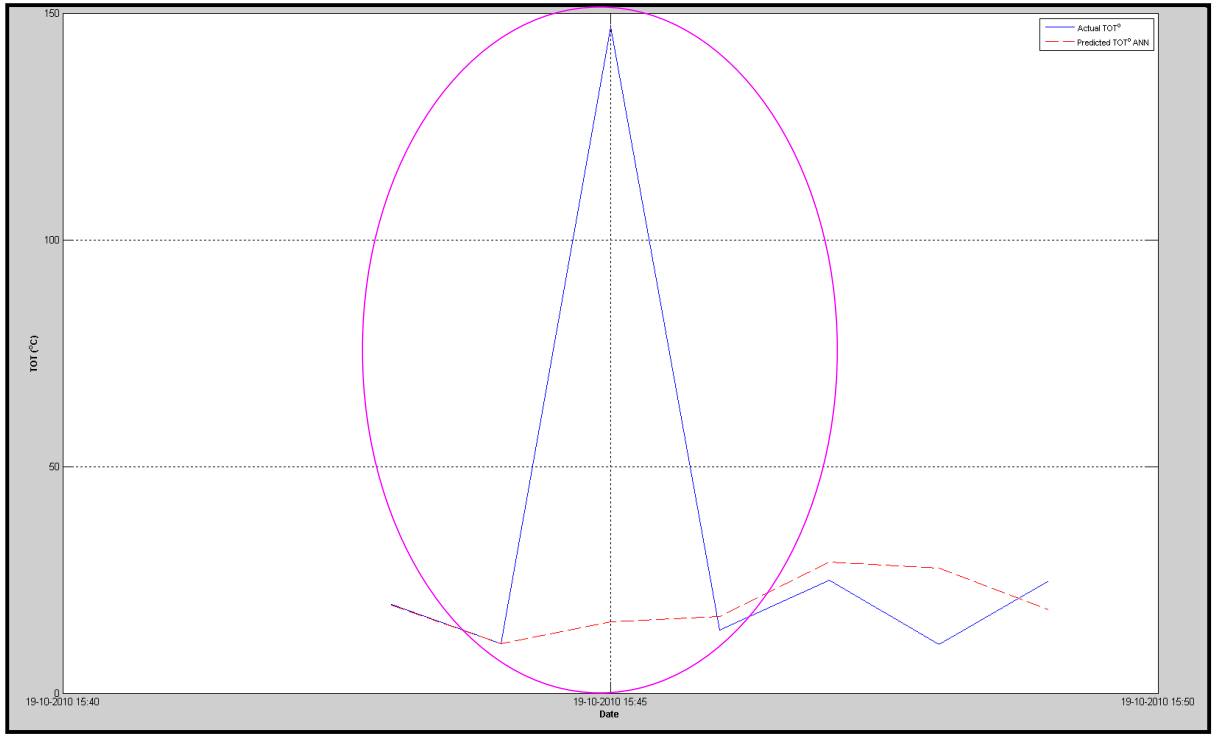
$$\theta_{o(n)} = \theta_{o(n-1)} + D\theta_{o(n)}$$



Matlab results for Neural Network top-oil temperature prediction

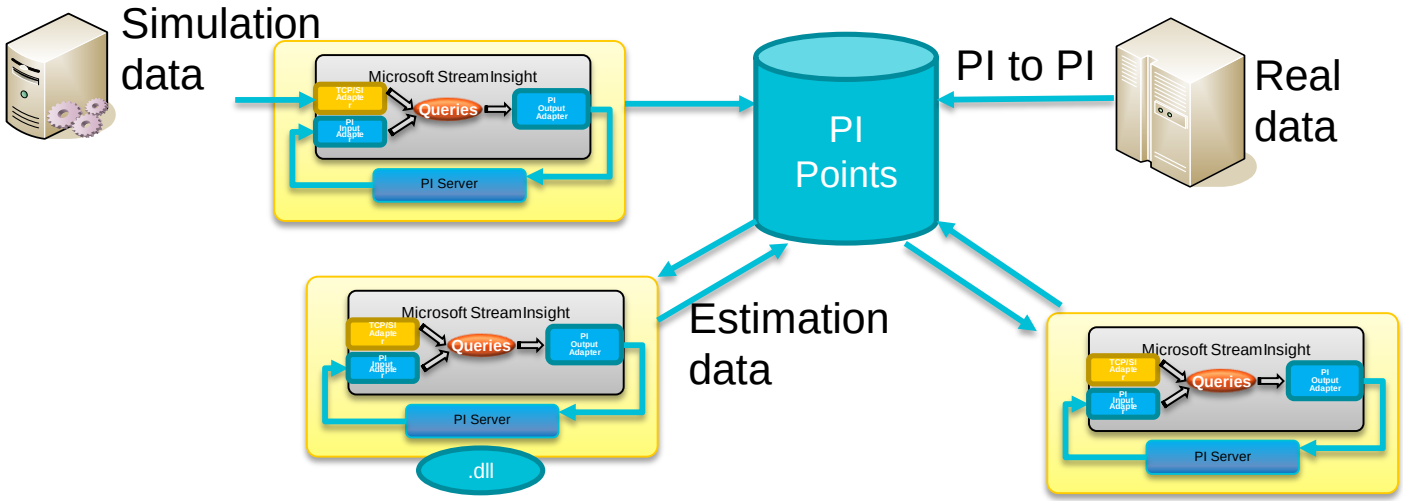


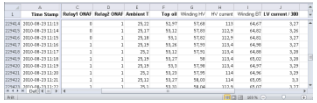
Abnormal behaviour (data cleaning)

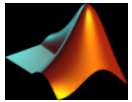


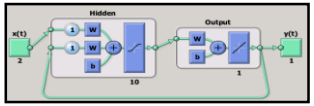
AmbT	load	Actual	ANN
9.68	36	19.52	19.49
9.68	36	10.85	10.89
9.68	11739	146.90	15.81
9.68	12339	13.86	16.88
9.56	3	24.86	28.95
9.58	36	10.79	27.59
9.37	3	24.75	15.70
9.38	3	10.70	10.71
9.37	3	10.72	10.69
9.38	3	10.72	10.69
9.37	3	10.67	10.66

Neural Network Estimator

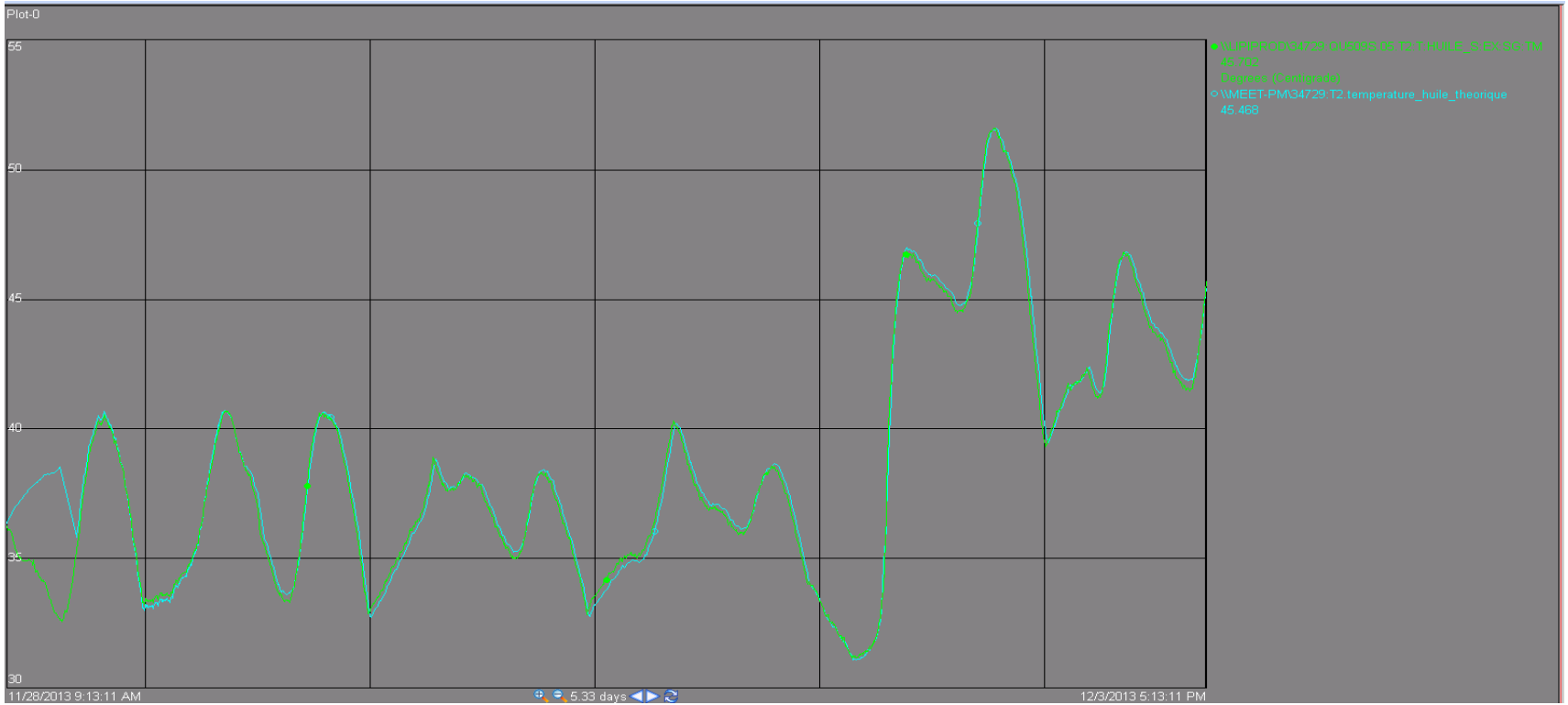








Neural Network prediction results with real data



Future work

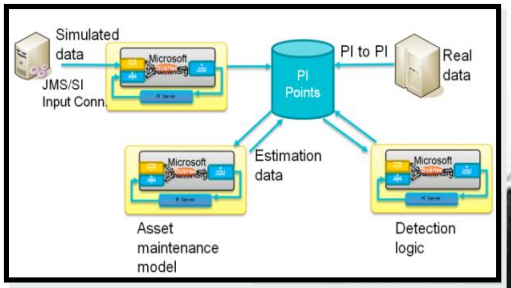
- Gradual implementation of models (2014-2018)
  - Thermal performance
  - Dissolved gas
  - Moisture and aging
  - Tap changer and bushing
  - Mechanical state
- Each model are developed with the following steps

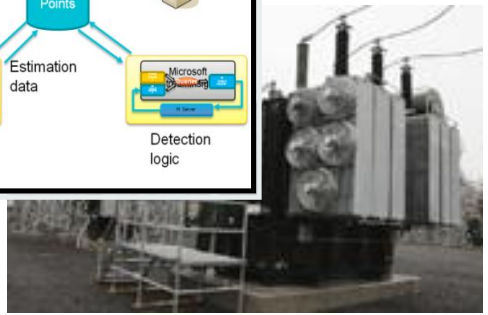
Proactive maintenance Advantages

- Transformers
  - Avoiding major failures
  - Avoiding unavailability and captive power
- Equipment
  - Awareness about equipment condition as it ages
- Sensors
  - Detection of malfunctioning equipment
  - Improvements on many equipment settings

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. »





Hydro Québec
Institut de recherche

Business Challenge

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

Solution

- Set up the infrastructure & organization needed to ensure real-time monitoring of transformer condition
- Real-time data analysis with predictive model

Results and Benefits

- Transformers
  - Avoiding major failures
- Equipment
  - Awareness about equipment condition as it ages

Nicolas Di Gaetano

- DiGaetano.Nicolas@hydro.qc.ca
- Fiability Engineer
- TransEnergie, Hydro-Québec

Arnaud Zinflou

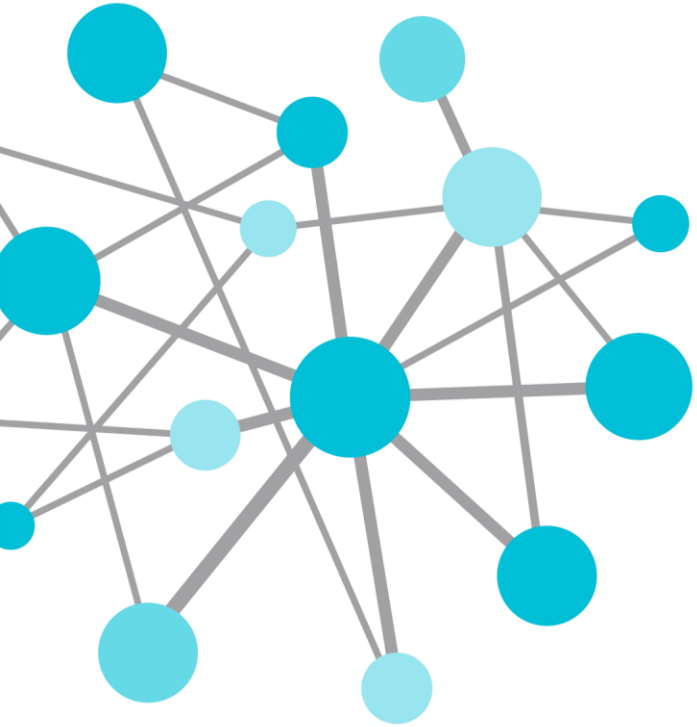
- Zinflou.Arnaud@ireq.ca
- Researcher
- IREQ, Hydro-Québec

Patrick Picher

- Picher.Patrick@ireq.ca
- Researcher & project manager
- IREQ, Hydro-Québec

Luc Vouligny

- Vouligny.Luc@ireq.ca
- Researcher
- IREQ, Hydro-Québec



THANK YOU

Brought to you by OSIsoft.