Data Driven, AIs and ML in Prognostic and Diagnostic of Electrical Machines and Batteries

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POWER ELECTRONICS UK Underpinning Research

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Outline

INTRODUCTION

CASE STUDIES

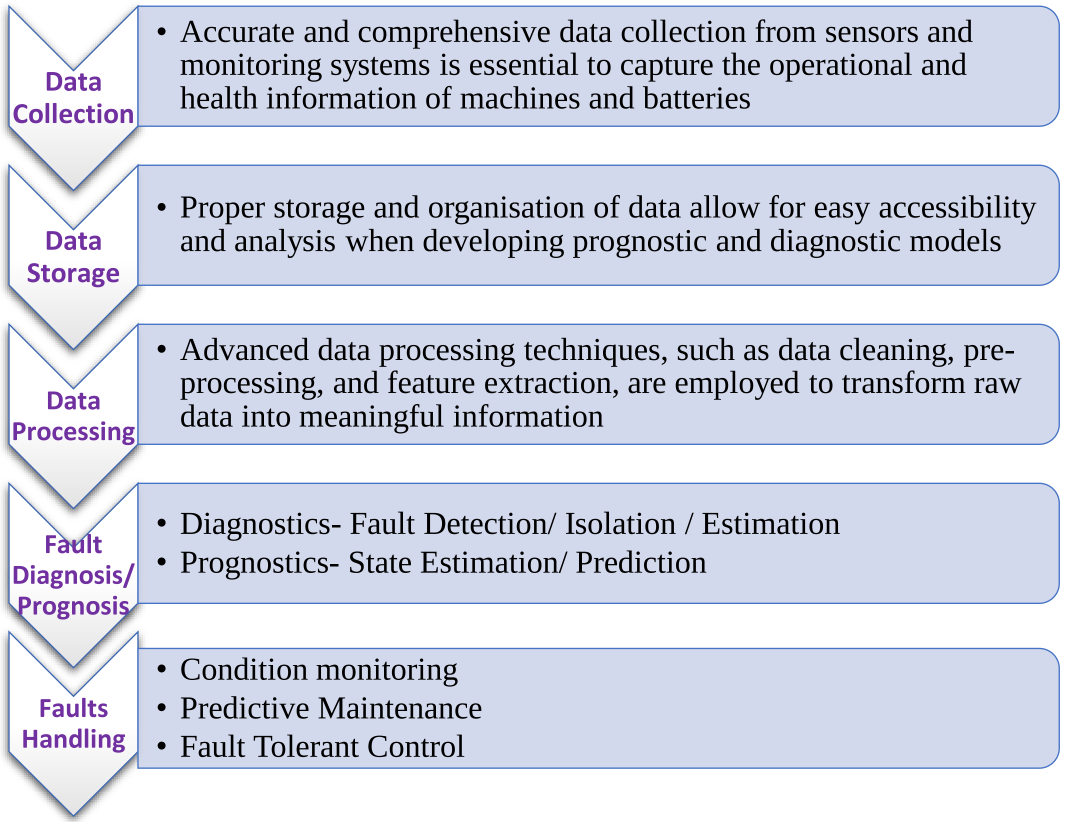
PLANS AND VISION

QUESTIONS

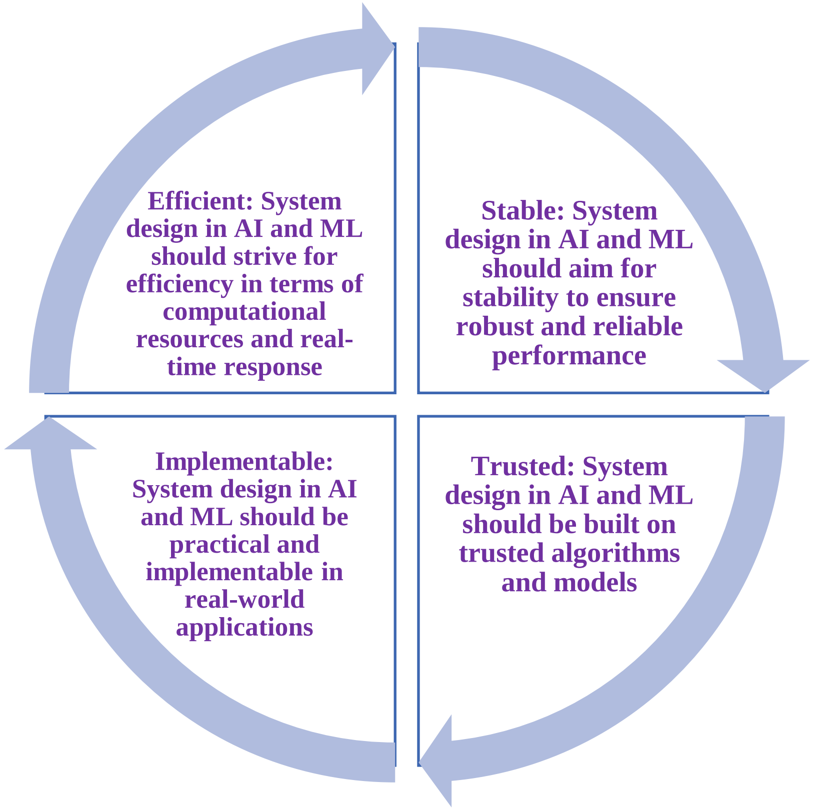
Prognostics and Diagnostics Overview

Diagnostics focuses on detecting faults and anomalies to facilitate timely maintenance and repairs

Prognostics involves predicting the remaining useful life and identifying potential failures



Data Driven General Fault Diagnosis/ Prognostic Procedure



Comprehensive Test/Validation is imperative

AIs & ML in PEMD

Innovate UK
KTN

We asked AI 'where will AI benefit power electronics, machines and drives?'

With AI being a common topic of discussion, we decided to ask AI "Where are the opportunities for using AI to benefit power electronics, machines and drives (PEMD)?".

The response from ChatGPT [https://openai.com], for which we would like your feedback, was as follows.

There are numerous opportunities for utilizing AI to benefit power electronics, machines, and drives (PEMD) and here are some areas where AI can make a significant impact:

1. Fault Diagnosis and Prognostics: AI techniques such as machine learning and deep learning can be employed to develop advanced fault diagnosis and prognostic systems for PEMD. By analysing data from sensors, AI algorithms can detect and predict faults in power electronics components, machines, and drives, allowing for proactive maintenance and minimizing downtime.

2. Energy Optimization: AI can optimize the energy consumption and efficiency of PEMD systems. By analysing real-time data from sensors and actuators, AI algorithms can adjust control parameters and optimize the operation of power converters, motor drives, and other components to minimize energy losses and improve overall system efficiency.

3. Condition Monitoring and Predictive Maintenance: AI can enable condition monitoring and predictive maintenance in PEMD systems. By continuously monitoring operational parameters and analysing historical data, AI algorithms can detect early signs of component degradation or failure, allowing for timely maintenance interventions and reducing the risk of unplanned downtime.

4. Control and Optimization: AI-based control techniques can enhance the performance and capabilities of PEMD systems. Reinforcement learning algorithms can learn optimal control policies

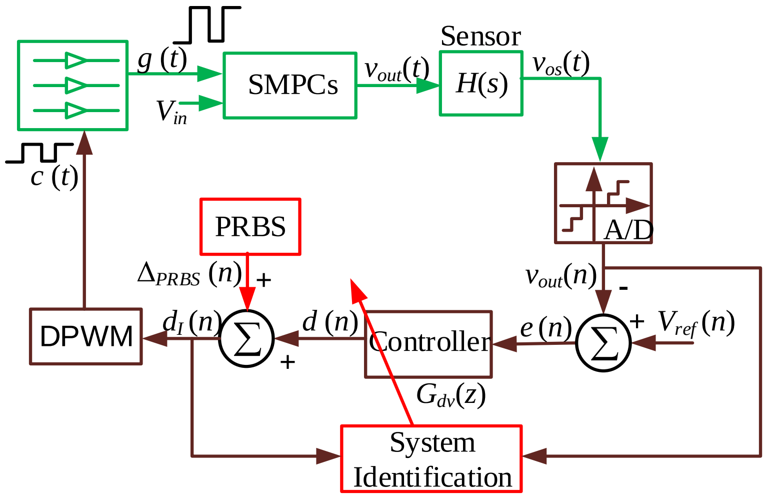
5. Power Quality Improvement: AI can contribute to improving power quality in PEMD systems. By analysing voltage and current waveforms, AI algorithms can identify and mitigate power quality issues, such as harmonics, voltage sags, or flicker, through active control strategies and optimized filtering techniques.

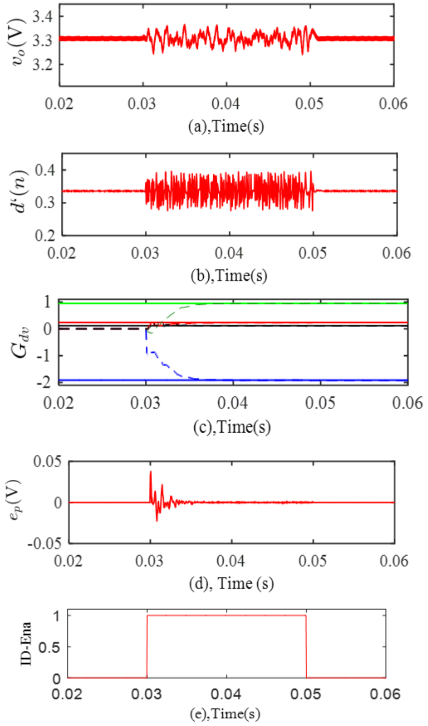
6. Intelligent Energy Management: AI can be used to develop intelligent energy management systems for PEMD applications. By considering multiple factors such as load demand, energy storage, renewable energy availability, and grid conditions, AI algorithms can optimize the allocation and utilization of energy resources, ensuring reliable and efficient operation.

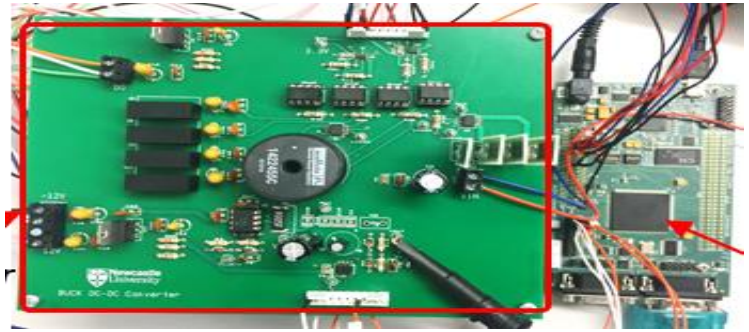
7. Virtual Prototyping and Design Optimization: AI-based simulation and optimization techniques can accelerate the design and development of PEMD systems. By using AI models and algorithms, designers can simulate and optimize different configurations, topologies, and control strategies, reducing the time and cost associated with physical prototyping.

8. Smart Grid Integration: AI can facilitate the integration of PEMD systems with smart grids. By analysing real-time grid data and considering demand response, energy pricing, and grid stability, AI algorithms can enable optimal coordination and control of PEMD systems, enhancing the reliability and efficiency of grid operations.

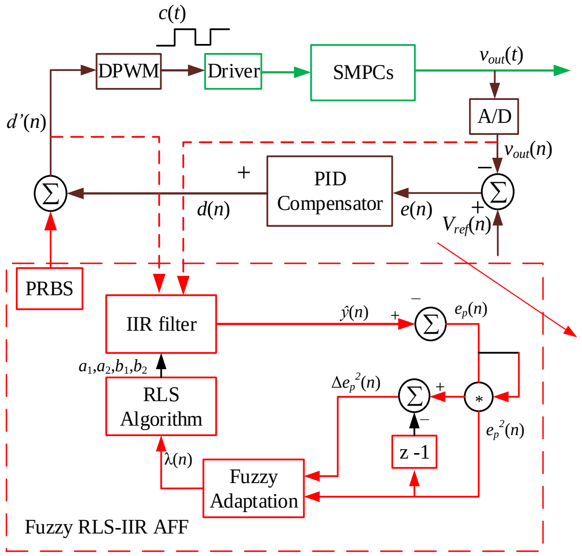
AIs & ML in PEMD

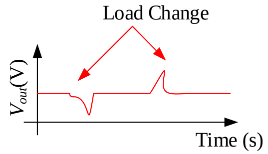


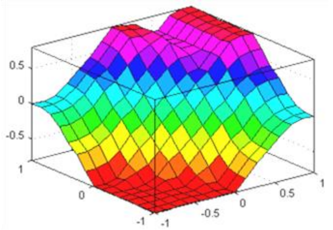


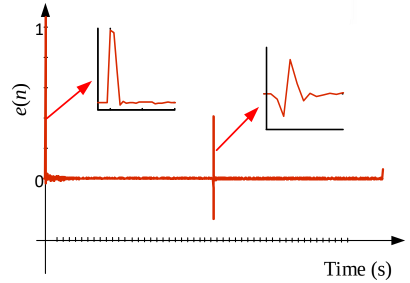


Digital Twins

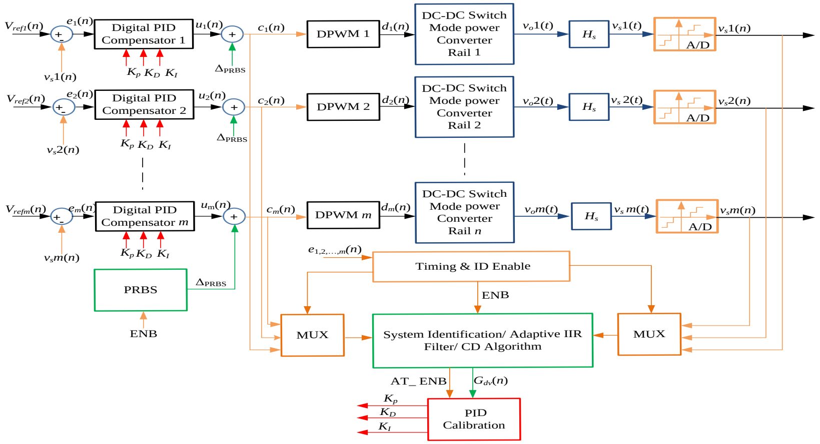


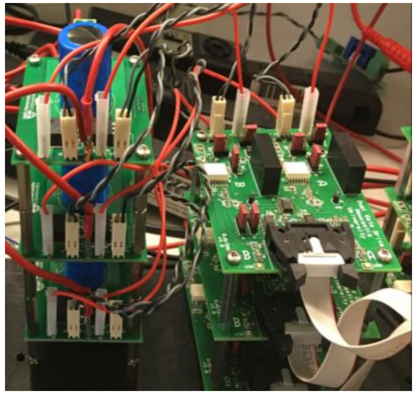






e(n)/Δe(n)	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NM	NB	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PM	PM	PM
PB	Z	PS	PM	PB	PB	PB	PB





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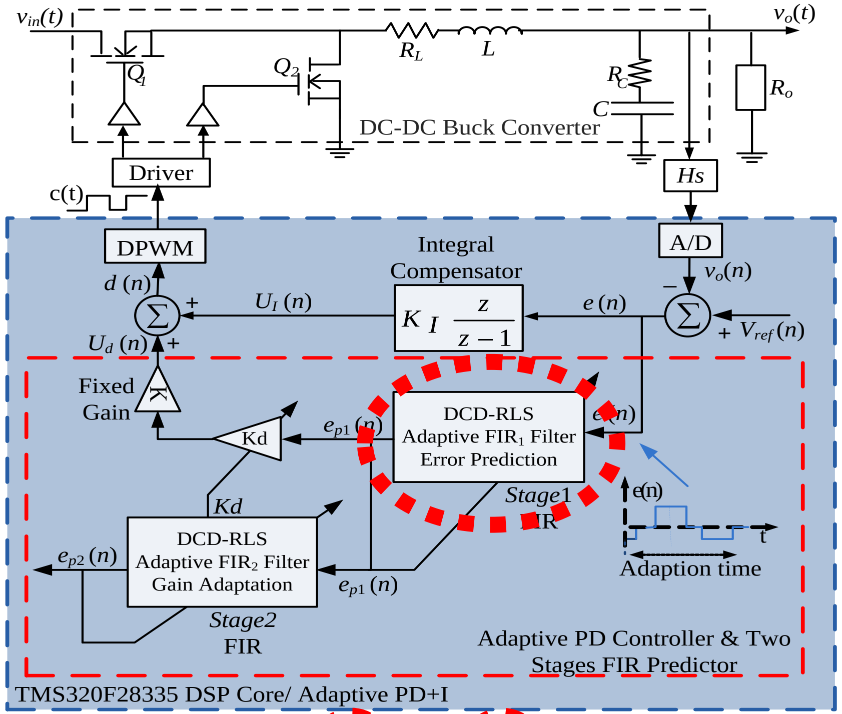
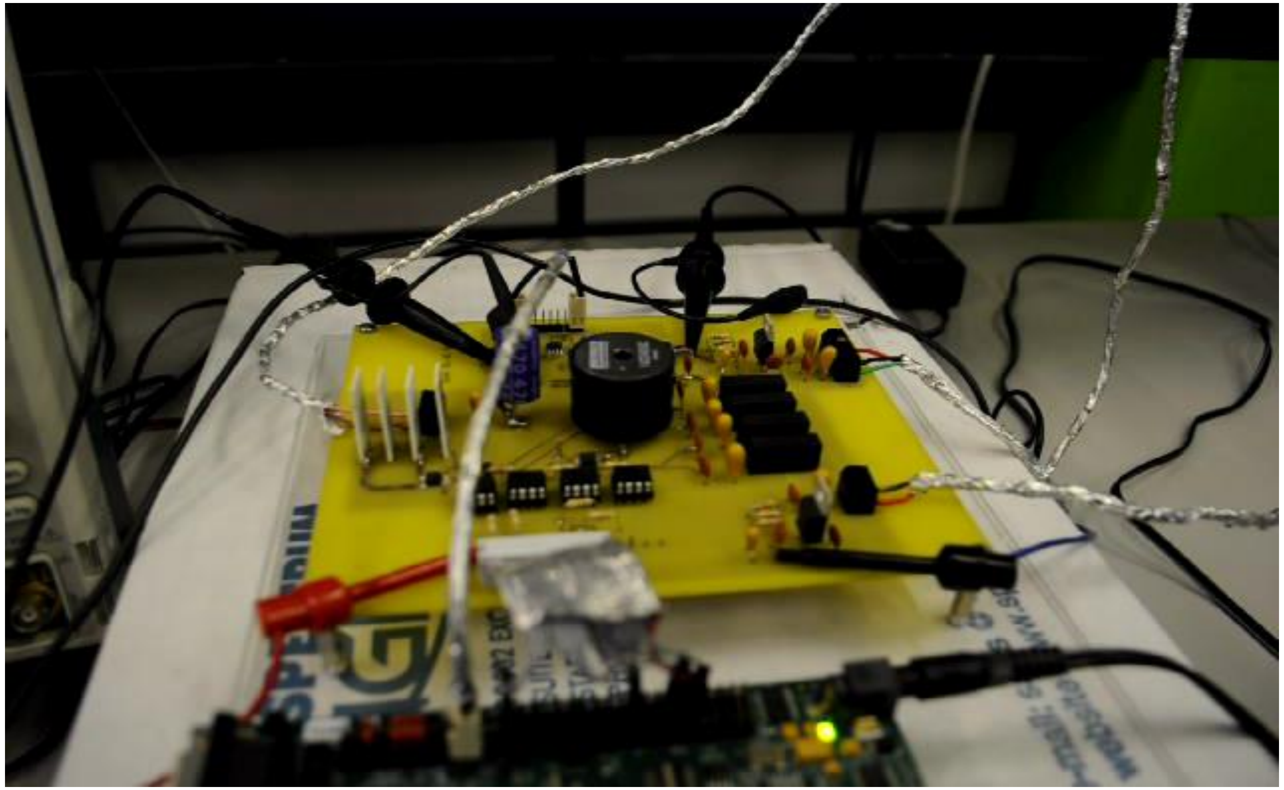
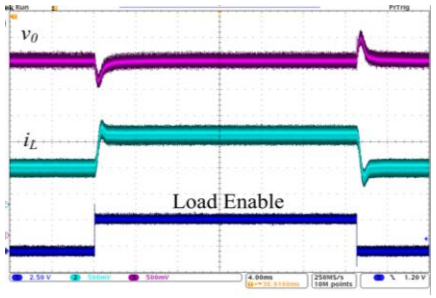
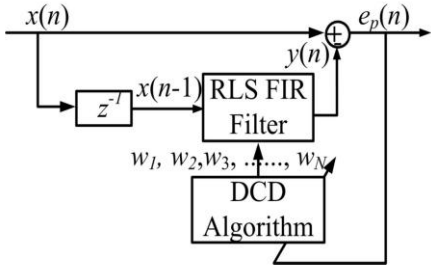
AIs & ML in PEMD

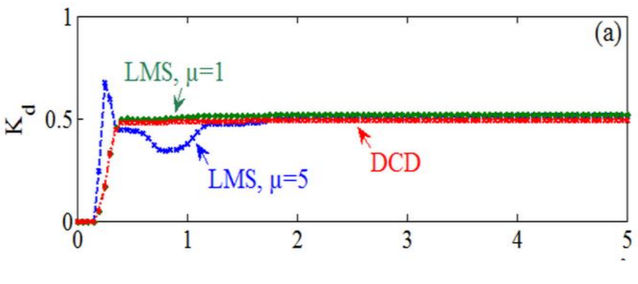


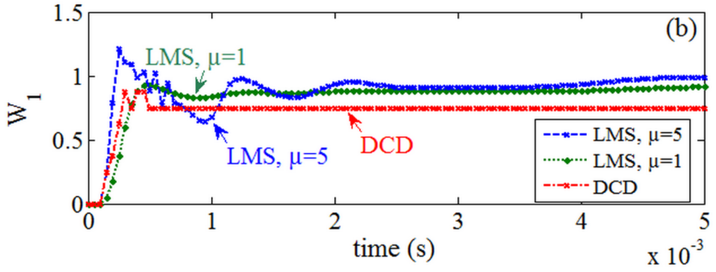
$$G_{pd}(z) = K_d(1 + w_1 z^{-1})$$











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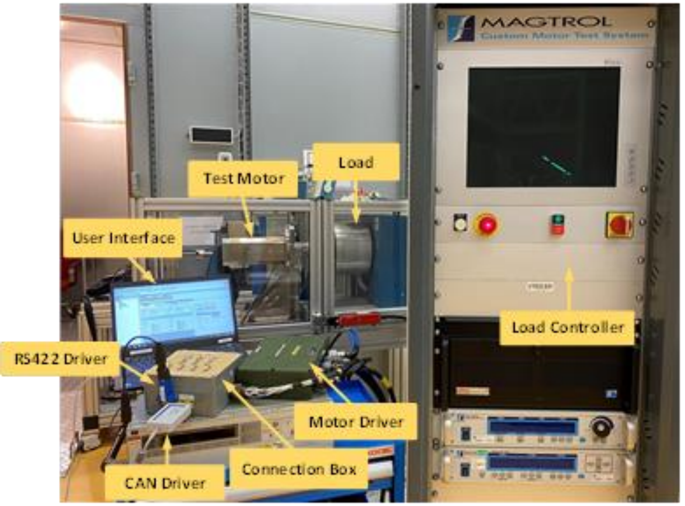
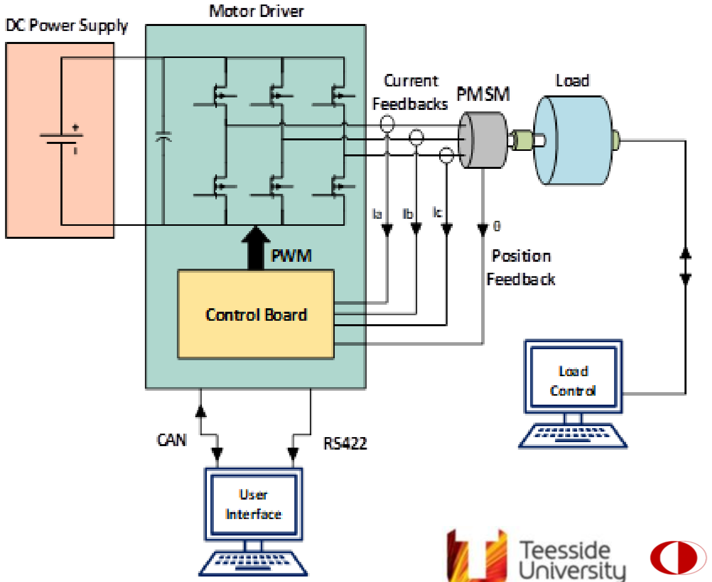
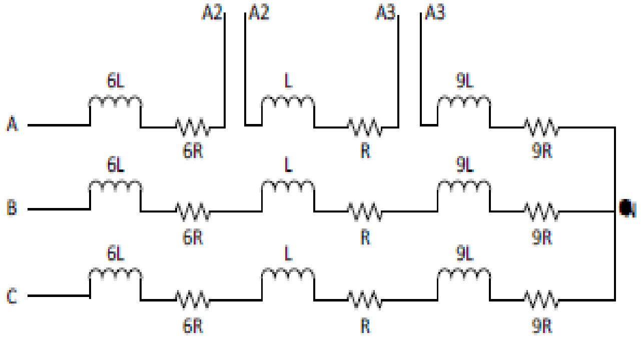
Condition Monitoring and Fault Detections of PMSM

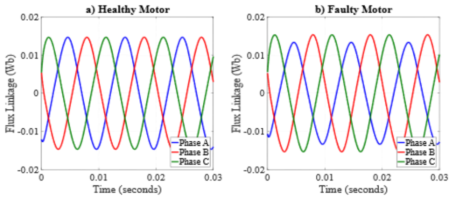




Stator Inter-turn Short Circuit Faults

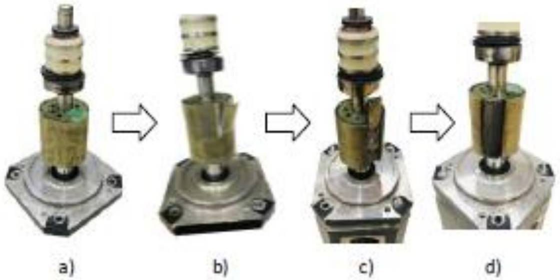
- The stator winding of a PMSM is a distributed winding consisting of 16 series turns stranded by eight conductors. One of the 16 turns was connected to the test terminal for the experiment.

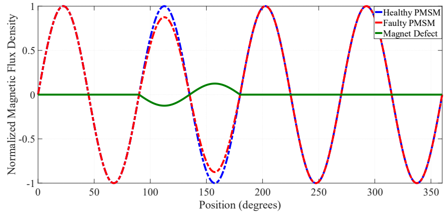




Non-Uniform Demagnetisation Faults

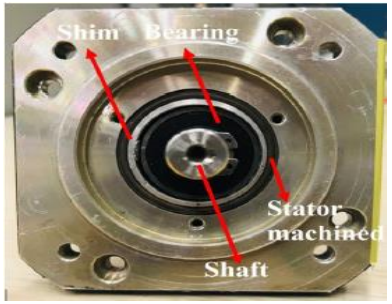
- Non-uniform demagnetisation was achieved using a test motor. For this purpose, one magnet is separated from the rotor and excessive heat is applied until it demagnetises.

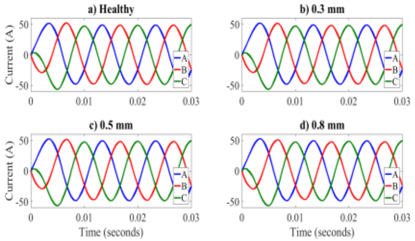




Static Eccentricity Faults

- The inner part of the motor cage was machined 0.5 mm from one side, and a shim was placed on the other side. When the air gap was 1.8 mm, the displacement of 0.5 mm corresponds to 28% SEF.



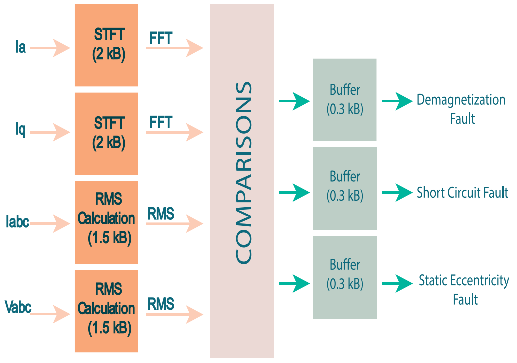


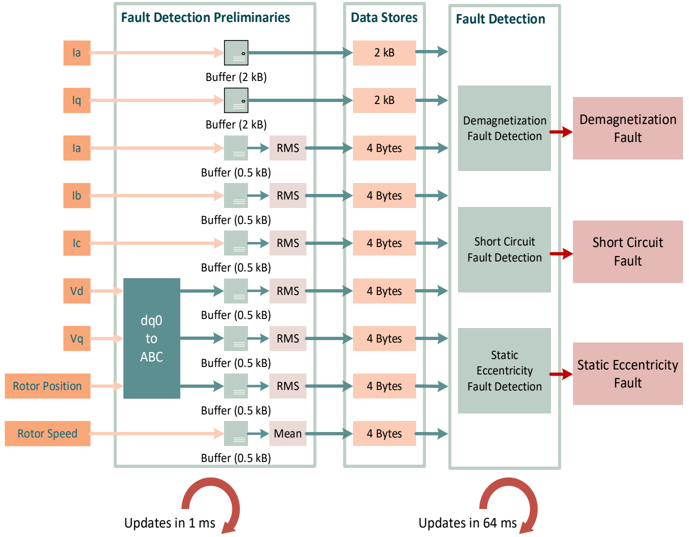
Teesside University · METU · Lloyd's Register Foundation

Project: (Sg2\100005): Condition Monitoring of Integrated Motors for Predictive Maintenance & Safe-Operation, TU and METU, Lloyds Foundation, June, 2021

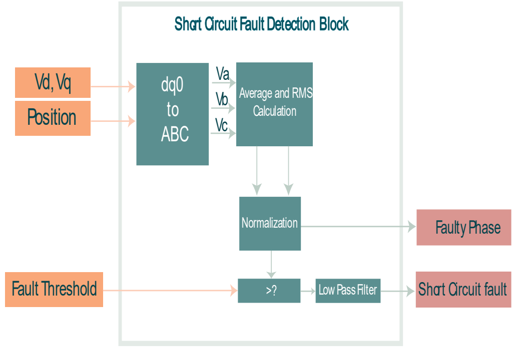
Condition Monitoring and Fault Detections of PMSM

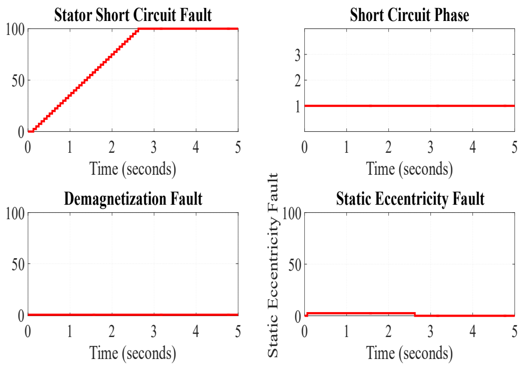
Memory requirement for data storage of the fault detection algorithm



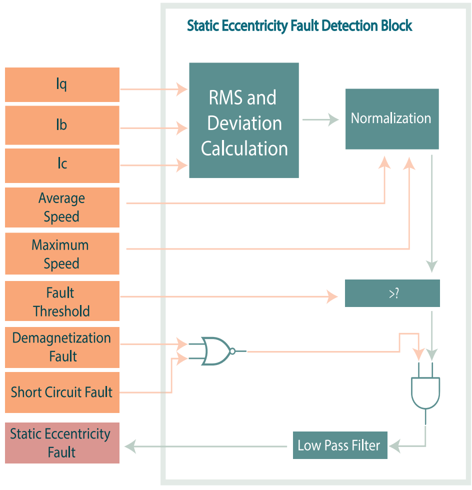


Content of the short circuit fault detection block

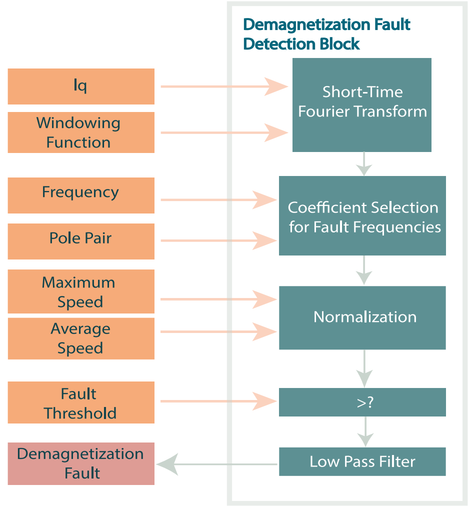


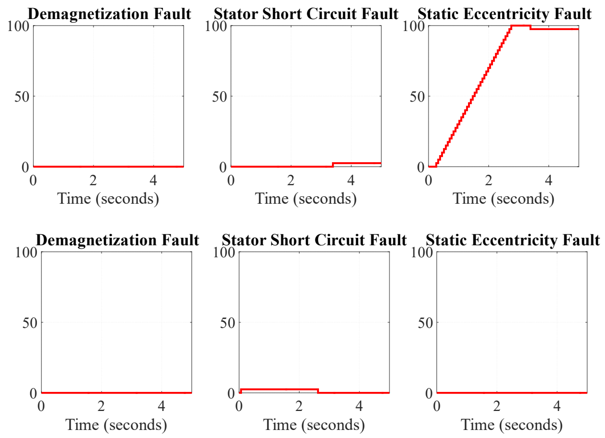


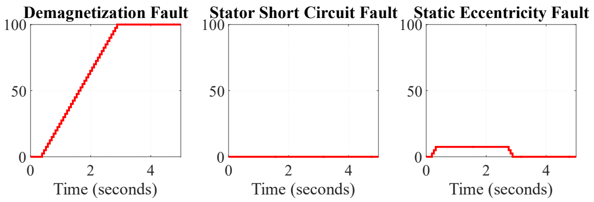
Content of the static eccentricity fault detection block

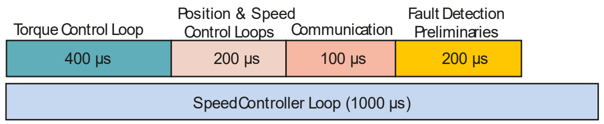


Content of demagnetization fault detection block









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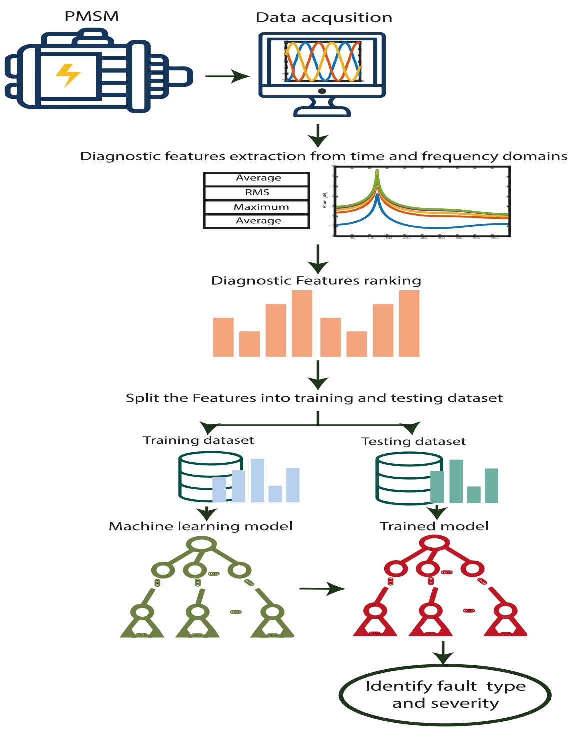
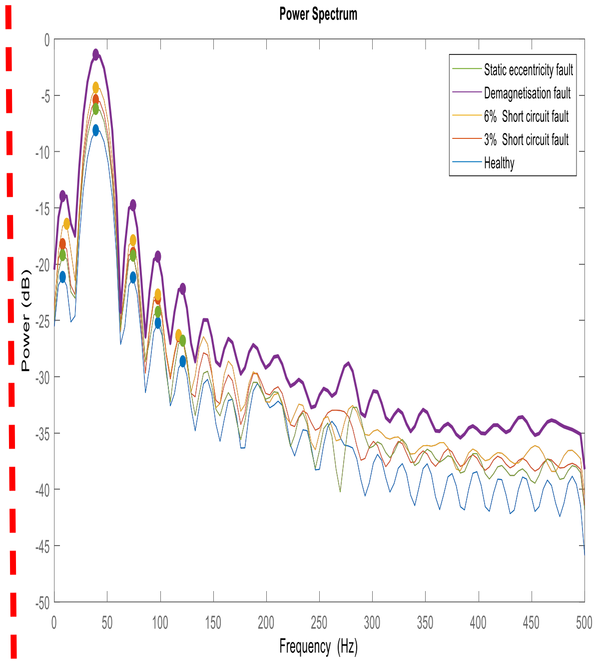
Condition Monitoring and Fault Detections of PMSM



Time-domain diagnostic features

Health indicators	Mathematical expression
Mean	$\frac{1}{K}\sum_{n=1}^{K} i_n$
RMS	$\sqrt{\frac{1}{K}\sum_{n=1}^{K} \lvert i_n \rvert^2}$
Standard Deviation	$\sqrt{\frac{\sum_{n=1}^{K}(i_n - \mathrm{mean}(i))^2}{K-1}}$
Shape Factor	$\frac{\mathrm{RMS}}{\mathrm{Mean}}$
Peak Value	The maximum absolute value of the stator current
Impulse Indicator	$\frac{\text{Peak value}}{\text{Mean}}$
Crest Factor	$\frac{\lvert\text{Peak}\rvert}{\text{RMS}}$
Kurtosis	$\frac{1}{K-1}\left(\frac{\sum_{n=1}^{K}(x_n - \mathrm{mean}(i))^4}{\text{Standard Deviation}^4}\right)$
Skewness	$\frac{1}{K-1}\left(\frac{\sum_{n=1}^{K}(x_n - \mathrm{mean}(x))^3}{\text{Standard Deviation}^3}\right)$

Frequency-domain diagnostic features

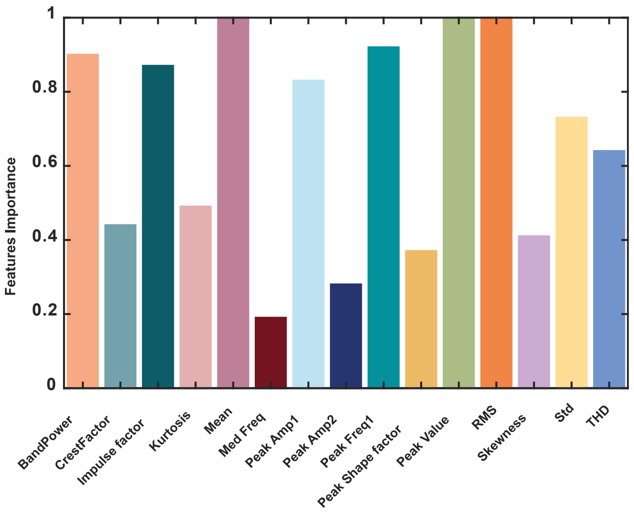


Ensemble Subspace Discriminant Tree (ESDT)

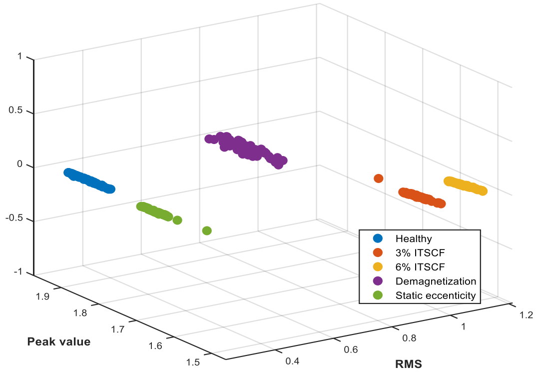
ESDT Algorithm	
1.	Input: a set of diagnostic features $\chi = \{x^{(1)}, x^{(2)}, \dots, x^{(d)}\}$.
2.	Parameters: Number of subspaces K, number of features per subspace n, weight coefficient α, features quality measure $qual_m(x^c)$.
3.	Output: feature subspace S.
4.	For $i = 1$ to k, do
5.	$S_i \longrightarrow \emptyset$
6.	End for
7.	Repeat
8.	For $i = 1$ to k, do
9.	For c= 1 to k, do
10.	If $x_c \notin S_i$ then
11.	$f_{score}(x^c) \longrightarrow \alpha \times qual_m(x^c) + (1-\alpha) \times div_m(S, S_i, x^c)$
12.	End if
13.	End for
14.	$x_{best} \longrightarrow argmax_{x^c} f_{score}(x^c)$
15.	$S_i \longrightarrow S_i \cup x_{best}$
16.	End for
17.	Until every subspace consists of n features
18.	Return S

[] Ma'D El-Dalahmeh, **M. Al-greer**, Aykut Demirel, Ozan Keysan, "Active Fault Detection Using Time Frequency Diagnostic Features for Electrical Machine", ***IET International Conf. on Power Electron., Machines and Drives***, PEMD, 2022.

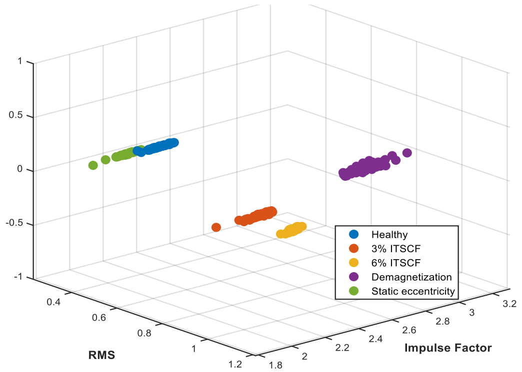
Condition Monitoring and Fault Detections of PMSM



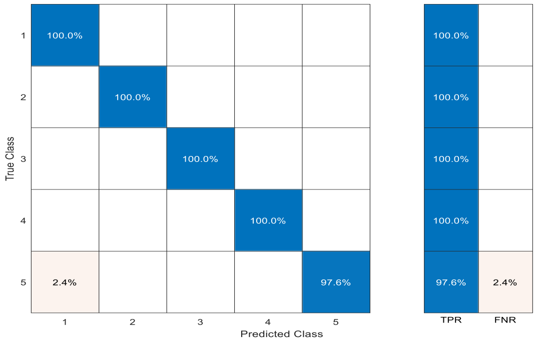
Features ranking results



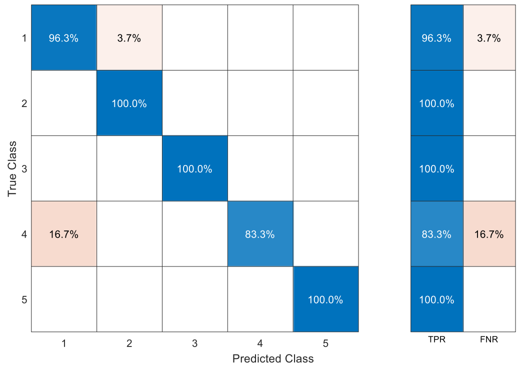
The extracted features for PMSM with 0.8Nm and running at 1800 rpm



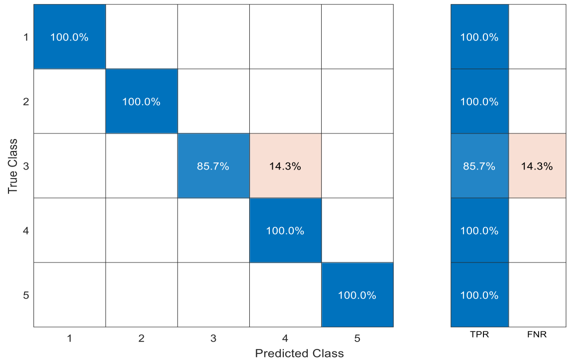
The extracted features for PMSM with 0.8Nm and running at 2400 rpm



PMSM loaded with 0.8 Nm and running at 1800 rpm



PMSM loaded with 1.2 Nm and running at 2400 rpm

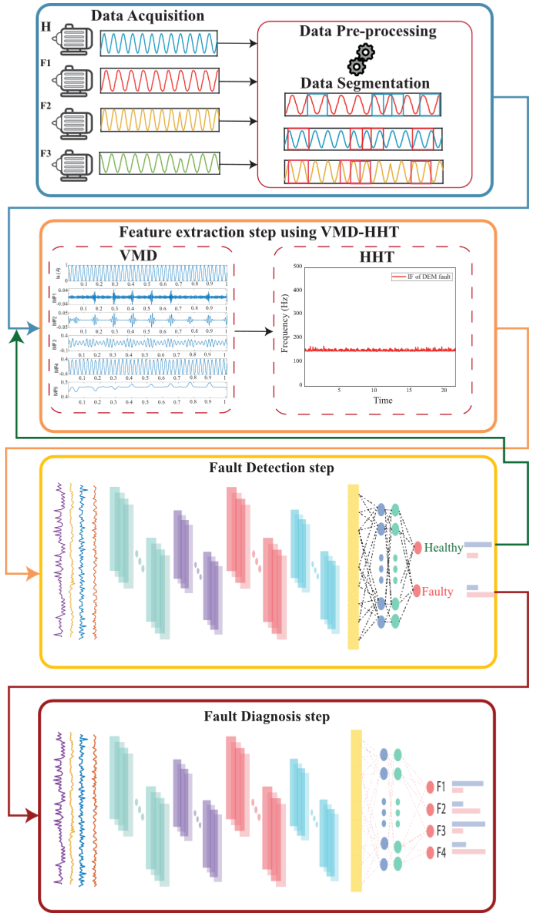


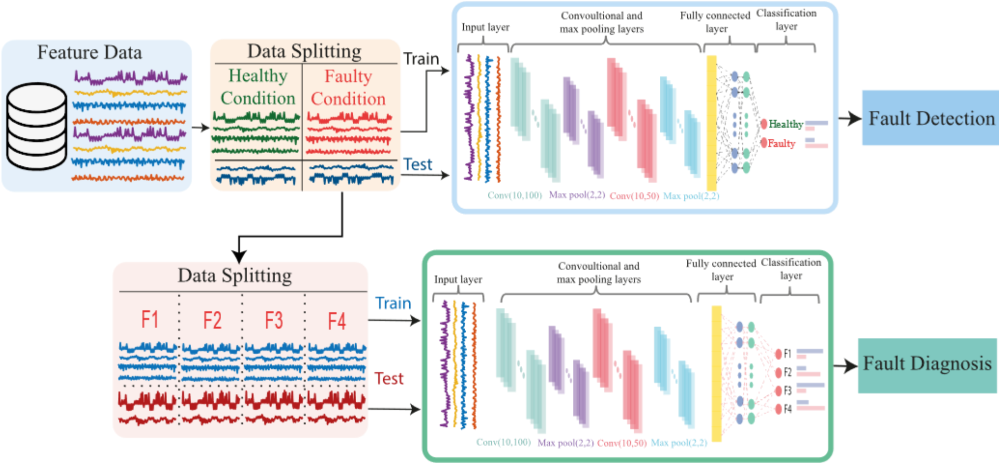
PMSM loaded with 1.2 Nm and running at 2400 rpm

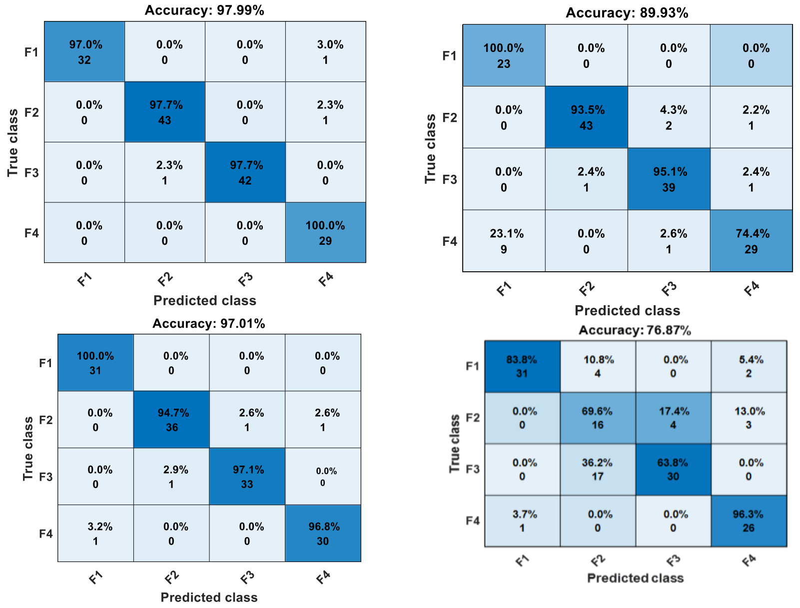
Confusion matrix of the trained model: (1) Healthy class. (2) 3% short circuit. (3) 6% short circuit. (4) Demagnetisation fault. (5) Static eccentricity.

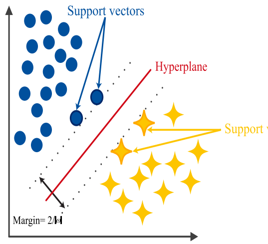
[] Ma'D El-Dalahmeh, **M. Al-greer**, Aykut Demirel, Ozan Keysan, "Active Fault Detection Using Time Frequency Diagnostic Features for Electrical Machine", ***IET International Conf. on Power Electron., Machines and Drives***, PEMD, 2022.

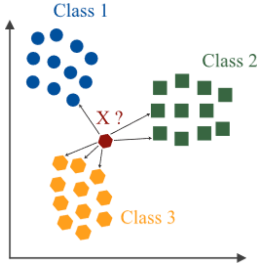
Condition Monitoring and Fault Detections of PMSM

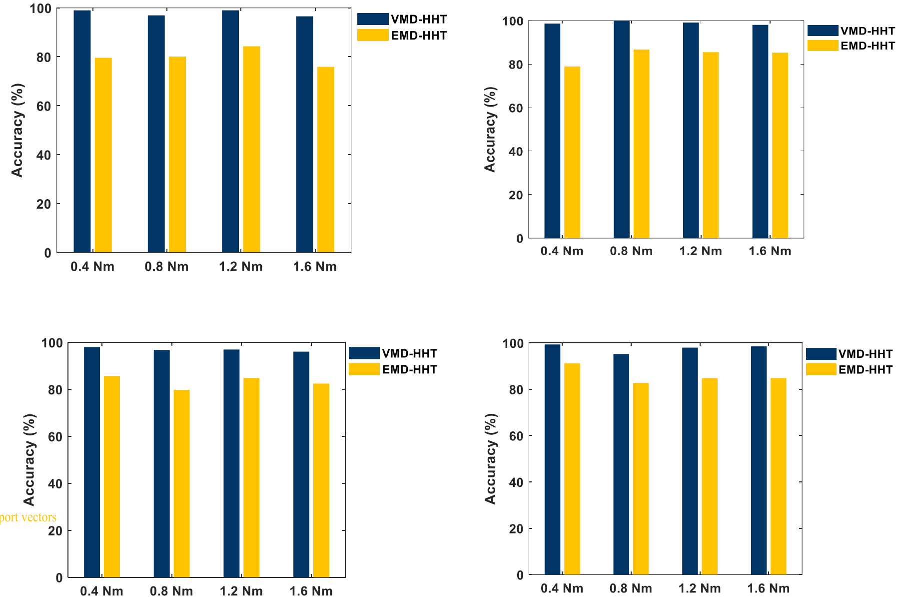












Fault diagnostic results of the PMSM working at different load torque and speed. (a) PMSM works at 600 rpm, (b) at 1200 rpm, (c) at 1800 rpm, and (d) at 2400 rpm.

Teesside University METU Lloyd's Register Foundation

[] Ma'D El-Dalahmeh, **M. Al-greer**, Moath El-Dalahmeh, Imran Bashir, Aykut Demirel, Ozan Keysan, "Autonomous Faults Detection of Electrical Machines Using Combined Variational Mode Decomposition Plus Hilbert-Huang Transform and Convolution Neural Network", ***Journal of Elsevier*, *Electrical and Computer Engineering***, 2023.

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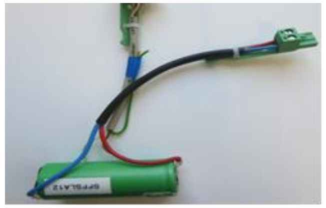

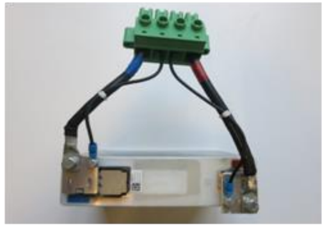

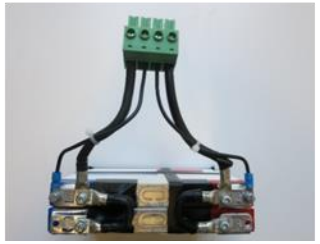

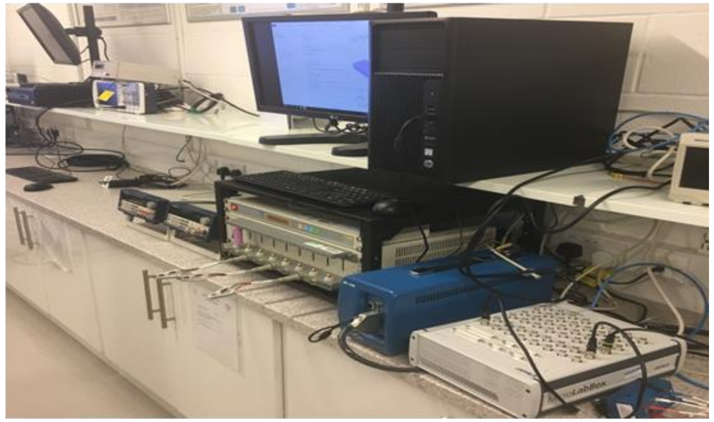

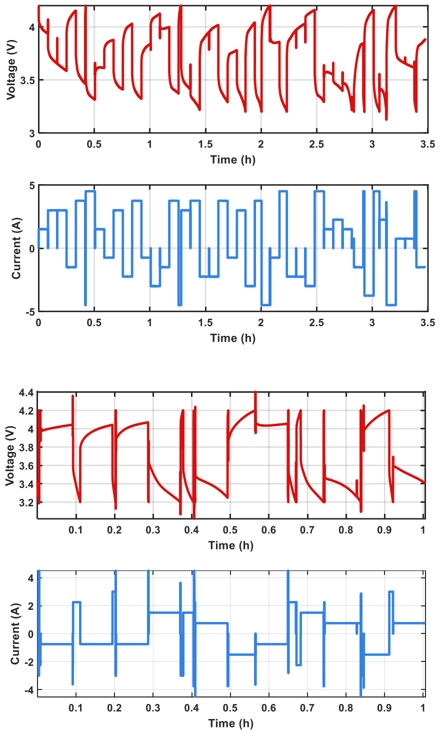

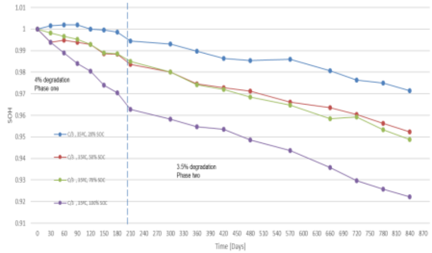

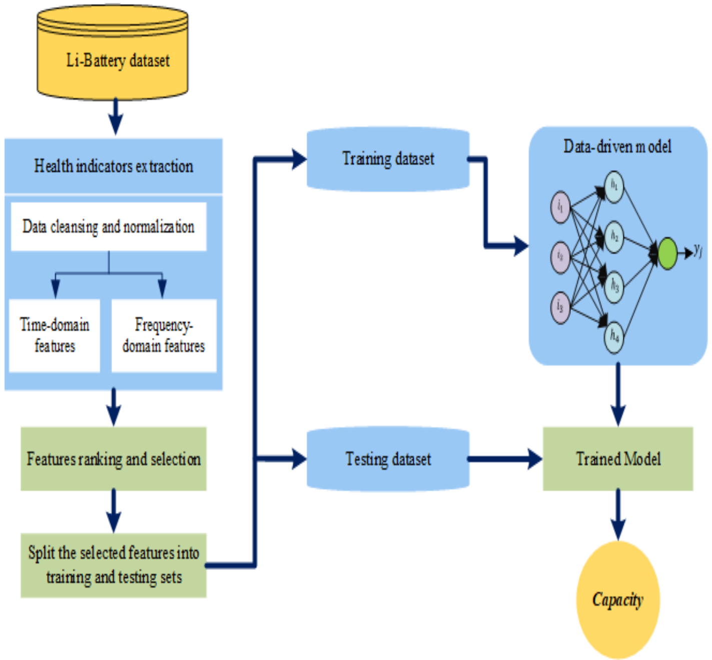

LiBs Experiential Calendar and Cycle Aging Analysis Based on Different Manufactures

[] Ma'D El-Dalahmeh, J. Lillystone, **M. Al-greer**, Mo'Ath El-Dalahmeh, "State of Health Estimation of Lithium-ion Batteries Based on Data-Driven Techniques", in ***56th IEEE International Universities Power Engineering Conference***, ***UPEC***, 2021.
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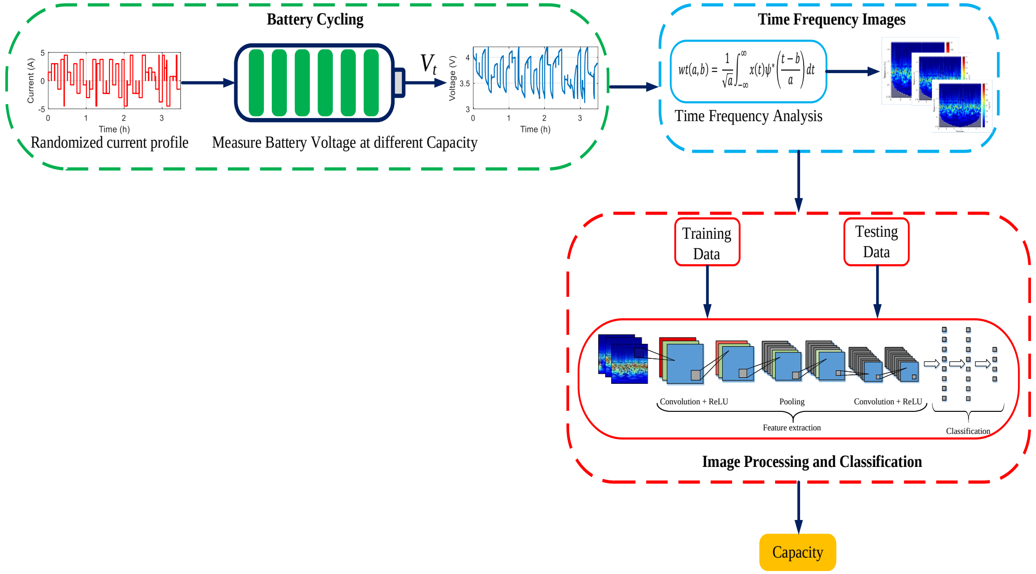
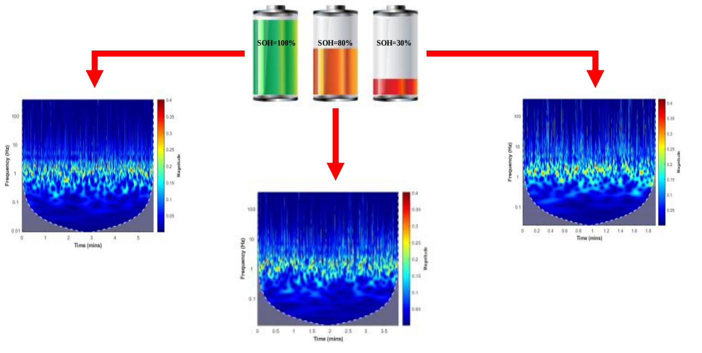
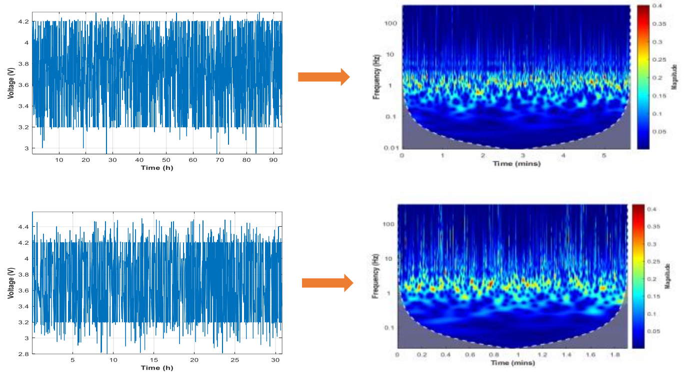
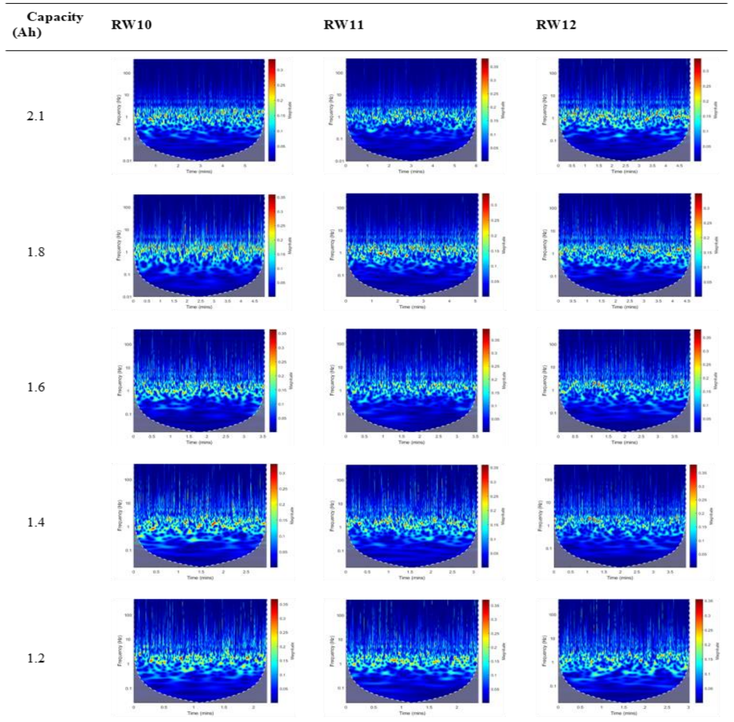






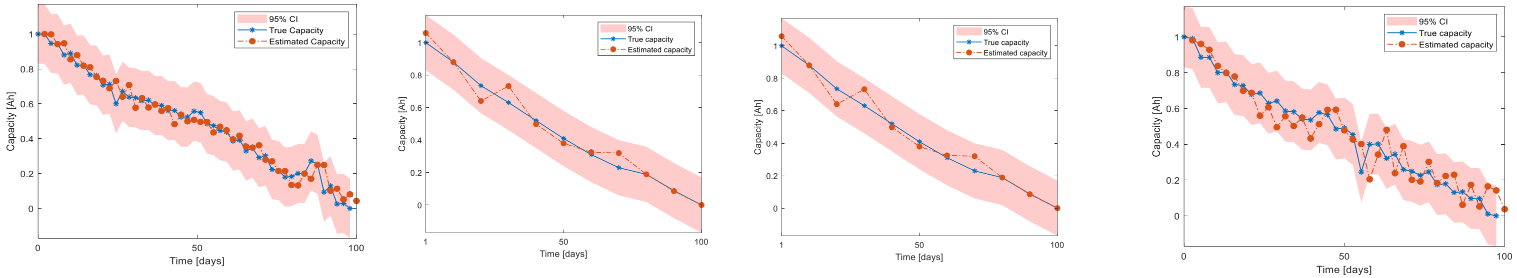


Capacity estimation accuracy for each battery cell using AlexNet

	RW9		RW10		RW11		RW12	
Optimiser	SGDM	Adam	SGDM	ADAM	SGDM	ADAM	SGDM	ADAM
Accuracy	95.0673%	95.69%	91.96%	94.20%	93.39%	94.27%	90.25%	91.5%

SoH estimation accuracy for each battery cell using the VGG-16 model

	RW9		RW10		RW11		RW12	
Optimiser	SGDM	ADAM	SGDM	ADAM	SGDM	ADAM	SGDM	ADAM
Accuracy	95.52%	95.52%	95.09%	95.60%	94.29%	94.92%	92.25%	95.5%



[] Ma'D El-Dalahmeh, **M. Al-greer**, Mo'Ath El-Dalahem, M.Short, "Time Frequency Image Analysis and Transfer learning for Capacity Estimation of Lithium-ion Battery.", Energies, 2020, 13(20), 5447.

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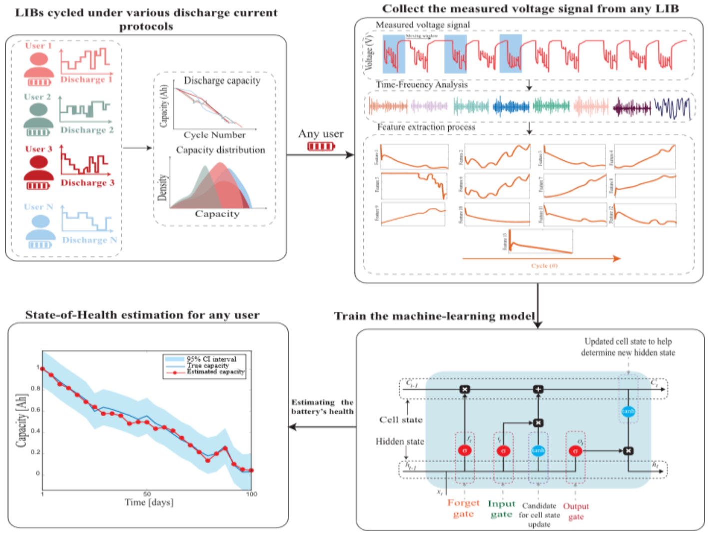

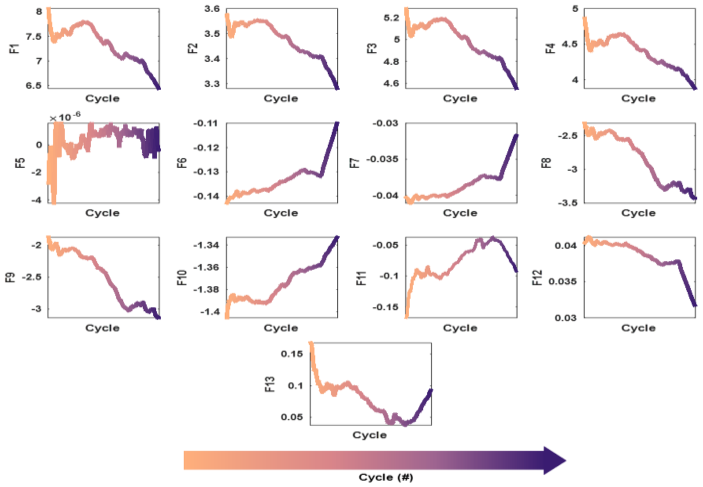

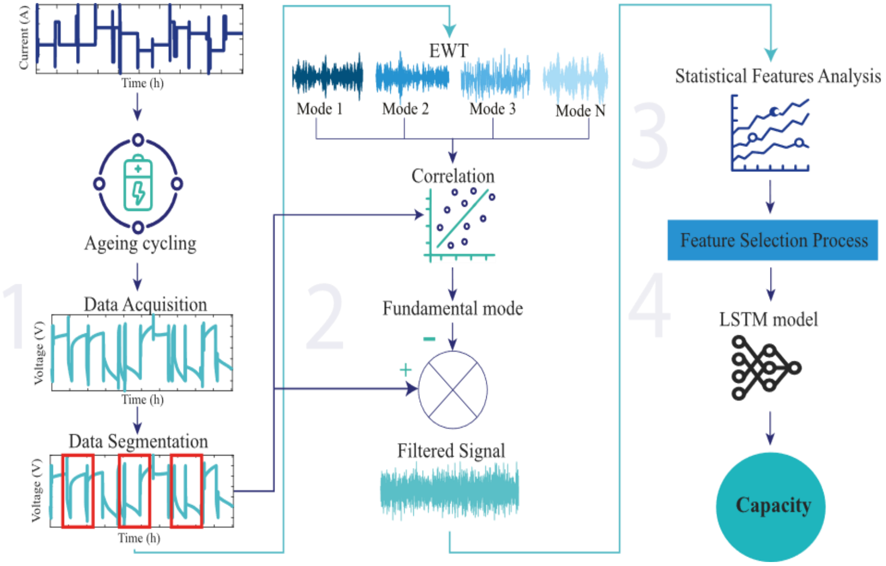

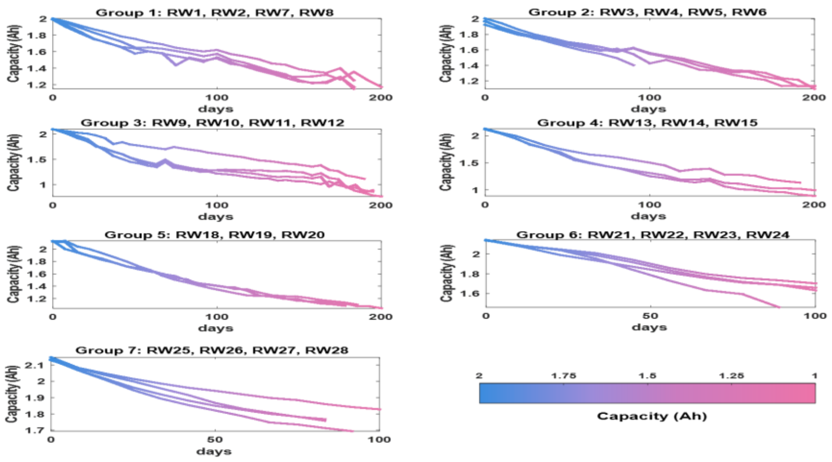

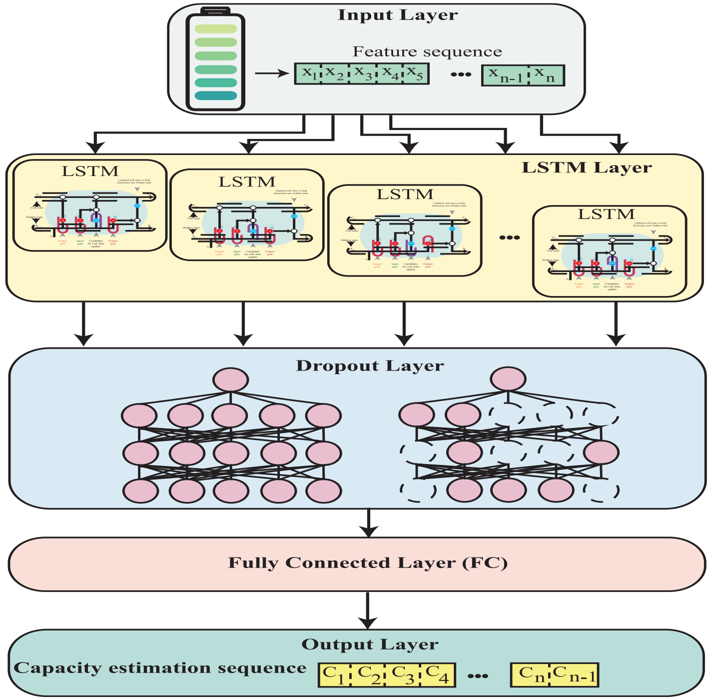

	RW1	RW4	RW9	RW14	RW19	RW22	RW25	W5	W9	Average
RMSE (%)	2.06	1.67	1.96	2.036	2.30	1.51	1.76	0.89	0.91	1.61%
AE (%)	3.87	3.56	7.39	3.82	4.34	2.69	3.72	1.62	1.50	3.61%

[] Ma'D El-Dalahmeh, **M. Al-greer**, Moath El-Dalahmeh, Imran Bashir, "Lithium-ion Batteries Capacity Estimation based on adaptive Empirical Wavelet Transform and LSTM Learning Neural Network", Journal of Energy Storage, 2023.
[] Ma'D El-Dalahmeh, **M. Al-greer**, Moath El-Dalahmeh, Imran Bashir, "Lithium-ion Batteries Capacity Degradation Trajectory Prediction Based on Decomposition Techniques and NARX Algorithm" in 57th IEEE International Universities Power Engineering Conference, UPEC, 2022.

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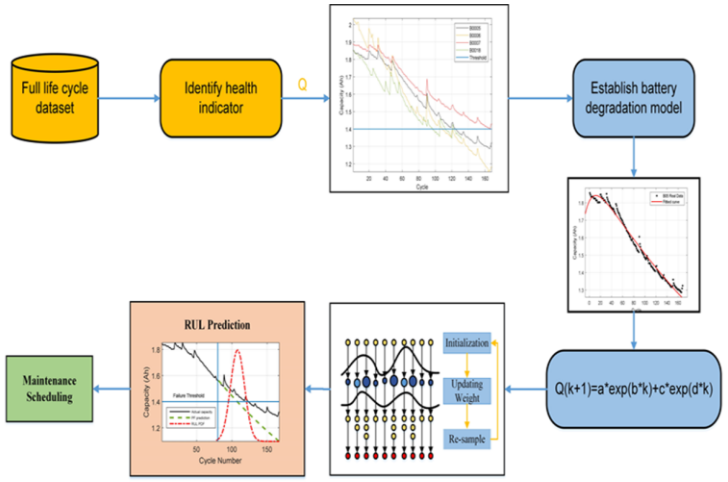
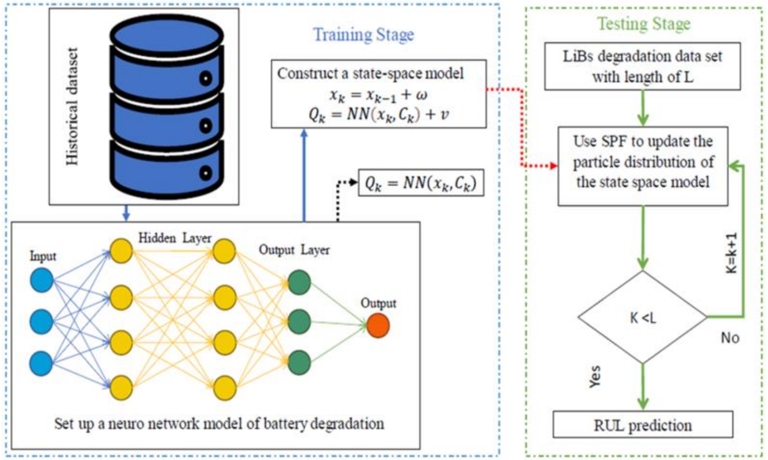
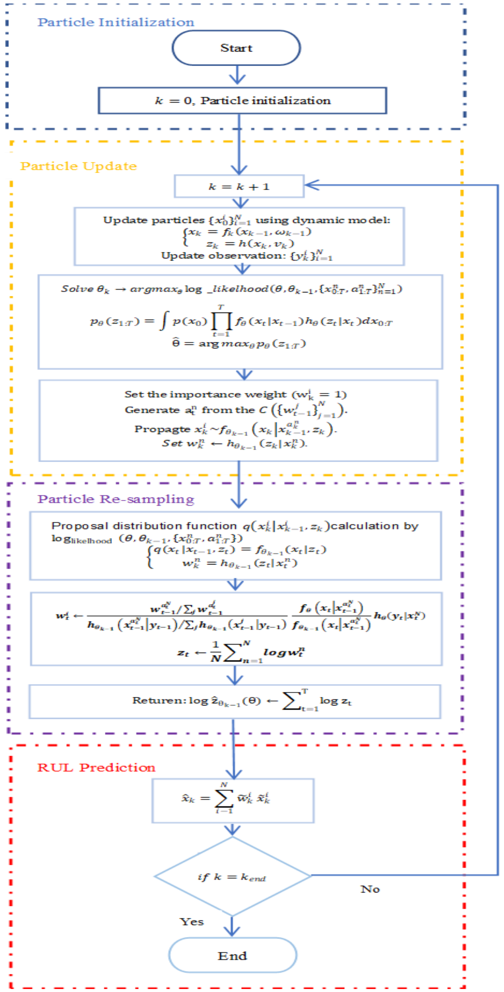
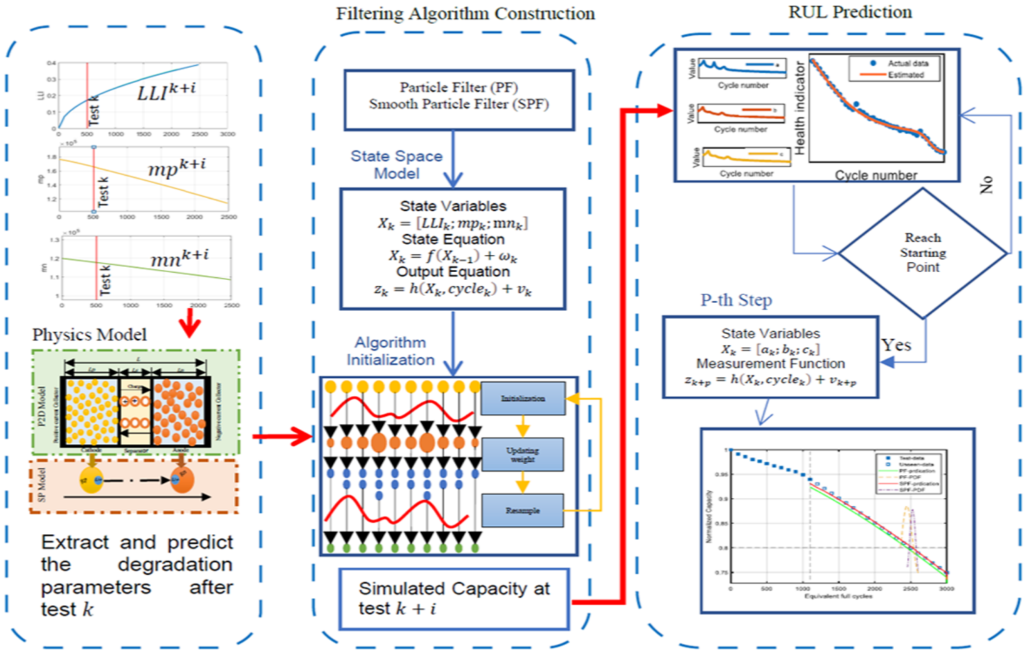
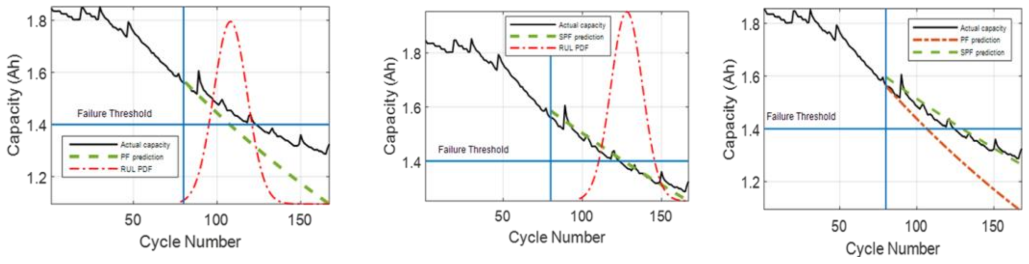








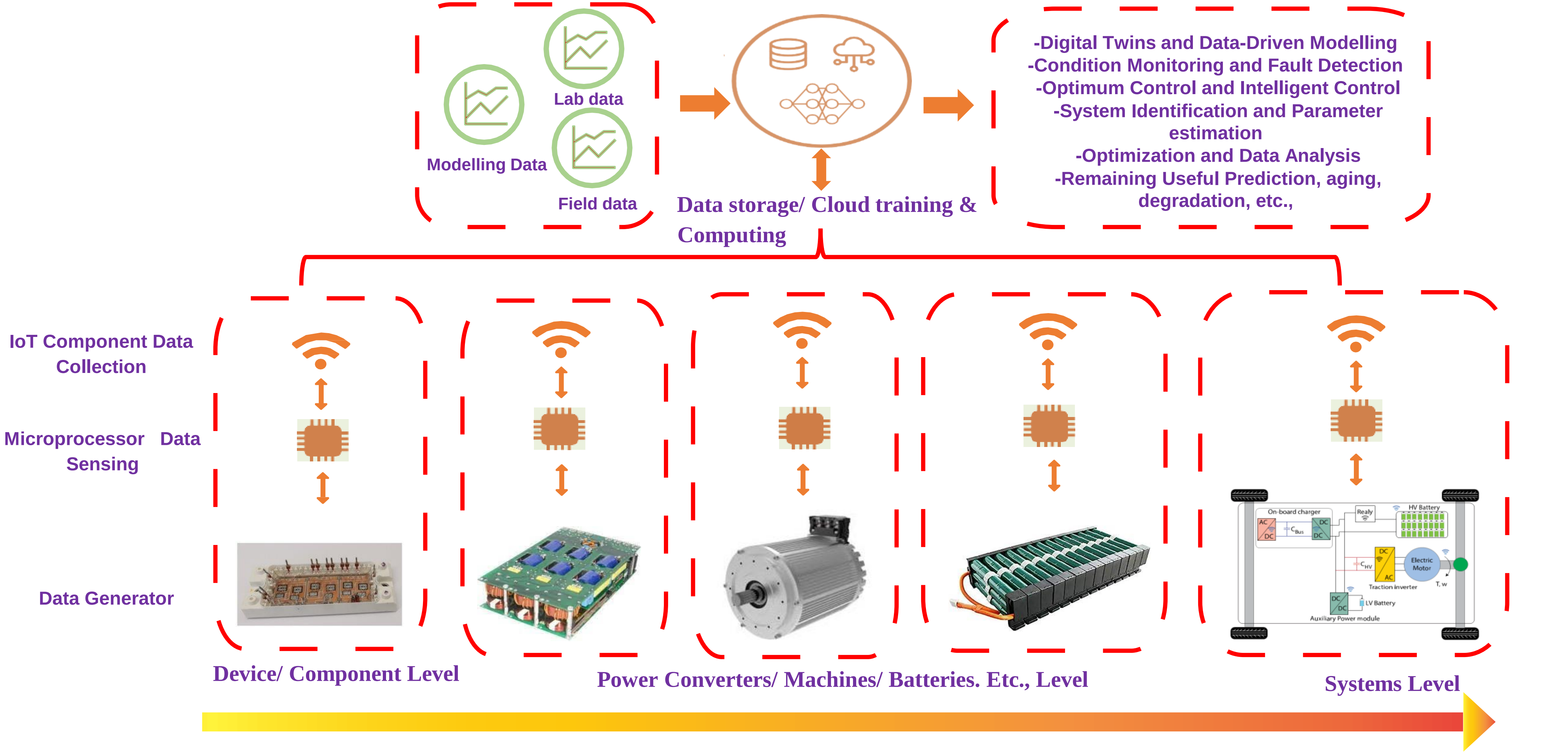


[] Mo'Ath El-Dalahmeh, **M. Al-greer**, Ma'D El-Dalahmeh, Imran Bashir, "Physics-Based Model Informed Smooth Particle Filter for Remaining Useful Life Prediction of Lithium-ion Battery", **Measurement, Elsevier**, 2023.

[] Mo'Ath El-Dalahmeh, **M. Al-greer**, Ma'D El-Dalahem, M.Short, "Novel Smooth Particle Filter for the Remaining Useful Life Prediction of Lithium-Ion Batteries" IET Smart Grid Journal, 2021.

[] Mo'Ath El-Dalahmeh, **M. Al-greer**, Ma'D El-Dalahmeh, Imran Bashir, "Online Hybrid Prognostic Health Management Prediction Using a Neural Network and Smooth Particle Filter for Lithium-ion Batteries" in 57th IEEE International Universities Power Engineering Conference, UPEC, 2022. Best paper awards

Plans and Vision



Intelligent Power Electronics 4.0- Cloud-based Health Monitoring and Intelligent Control Platform

Thanks!

I would also like to thank my team and collaborators, in particular Ma'd El-Dalahmeh, Mo'ath El-Dalahmeh, Imran Bashir, Aykut Demirel and Ozan Keysan

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