Hybrid dynamic classifier for single and multiple drift-like fault diagnosis in a class of hybrid dynamic systems: application to wind turbine converters

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Outline

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  - ✓ Research objectives and contributions
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- **Challenges related to wind turbine converter fault diagnosis**
- **Proposed approach**
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- **Experimentation and obtained results**
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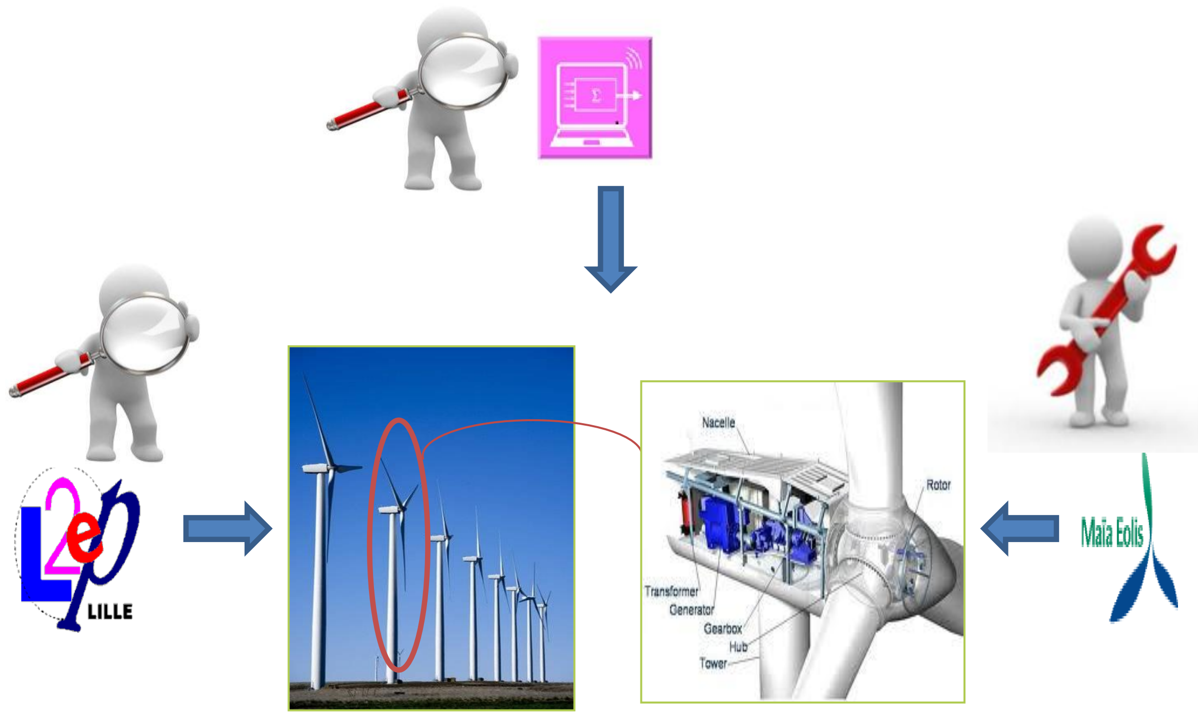
  - ✓ Multiple drift-like fault in C_1 and C_2
- **Conclusion and future directions**

Context and motivations

- Context
  - DFSER Project
  - Skills
    - L2EP
    - MAIA EOLIS
    - URIA



Research objectives and Contributions

- ✓ Research objectives
  - – Maintenance and operation costs reduction
  - – Increase the availability of wind turbine

- ✓ Contributions
  - – The contributon of the project aims at achieving a drift-like fault diagnosis of wind turbine

Early Detection of Drift-like fault

Oui

Non

$ 40 K

$ 250 K

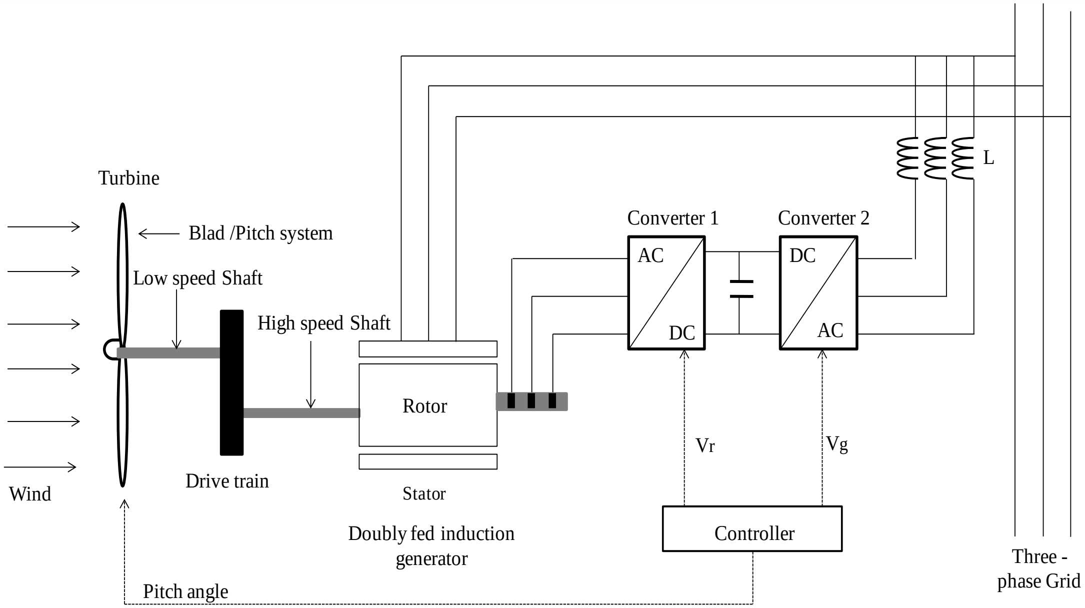
Wind Turbine Description

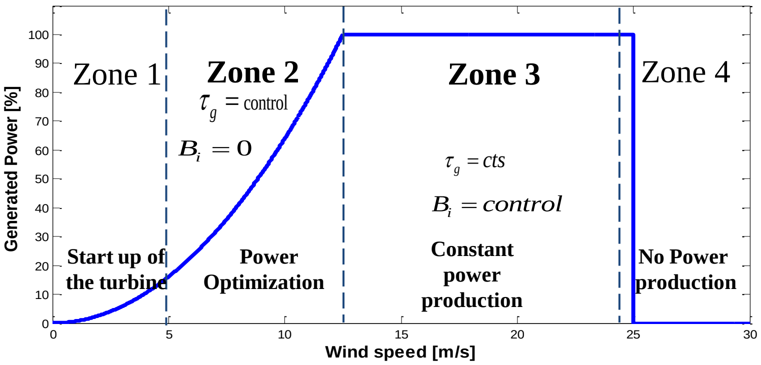
- Doubly Fed Induction Generator structure consists of two converters :
  - Grid power side converter
  - Rotor side converter

- Controller operates in four zones in order to optimize the energy production according to the wind speed

- Control strategies are applied to optimize the energy production :
  - Converter torque
  - The blades angle

- The focus of converter control of WT is in zone 2 and 3



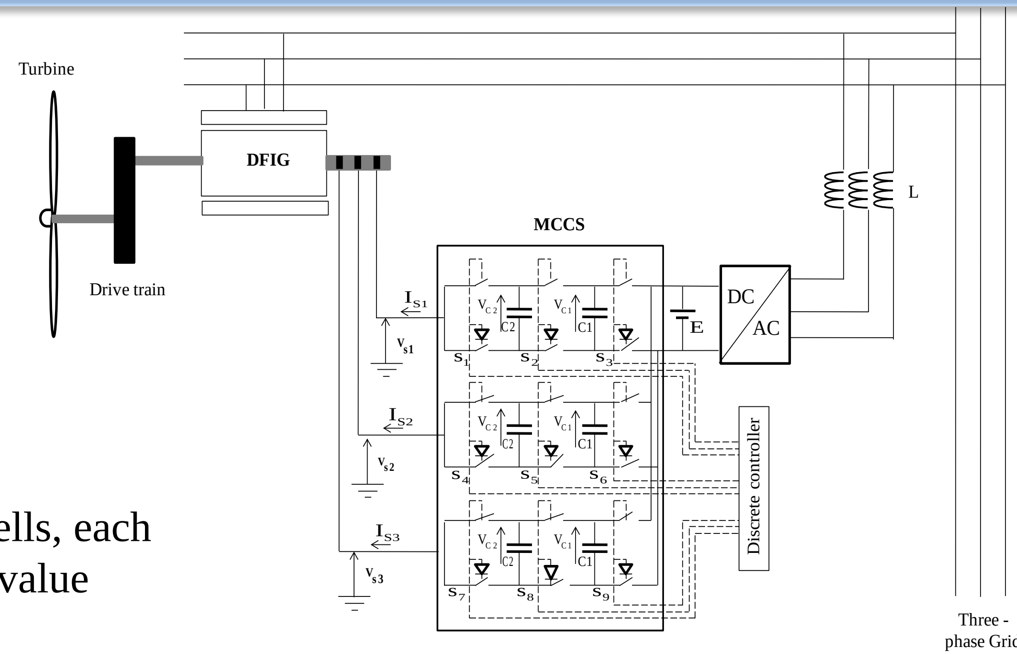


Power converter within wind turbine

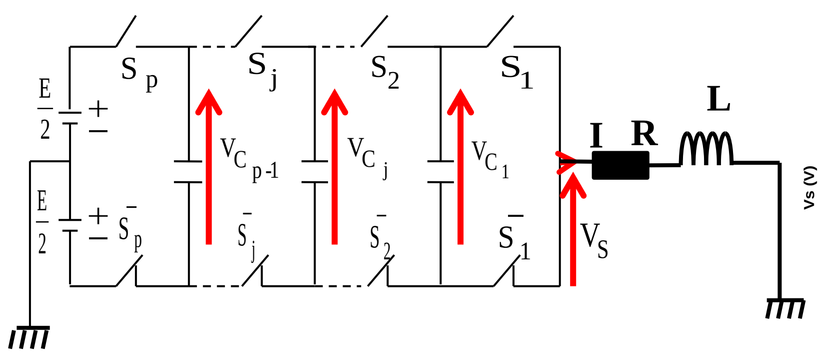
- The rotor side converter consists of three identical three cell converters used in DC-AC

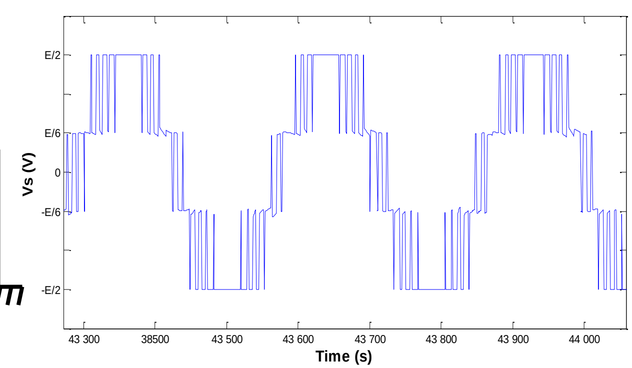
- The multicellular converters are used to control the currents of the DFIG rotor

- The multicellular converters consist of serial cells, each cell contains two switches with complementarty value



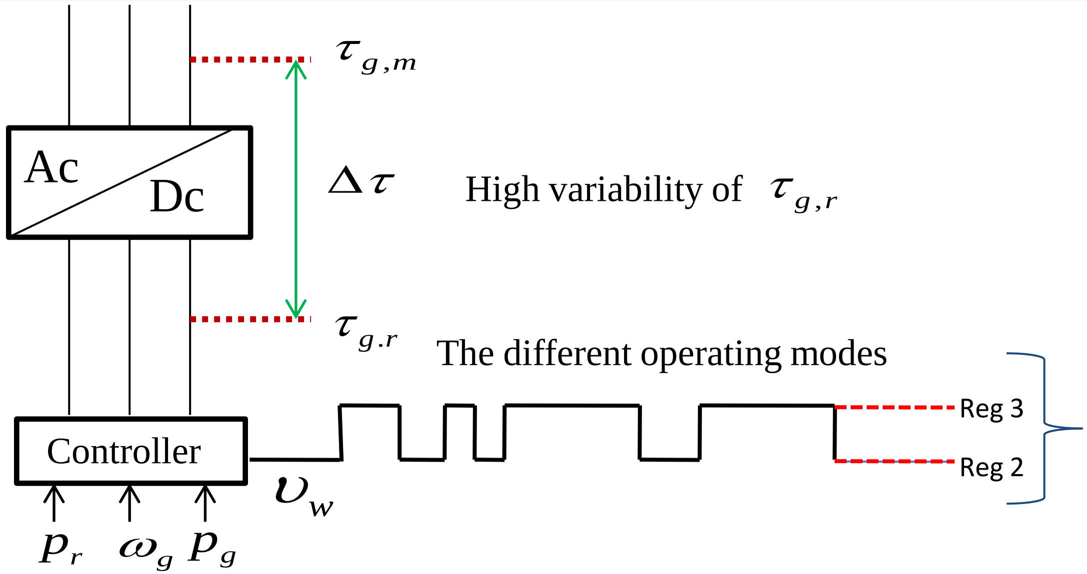
$$V_{C_j,ref} = j.\frac{E}{p}, \quad j = 1, \ldots\ldots\ldots, p-1$$





Challenges

Power Converters



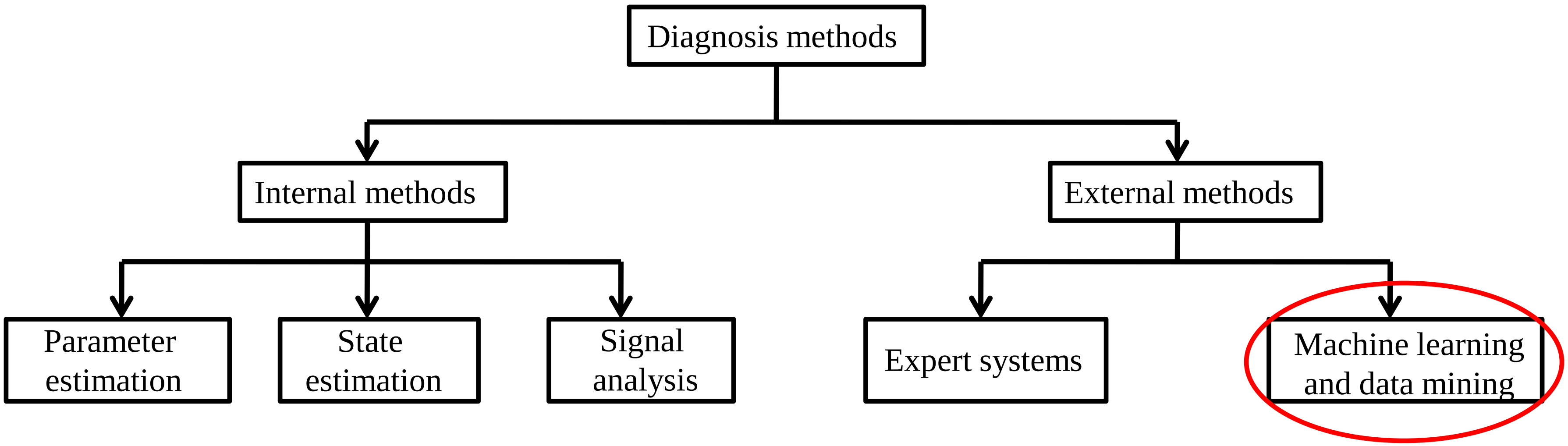
Challenges

- Unknown aerodynamique torque related to the wind speed
- sensor : isolation problem
- High variability of $\tau_{g,r}$
- The différent operating modes correlated to the wind speed

objectives

- Converter drifts detection and isolation

Proposed approach



Major Advantages

- Ability to learn without to a priori physical knowledge of the system
- Very simple to implement
- Powerfull tool of handling non-linear and multi-variable problems
- Ability to learn on-line

Proposed approach

Hybrid dynamic data-mining scheme

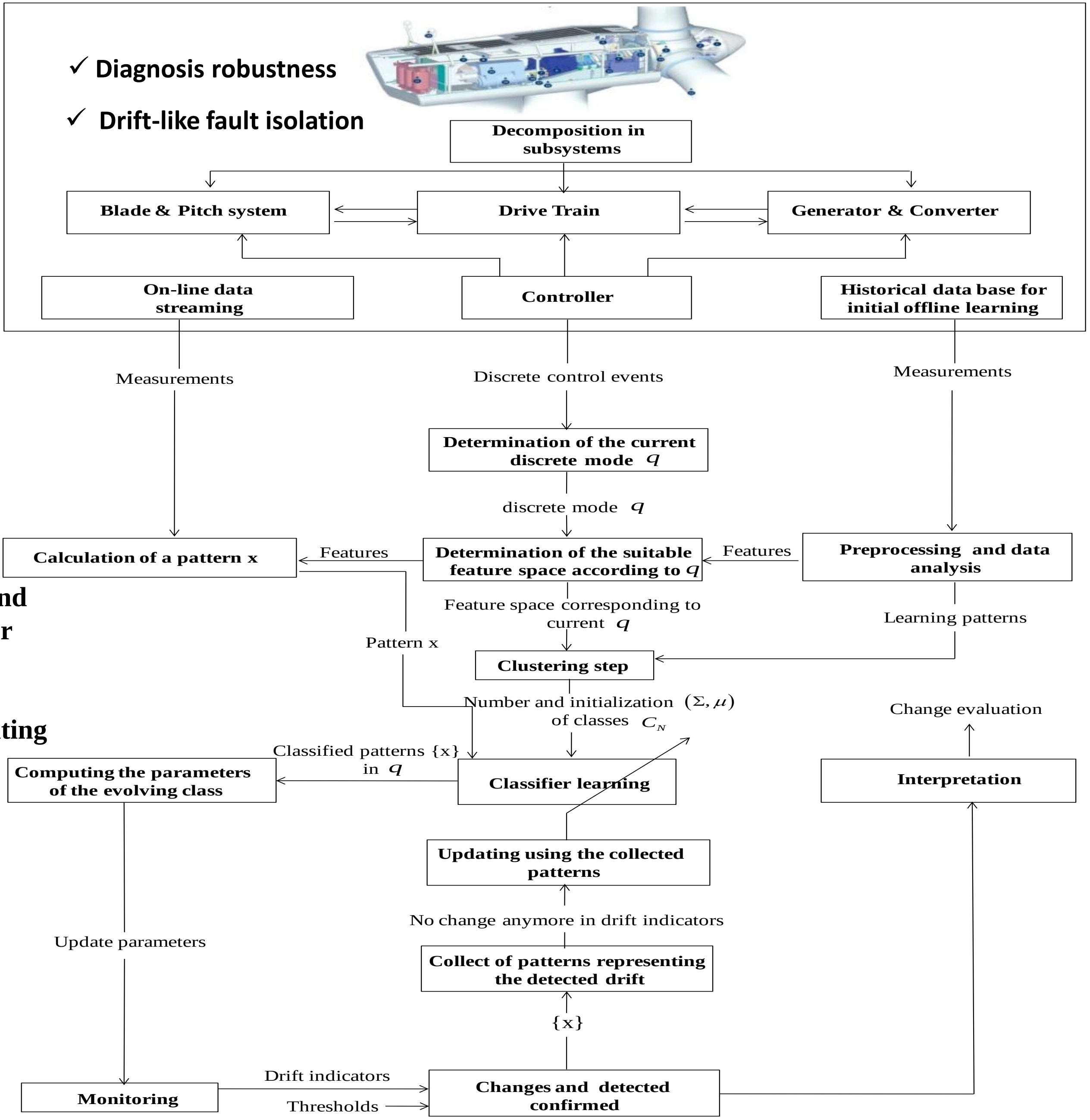
- ✓ A generic on-line and adaptative machine learning and data mining scheme

  - Use of any learning method

- ✓ A hybrid dynamic classifier for signale and multiple drift-like faults diagnosis in power Converter

  - Maximize the discriminition between operating conditions in the feature space

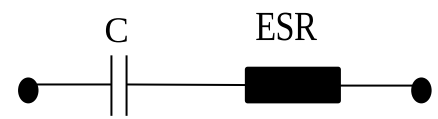
- ✓ This scheme consider only data samples about normal operating conditions



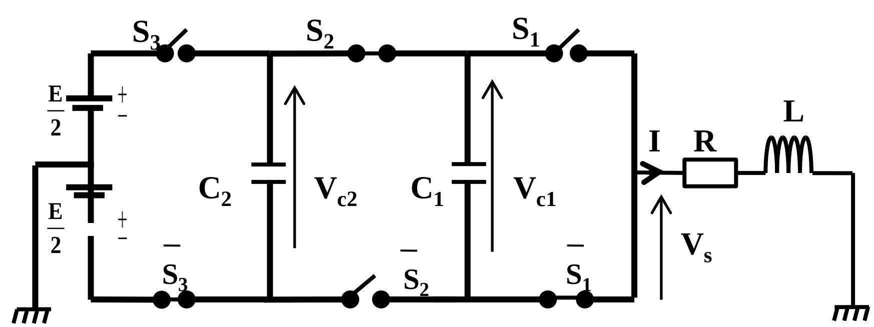
Fault scenarios

Fault N°	Drift speed	Converter Fault	Type
F1h	5s (High)	$ESR_1 \rightarrow ESR_{1F}$	Simple fault in C_1
F2m	10s (Medium)	$ESR_1 \rightarrow ESR_{1F}$	Simple fault in C_1
F3s	15s (Slow)	$ESR_1 \rightarrow ESR_{1F}$	Simple fault in C_1
F4h	5s (High)	$ESR_2 \rightarrow ESR_{2F}$	Simple fault in C_2
F5m	10s (Medium)	$ESR_2 \rightarrow ESR_{2F}$	Simple fault in C_2
F6s	15s (Slow)	$ESR_2 \rightarrow ESR_{2F}$	Simple fault in C_2
F7h	5s (High)	$ESR_2 \rightarrow ESR_{2F}$ and $ESR_2 \rightarrow ESR_{2F}$	Multiple fault in C_1 and C_2
F8m	10s (Medium)	$ESR_2 \rightarrow ESR_{2F}$ and $ESR_2 \rightarrow ESR_{2F}$	Multiple fault in C_1 and C_2
F9s	15s (Slow)	$ESR_2 \rightarrow ESR_{2F}$ and $ESR_2 \rightarrow ESR_{2F}$	Multiple fault in C_1 and C_2

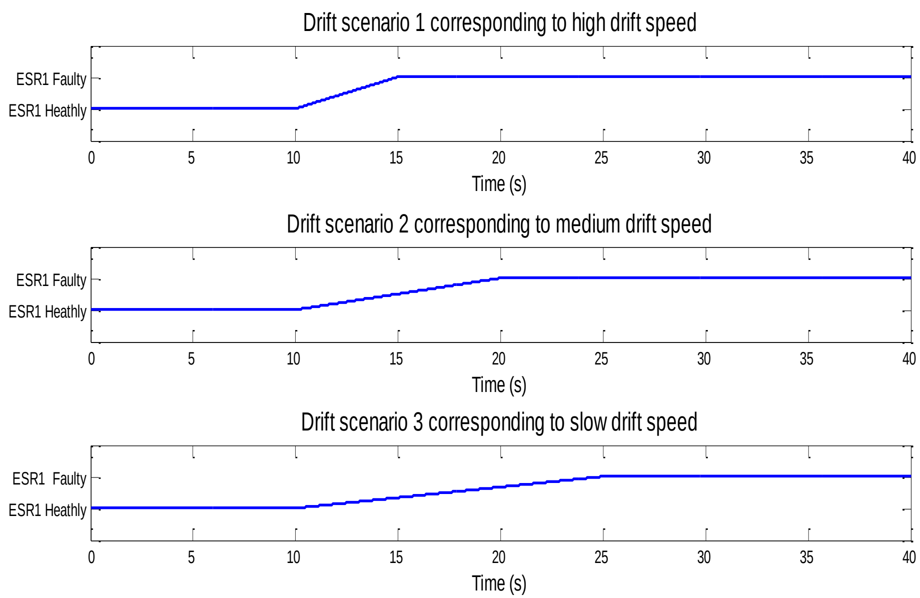
Generated converter fault scenarios

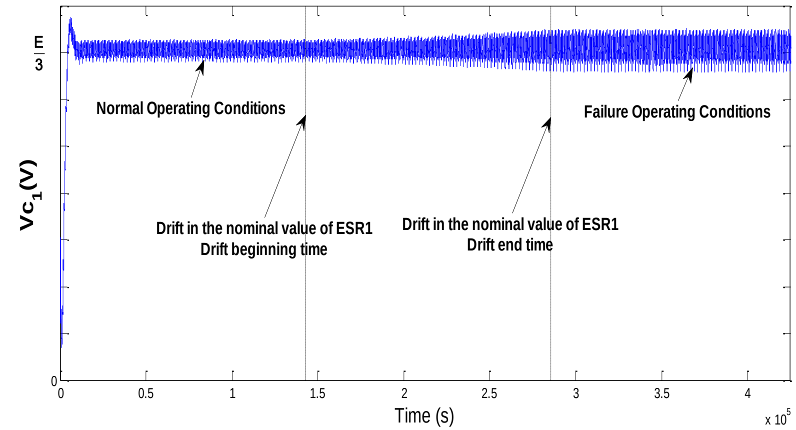


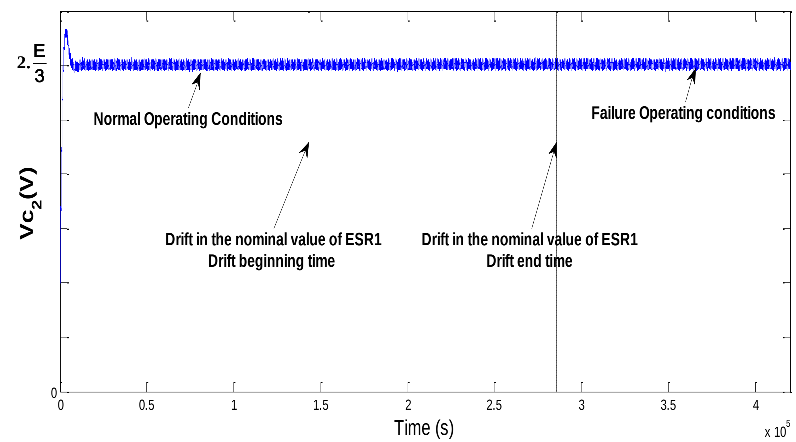
Simplified diagram
of the equivalent serial resistance (ESR)



Converter drift-like fault scenarios related to capacitor C_1

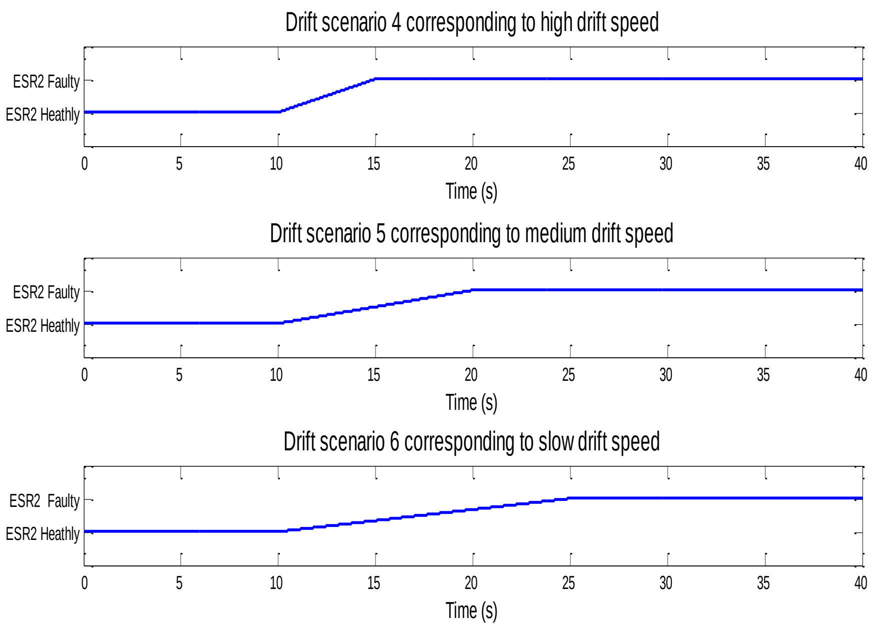




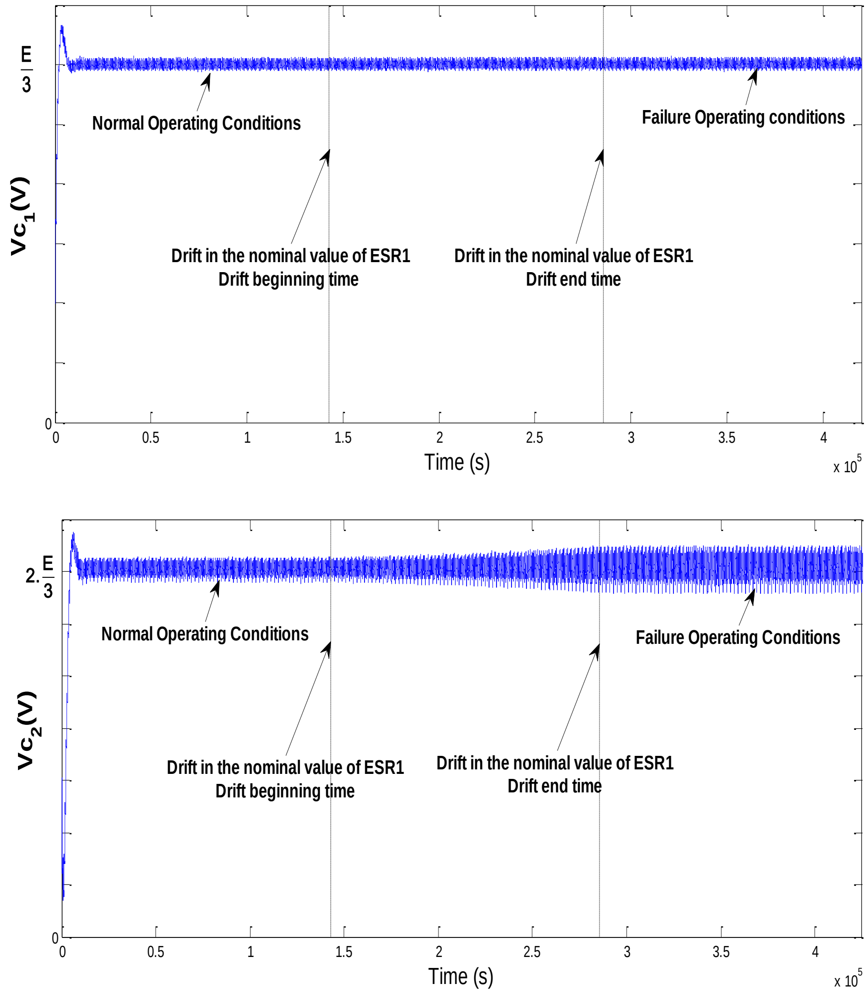


Converter drift-like fault scenarios related to capacitor C_1

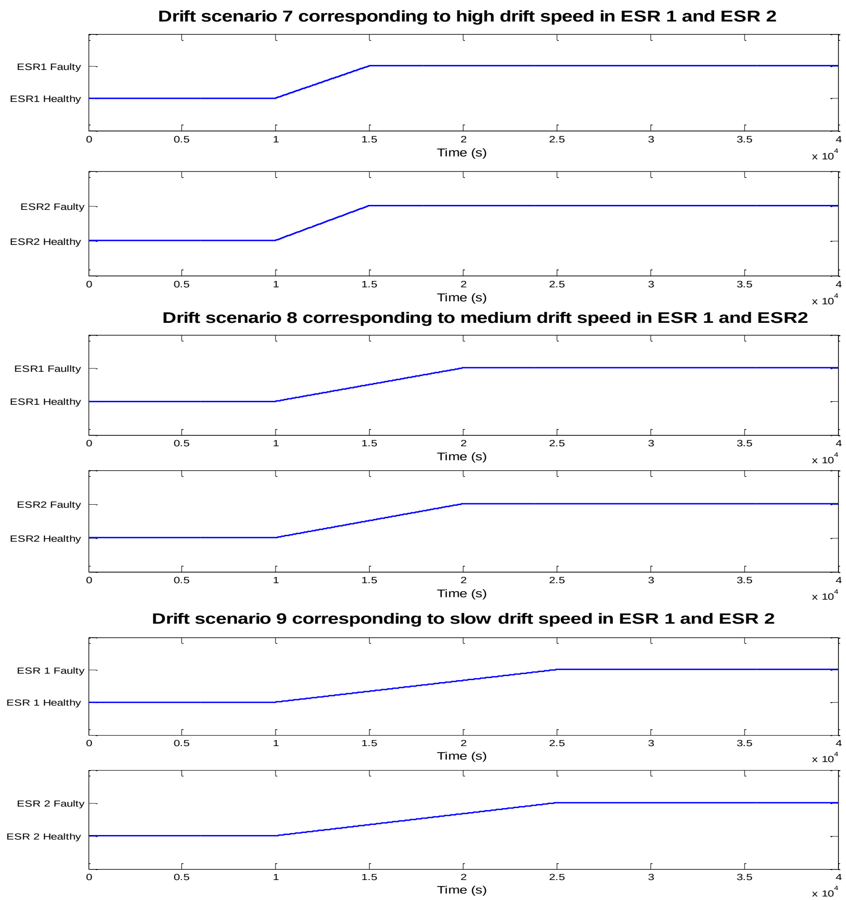
Simple drift-like fault scenarios related to capacitor C_2

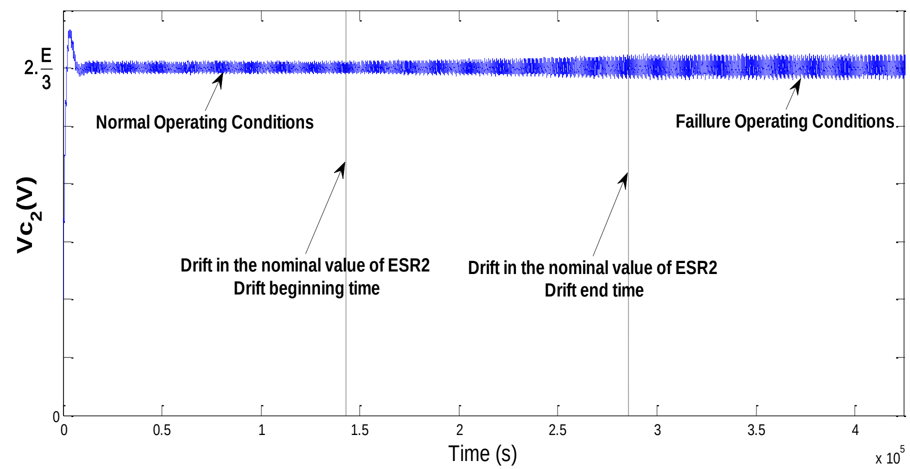


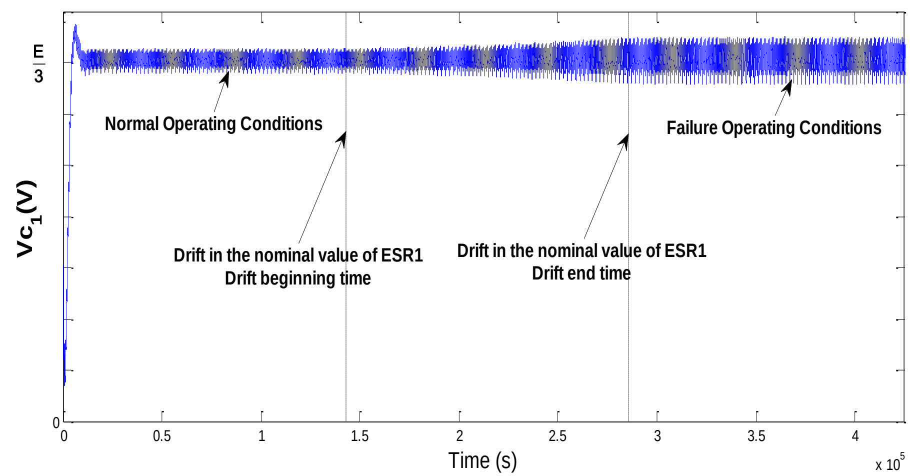
Converter drift-like fault scenarios related to capacitor C_2



Multiple drift-like fault scenarios related to capacitor C_1 and C_2







Converter drift-like multiple fault scenarios related to capacitor C_1 and C_2

Dynamical Feature spaces

✓ The features are represented by residuals R_{r,q_n} $(r = 1, 2, 3)$

Feature 1

$$R_{1,q_i} = V_{C_1,m} - \left(V_{C_1,ref} = \frac{E}{3}\right)$$

Feature 2

$$R_{2,q_i} = V_{C_2,m} - \left(V_{C_2,ref} = \frac{2E}{3}\right)$$

Feature 3

$$R_{3,q_i} = V_{S,m} - V_{S,ref}$$

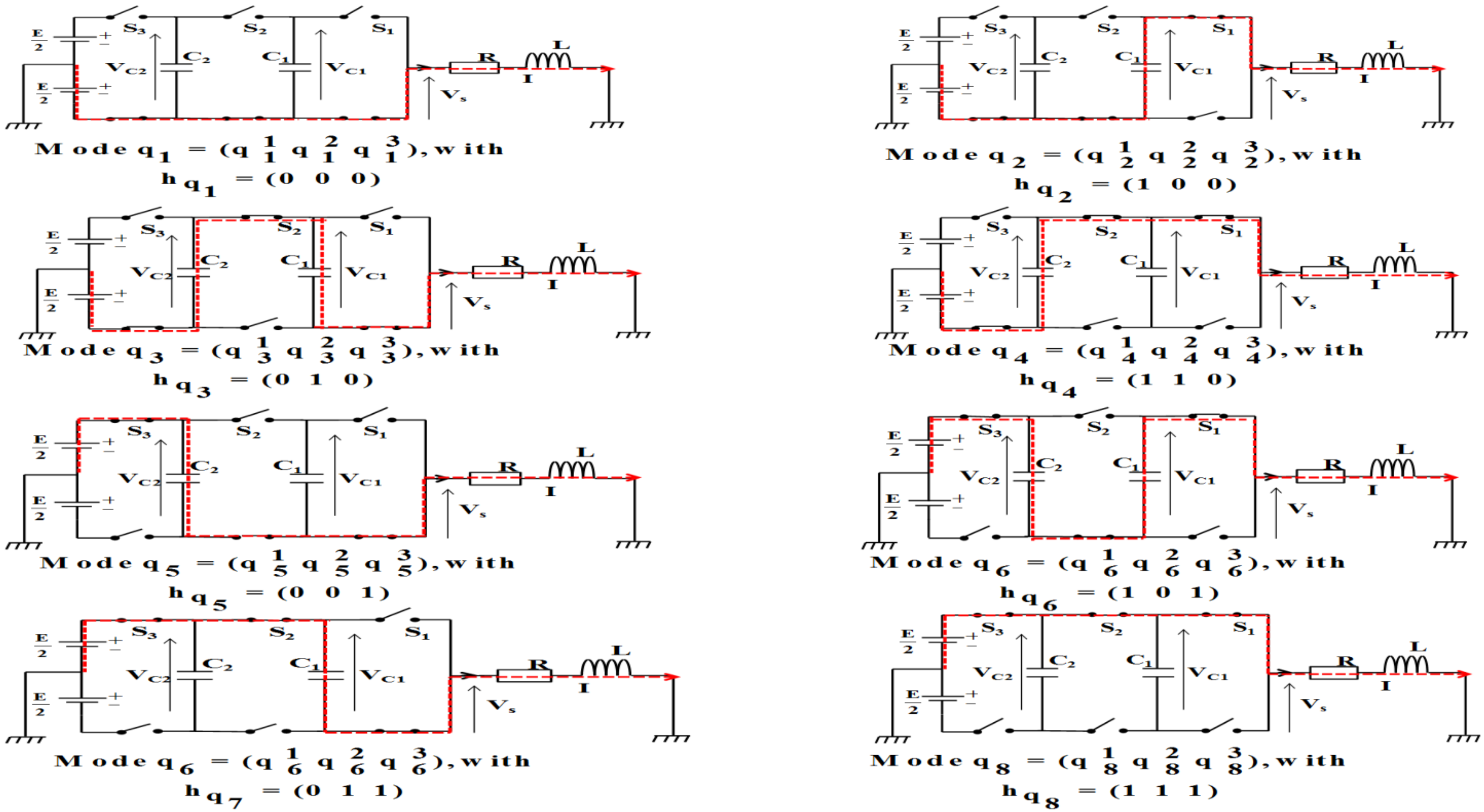
Dynamical Feature spaces

Feature space in q_i \ Feature R_n	R_1	R_2	R_3
Feature space in q_2	+	-	+
Feature space in q_3	+	+	+
Feature space in q_4	-	+	+
Feature space in q_5	-	+	+
Feature space in q_6	+	+	+
Feature space in q_7	+	-	+

Feature space Matrix

✓ Physical knowledeg is used in order to construct the feature space

Dynamical Feature spaces



Different discrete modes of a three-cell converter.

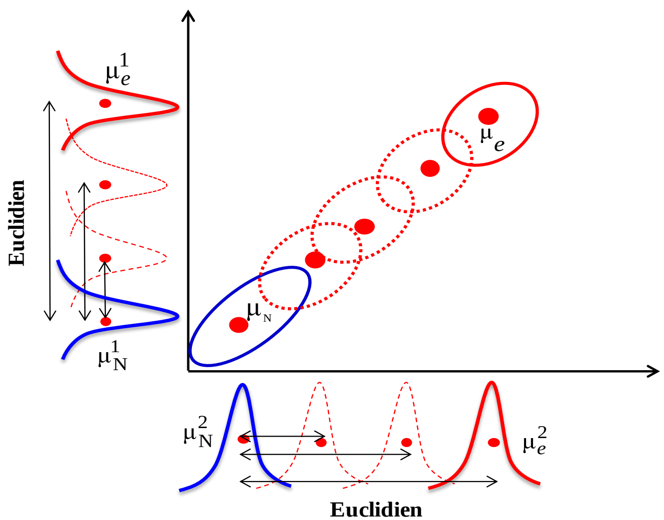
Dynamical Feature spaces

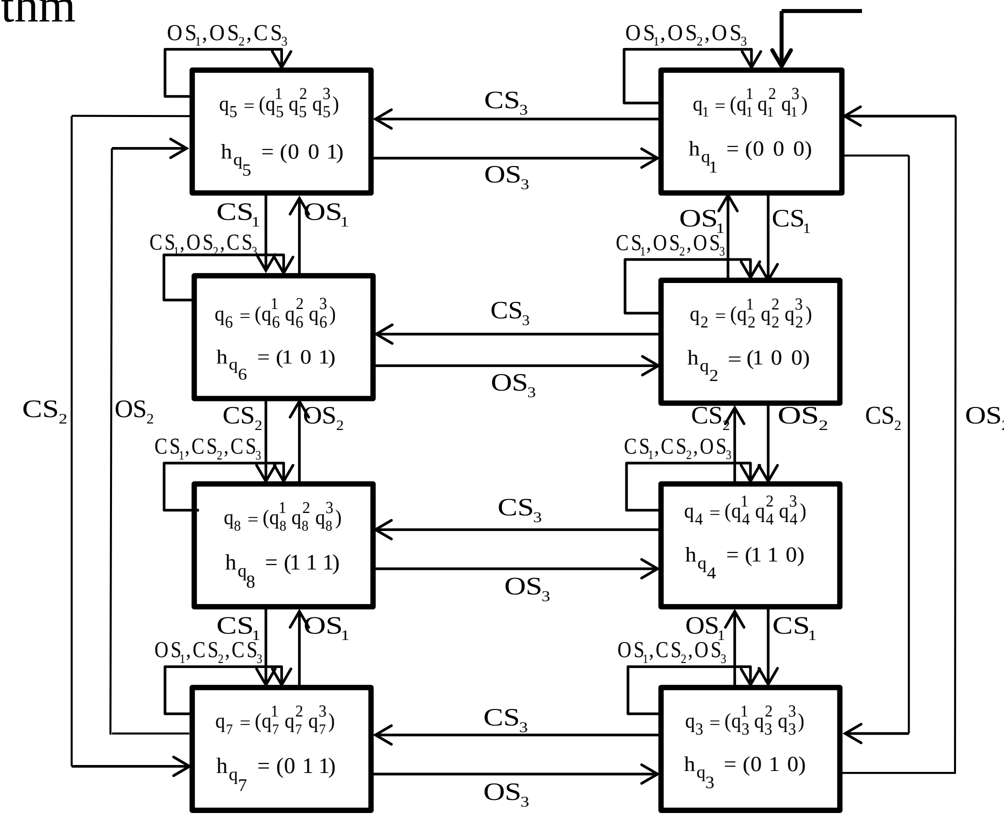
q_i \ R_i	R_1	R_2	R_3
q_2	F_{C1}	-	F_{C1}
q_3	F_{C1}	F_{C2}	$F_{C1}, F_{C2}, F_{C1}F_{C2}$
q_4	-	F_{C2}	F_{C2}
q_5	-	F_{C2}	F_{C2}
q_6	F_{C1}	F_{C2}	$F_{C1}, F_{C2}, F_{C1}F_{C2}$
q_7	F_{C1}	-	F_{C1}

SENSITIVITY OF RESIDUALS R_1, R_2 AND R_3 TO THE PARAMETRIC FAULTS IN C_1 (INDICATED BY THE FAULT LABEL FC1) AND IN C_2 (INDICATED BY THE FAULT LABEL FC2) IN EACH DISCRETE MODE OF THE MCC.

Classifier learning and updating

Auto-adaptive Dynamical Clustering Algorithm





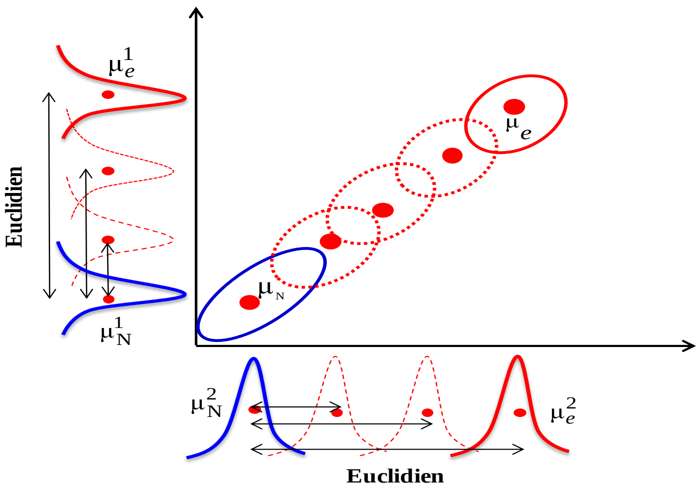
A hybrid dynamic classifier that able to change its decision function as well as its feature space according to the discrete mode

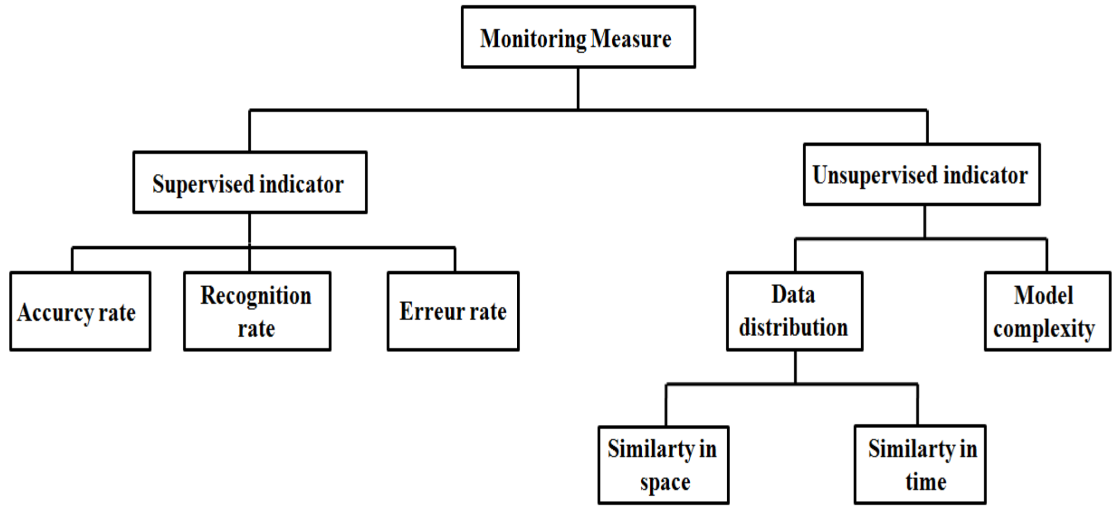
Updating step $\left\{ \mu_{pj}(t) = \mu_{pj}(t-1) + f\ (\mu_{pj}(t-1), x^{new}, x^{old}, N_{win}) \right.$

Updating according to active discrete mode

Drift Monitoring

✓ We suppose that only data corresponding to normal operating conditions (normal class) are avalible in advance





✓ Unsupervised drift indicators based on Ecludean distance are used

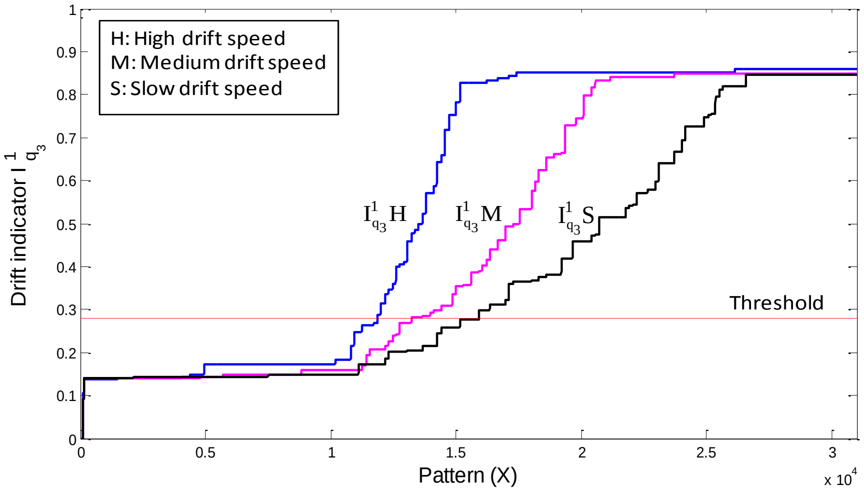
Drift Monitoring

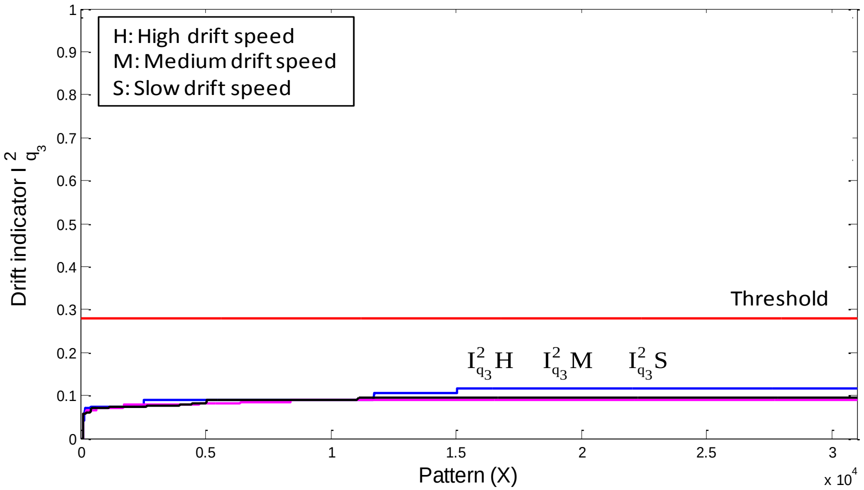
$$\begin{cases} I_{q_i}^1\left(x_{new}^1\right) = d_E\left(\mu_N^1, \mu_e^1\right) \\ I_{q_i}^2\left(x_{new}^2\right) = d_E\left(\mu_N^2, \mu_e^2\right) \\ I_{q_i}^3\left(x_{new}^3\right) = d_E\left(\mu_N^3, \mu_e^3\right) \end{cases}$$

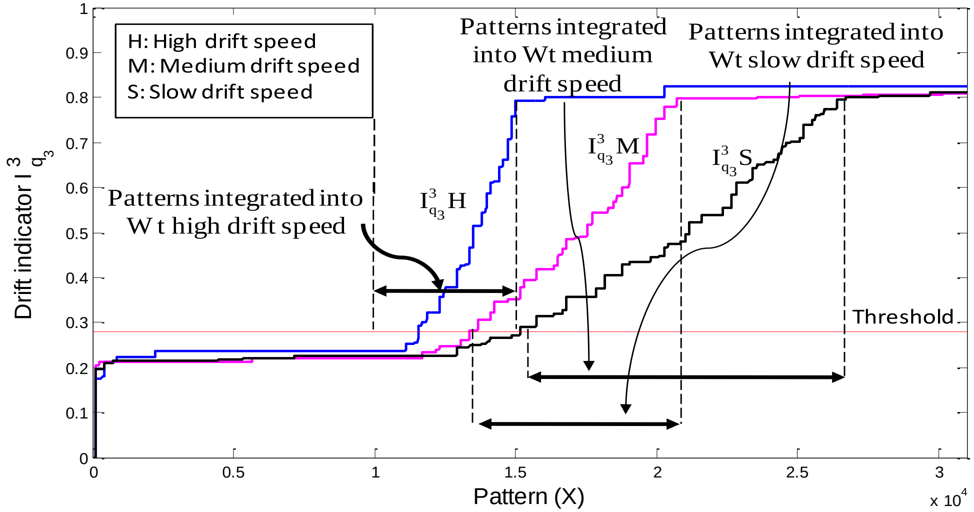
$$d_E\left(\mu_N^j, \mu_e^j\right) = \left|\mu_N^j - \mu_e^j(x_{new}^j)\right|$$

$$I_{q_i}^j\left(x^{New}\right) = d_E\left(\mu_N^1, \mu_e^1\right) \quad , j = 1, \ldots, d;\ i = 1, \ldots, n$$

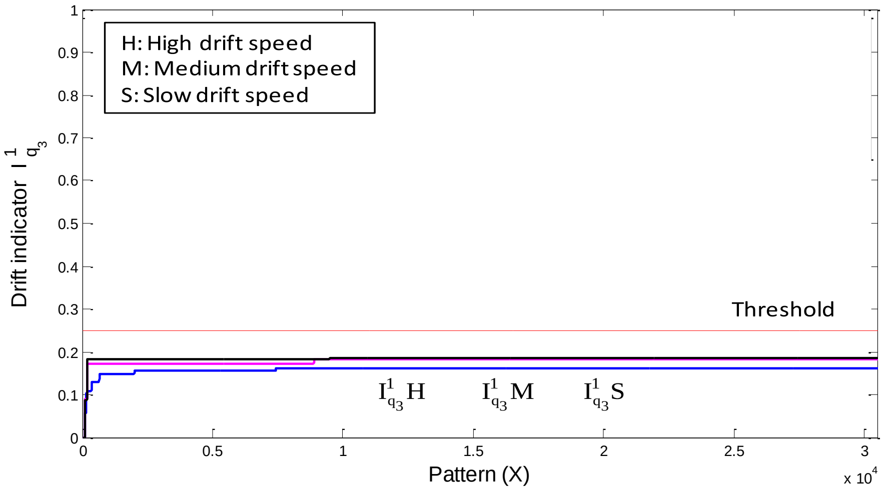
Simple drift-like fault scenarios related to capacitor C_1

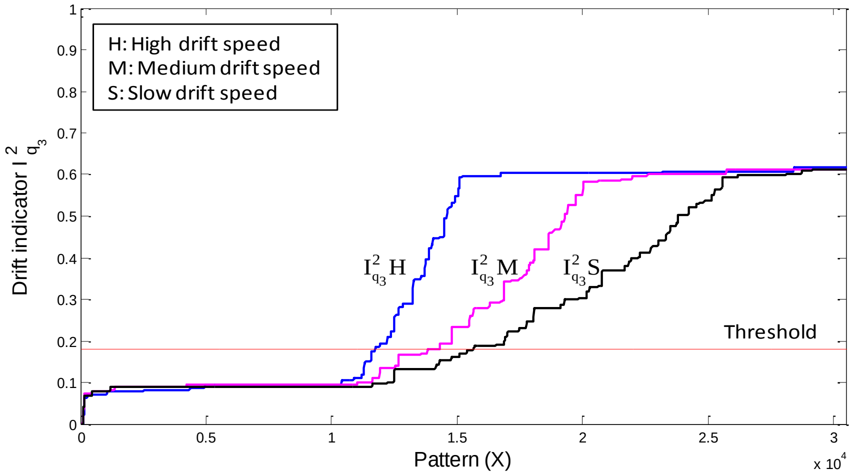


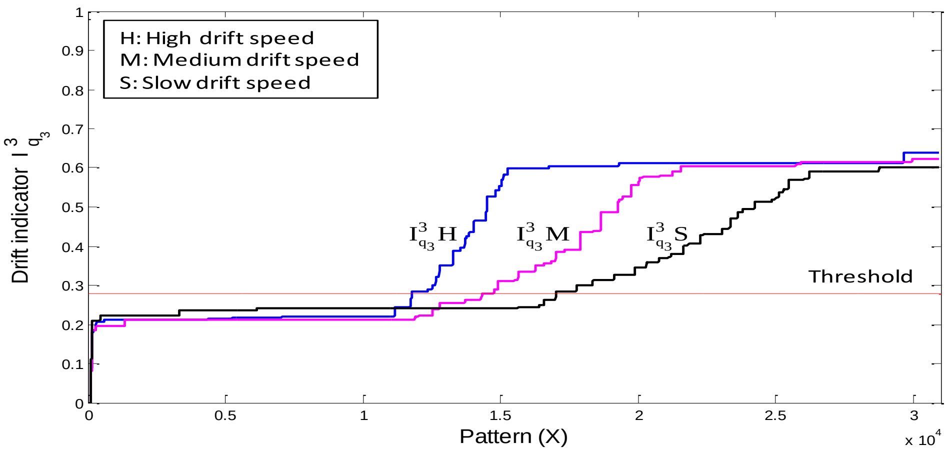




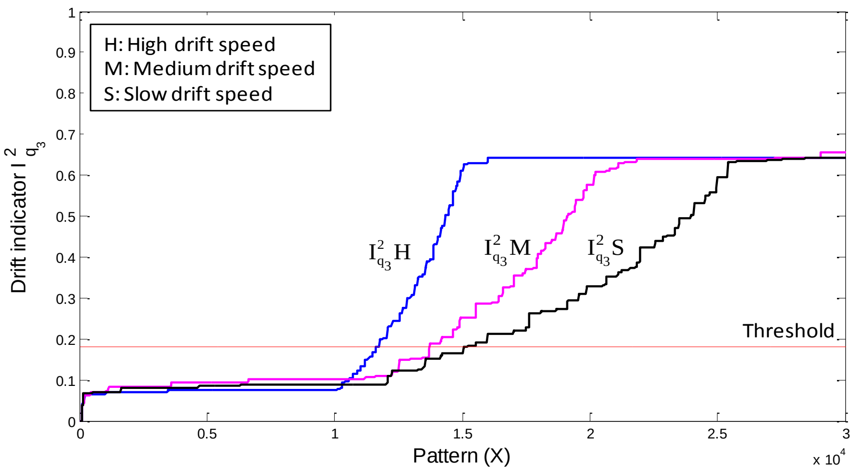
Simple drift-like fault scenarios related to capacitor C_2

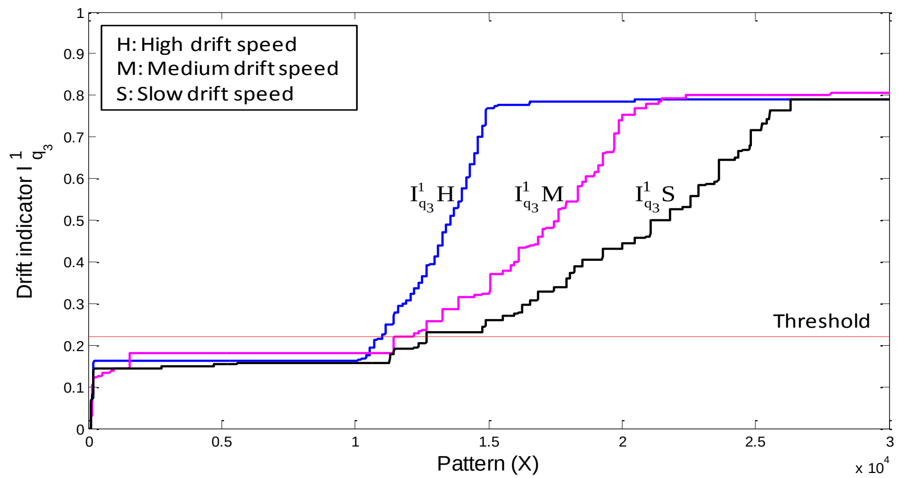


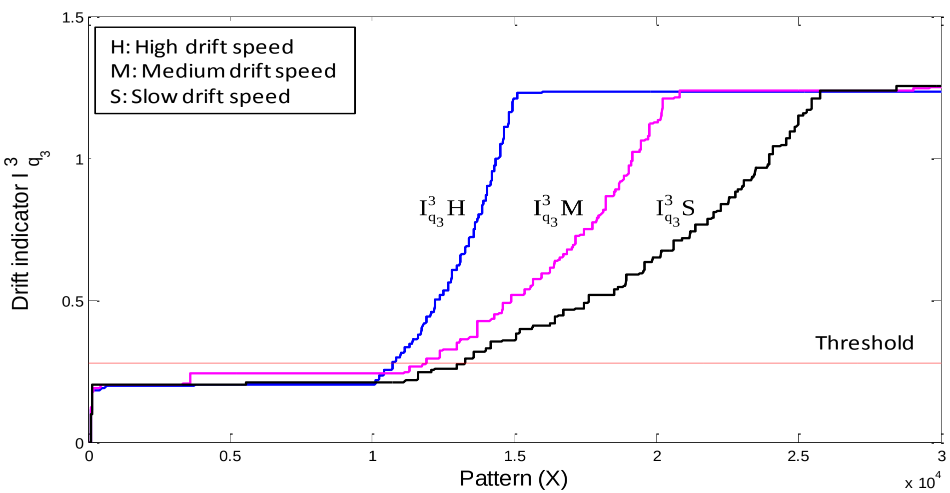




Multiple drift-like fault scenarios related to capacitor C_1 and C_2







Obtained results

Fault N°	Type	Drift speed	I^1	I^2	I^3
F1h	Simple fault in C_1	5s	0.74s	No detection	1.65s
F2m	Simple fault in C_1	10s	1.78s	No detection	3.34s
F3s	Simple fault in C_1	15s	2.71s	No detection	5.09s
F4h	Simple fault in C_2	5s	No detection	0.79s	1.71s
F5m	Simple fault in C_2	10s	No detection	1.81s	3.42s
F6s	Simple fault in C_2	15s	No detection	2.77s	5.17s
F7h	Multiple fault in C_1 and C_2	5s	0.75s	0.78s	1.09s
F8m	Multiple fault in C_1 and C_2	10s	1.79s	1.77s	2.87s
F9s	Multiple fault in C_1 and C_2	15s	2.69s	2.65s	4.10s

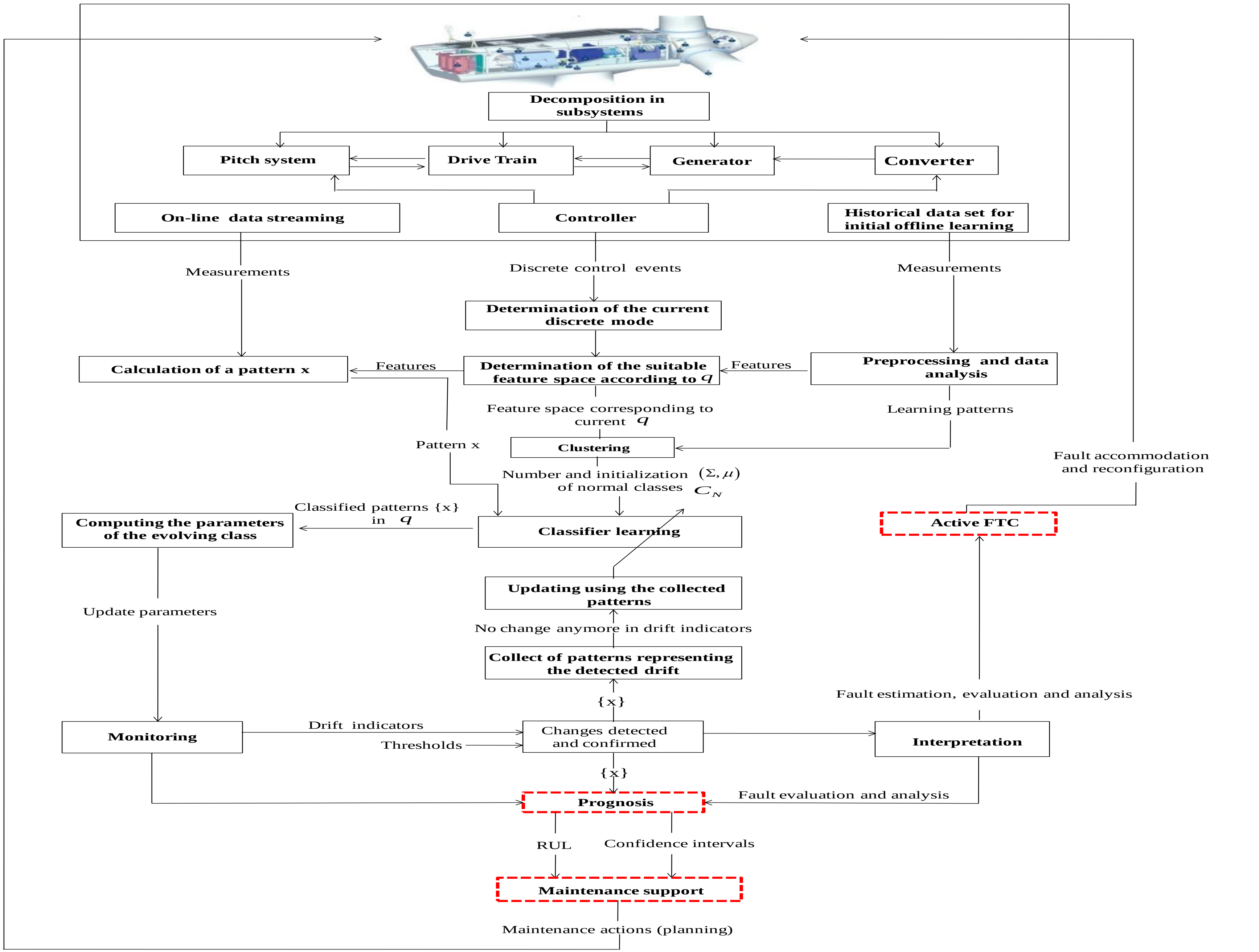
Conclusion and future directions

Work done

- Automated on-line early fault diagnosis of wind turbine power converter
- Hybrid classifier able to detect a drift in the normal operating conditions of wind turbine power converter
- Dynamical feature space is realized to detect a drift in the normal operating conditions of the multicellular converter in each discrete mode
- Drift indicator for each attributes of feature space for fault detection and isolation

Perspective

- Enrichement of the proposed scheme by the integration of the prognosis module
- Enrichement of the proposed scheme by the integration of the Fault-Tolerant Control module
- Enrichement of the proposed scheme by the integration of Condition Based Maintenance



Decomposition in subsystems
Pitch system
Drive Train
Generator
Converter
On-line data streaming
Controller
Historical data set for initial offline learning
Measurements
Discrete control events
Measurements
Determination of the current discrete mode
Calculation of a pattern x
Features
Determination of the suitable feature space according to q
Features
Preprocessing and data analysis
Feature space corresponding to current q
Learning patterns
Pattern x
Clustering
Number and initialization of normal classes (Σ, μ) C_N
Fault accommodation and reconfiguration
Classified patterns {x} in q
Computing the parameters of the evolving class
Classifier learning
Active FTC
Updating using the collected patterns
Update parameters
No change anymore in drift indicators
Collect of patterns representing the detected drift
{x}
Fault estimation, evaluation and analysis
Monitoring
Drift indicators
Thresholds
Changes detected and confirmed
Interpretation
{x}
Prognosis
Fault evaluation and analysis
RUL
Confidence intervals
Maintenance support
Maintenance actions (planning)

Publications

Journal papers:

• **H. Toubakh**, M. Sayed-Mouchaweh, "Hybrid dynamic classifier for drift-like fault diagnosis in a class of hybrid dynamic systems: Application to wind turbine converter". Neurocomputing. Accepted, Elsevier, DOI: 10.1016/j.neucom.2015.07.073. 2015.

• **H. Toubakh**, M. Sayed-Mouchaweh, "Hybrid dynamic data-driven approach for drift-like fault detection in wind turbines," Evolving Systems, Springer. (Vol. 6, pp:115-129). 2014.

Conference papers:

• **H.Toubakh**, M.Sayed-Mouchaweh, A.Fleury and J.Boonaert. " Hybrid Dynamic data mining scheme for Drift-like Fault Diagnosis in multicellular converters.", In Third International Conference on Technological Advances in Electrical, Electronics and computer Engineering (TAEECE), Beyrouth, Lebanon, IEEE, (pp. 56-61), 2015.

• **H.Toubakh**, M.Sayed-Mouchaweh. "Advanced data mining approach for wind turbines fault prediction.", In Proceedings of second European conference of the prognostics and health management society, Nantes, France, (Vol. 5: pp. 288-296), 2014.

•B.Abichou, D.Florez, M.Sayed-Mouchaweh, **H.Toubakh,** B.François, N.Girard. "Fault Diagnosis Methods for Wind Turbines Health Monitoring: a Review.", In Proceedings of second European conference of the prognostics and health management society, Nantes, France, (Vol. 5: pp. 297-304), 2014.

• **H.Toubakh**, M.Sayed-Mouchaweh and E.Duviella. “Advanced pattern recognition approach for fault diagnosis of wind turbine,” In Machine Learning and Applications (ICMLA), 12th International Conference, Miami, USA, IEEE , (Vol.2, pp. 368-373), 2013.


Thank you