Robust and reliable general management tool for performance and durability improvement of fuel cell stationary units

SOFC modeling via neural networks

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RUBY MEETING, CAPRI

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- INTRODUCTION
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- CONCLUSIONS

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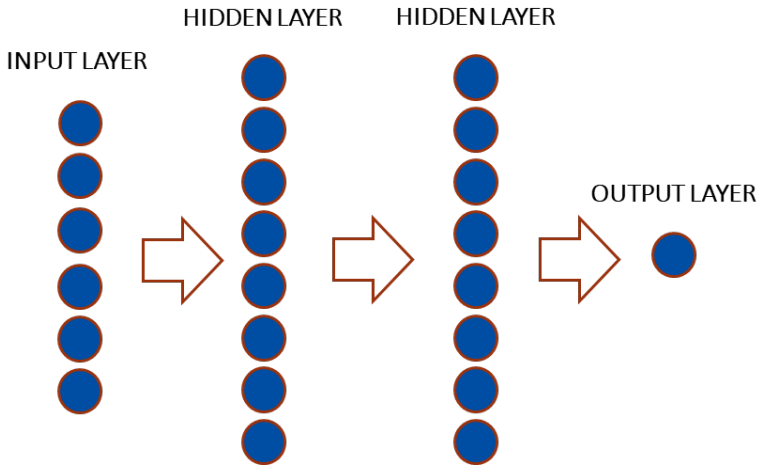
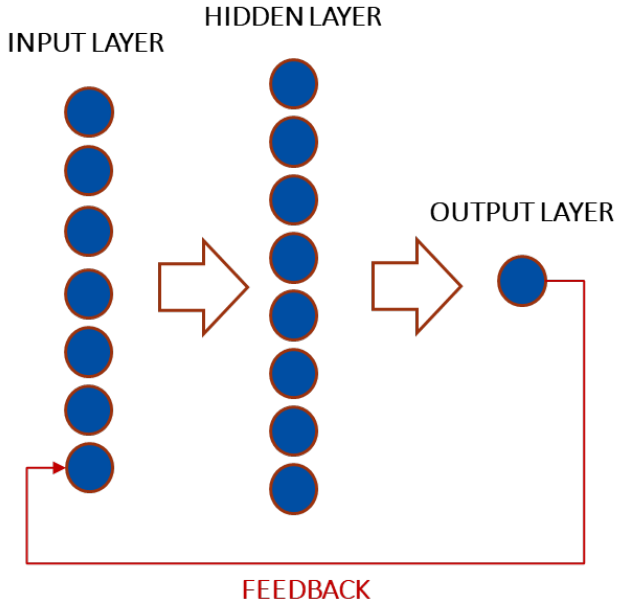
Introduction

Within the objectives of the RUBY project regarding the procedures for **diagnosis and prognosis** of fuel cell systems, based on the data provided by Sunfire, **two different methodologies** were constructed in order to explore its different potentials in modeling a SOFC stack voltage.

FFNN methodology



RNN methodology



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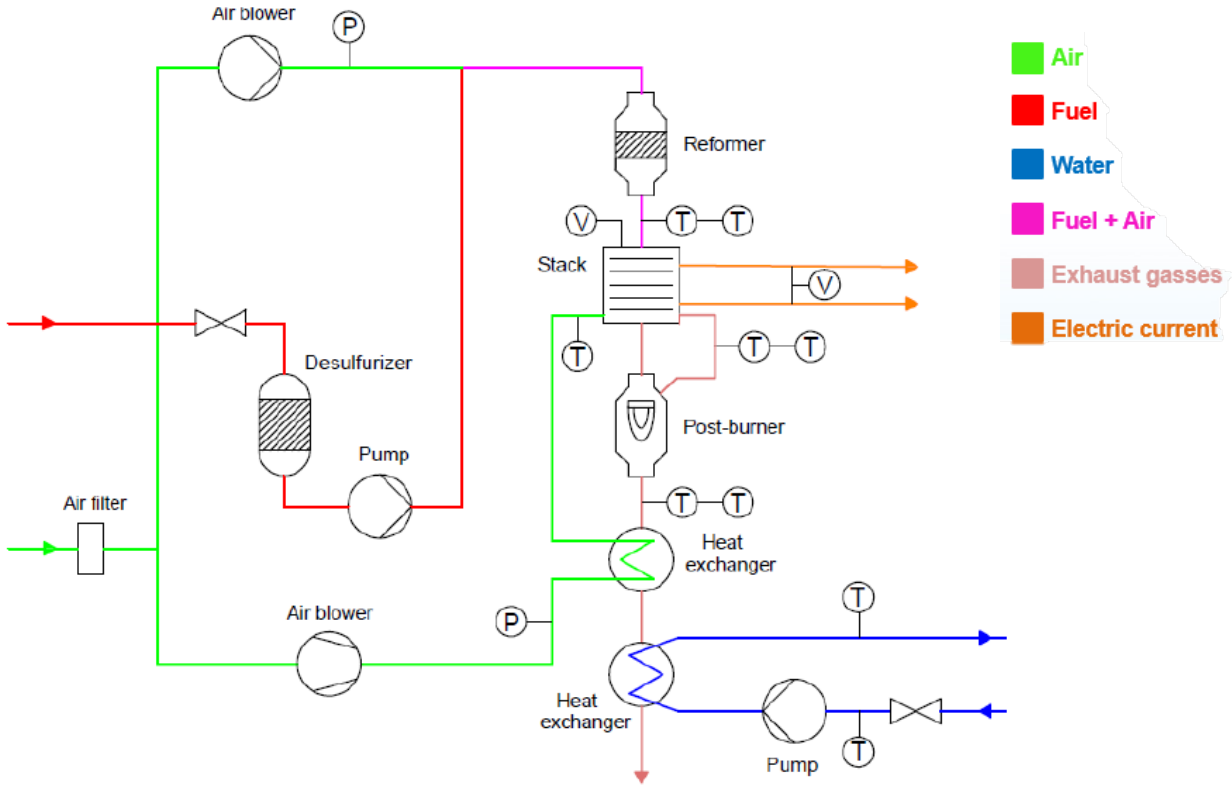
System description

The system studied is a **micro-CHP plant**, based on solid oxide fuel cell technology, developed by project partner Sunfire. Specifically, the system analyzed is the **Sunfire-Home 750**, which is a micro-CHP system for residential use.

SUNFIRE HOME - 750



Technology	SOFC
# of cells	57
Single cell area	127 cm^2
Nominal voltage	45 Vdc
Nominal current	19 A

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Dataset description

	FILE NAME	FUEL	SAMPLING	COMMENTS
1° condition	normal operation 20210414-20210630	NG	≈ 17.5 sec	Data on normal system operation with the presence of some shutdowns
	normal operation 20210701-20211130			
	normal operation 20211223-20220620			
2° condition	soot formation 20200716 - 20210318	LPG		Data on normal system operation until failure due to formation and accumulation of soot
	soot formation 20210318 - 20210707			
	soot formation 20210708 - 20210930			
3° condition	Data 20210609 - 20210630		≈ 6 min	Data on normal system operation with the presence of some shutdowns
	Data 20210701 - 20210930			
	Data 20211001 - 20211231			
	Data 20220101 - 20220331			
	Data 20220401 - 20220630			
	Data 20220701 - 20220927			

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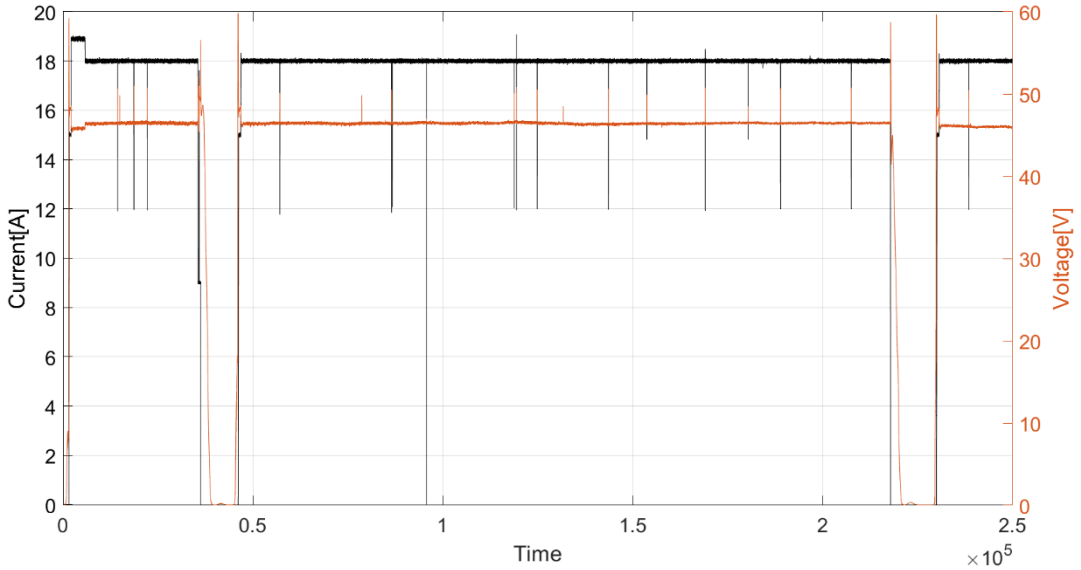
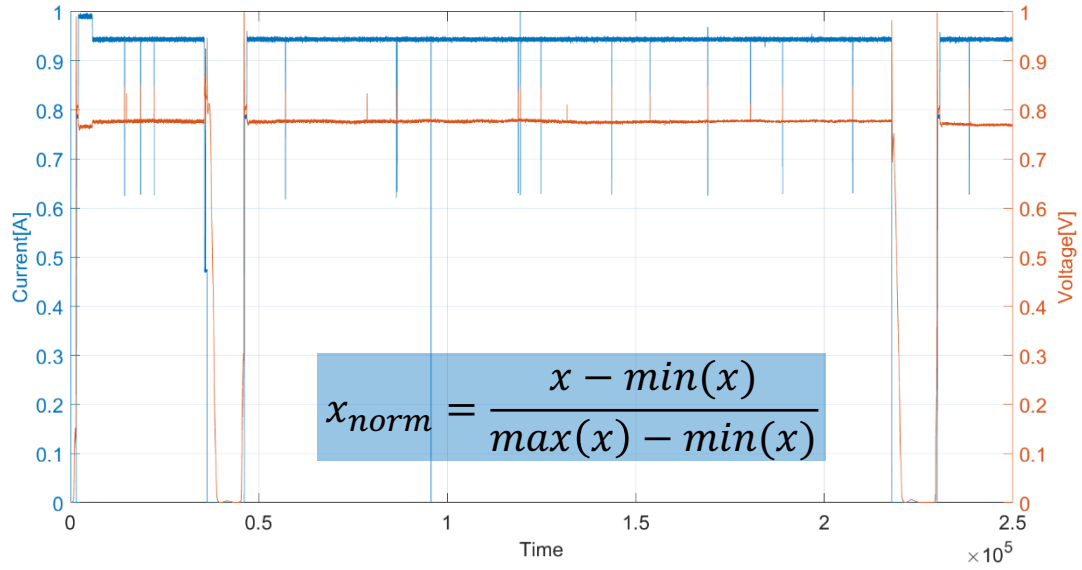
Data pre-processing

The data must undergo a **pre-processing** phase before being given to the model:

- Sampling rate alignment:
  - 1° condition: 17.5 s
  - 2° condition: 17.5 s
  - 3° condition: 6 min

→ All dataset: 6 min





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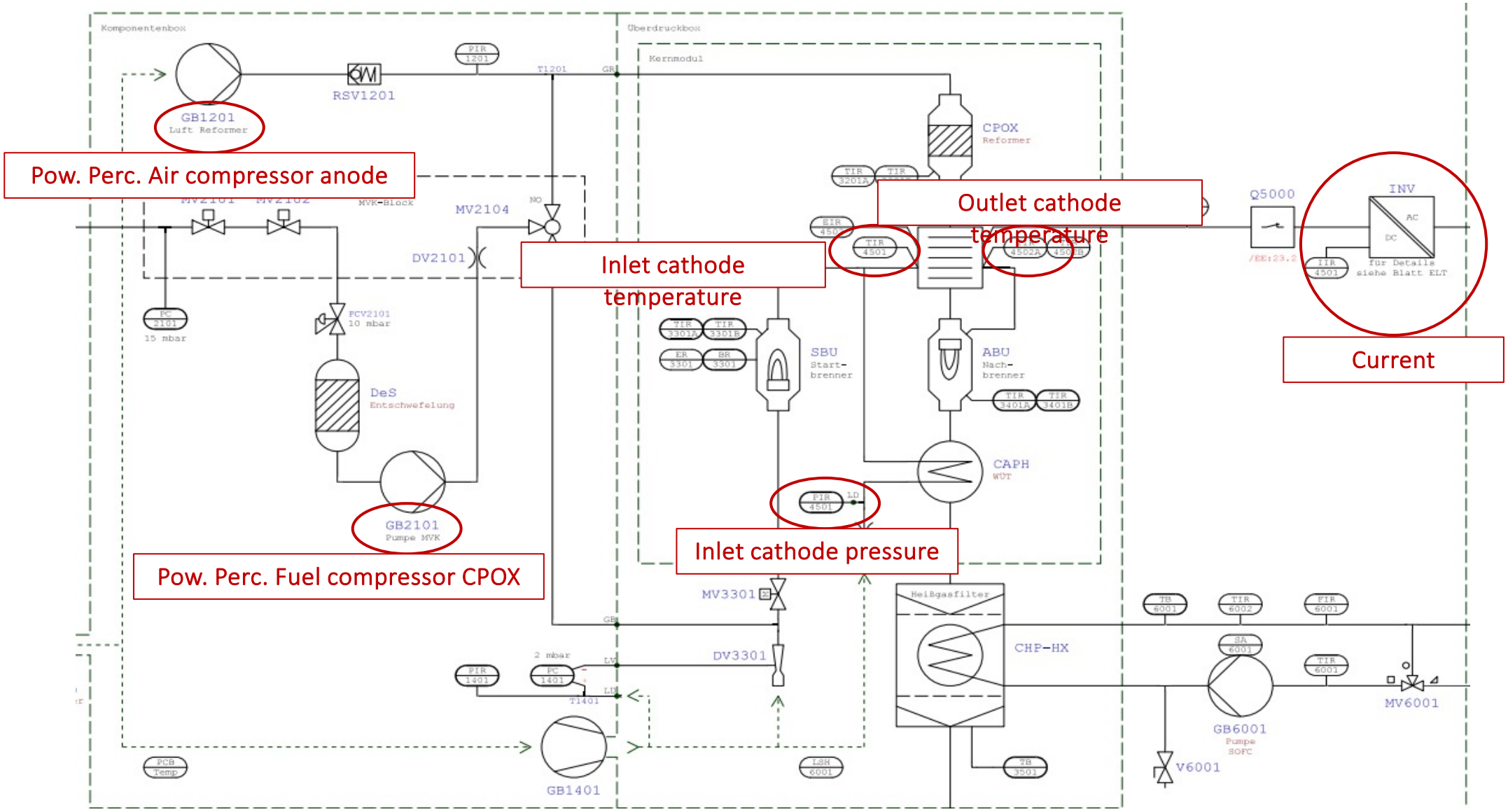
Considered Variables



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FFNN methodology

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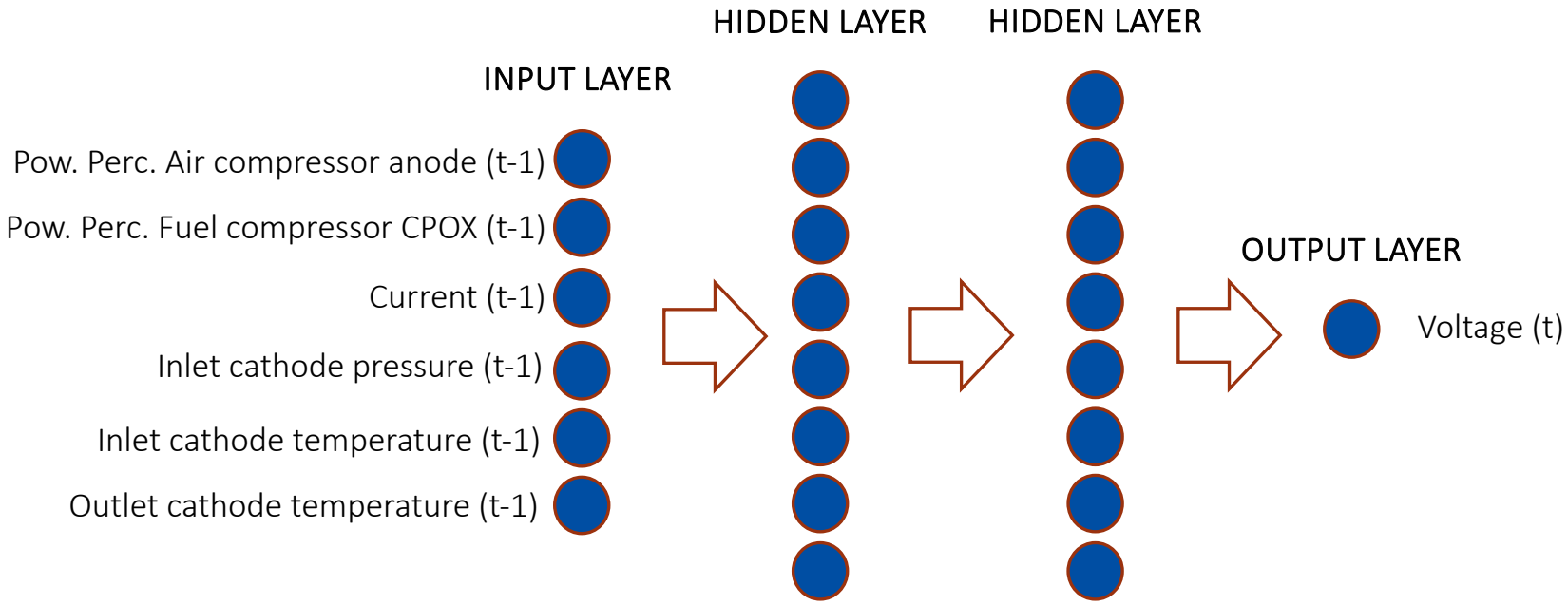
Feed Forward Neural Network (FFNN)



NETWORK SETTINGS:

INPUT PRE-PROCESSING:
Normalization
INPUT:
6 Variables
OUTPUT:
1 Variable
HIDDEN LAYER:
2 Hidden Layers with 8 neurons
TRAINING ALGORITHM:
Levenberg-Marquardt
ACTIVATION FUNCTION:
Hyperbolic Tangent

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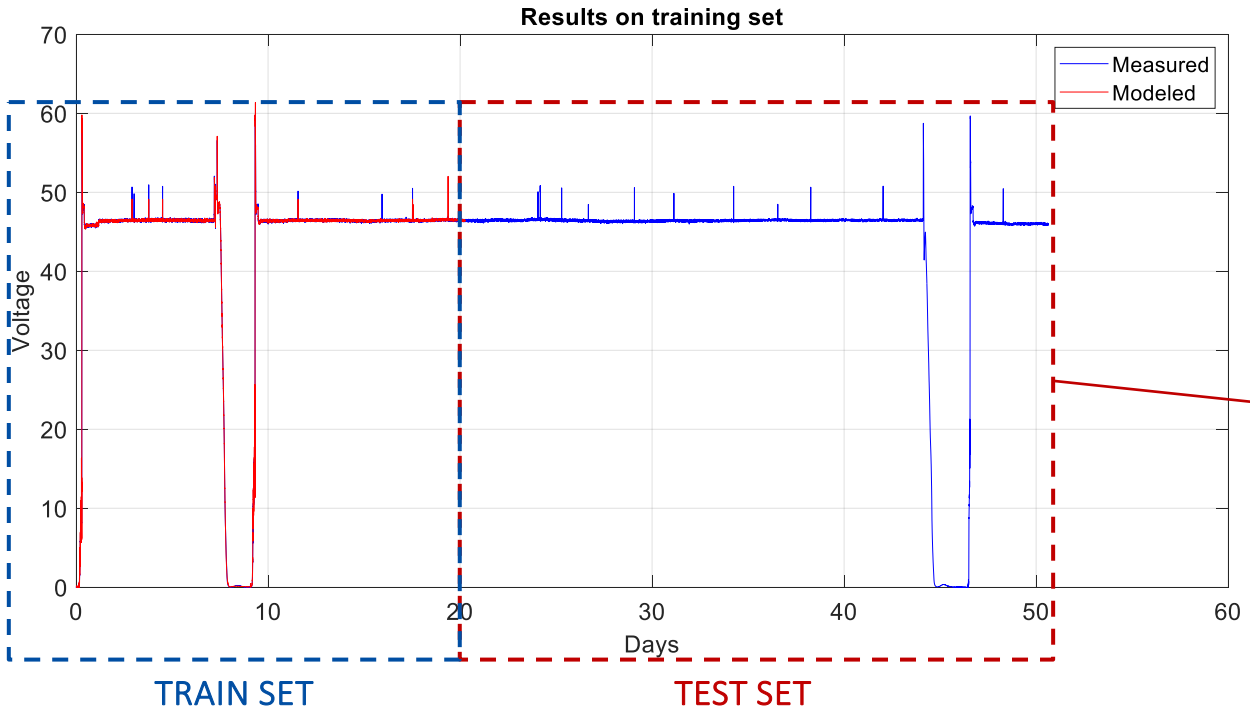
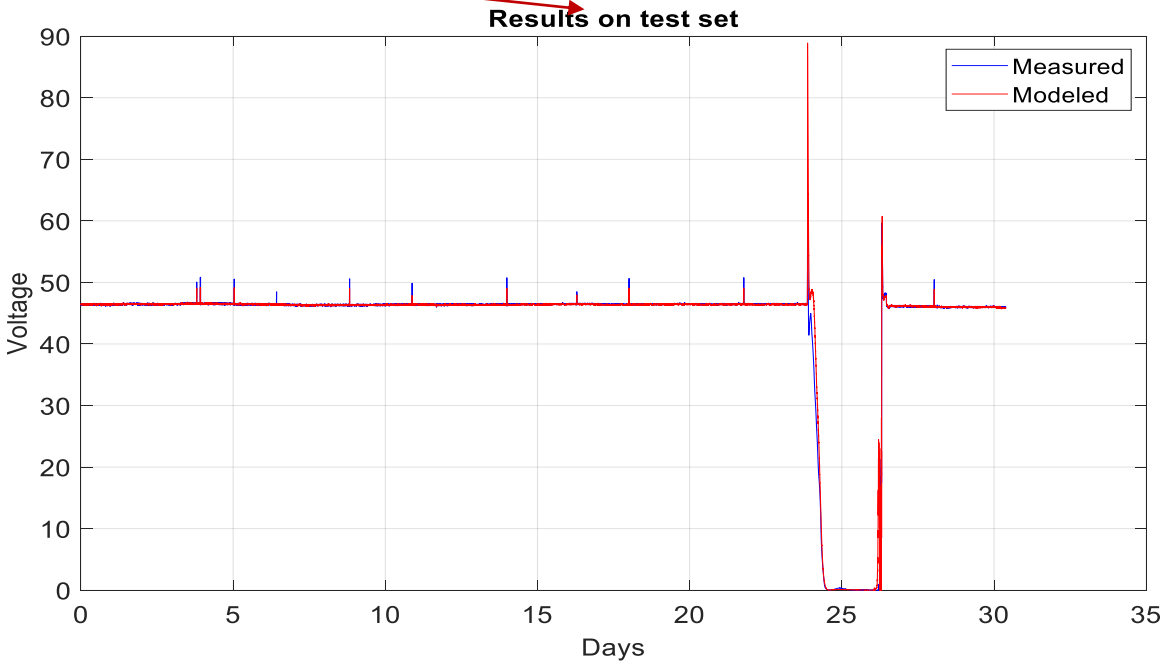
Performance evaluation 1/2



1° CONDITION DATASET WAS USED FOR THIS PERFORMANCE EVALUATION



THE RESULTS SHOW A HIGH DEGREE OF ACCURACY, BUT...

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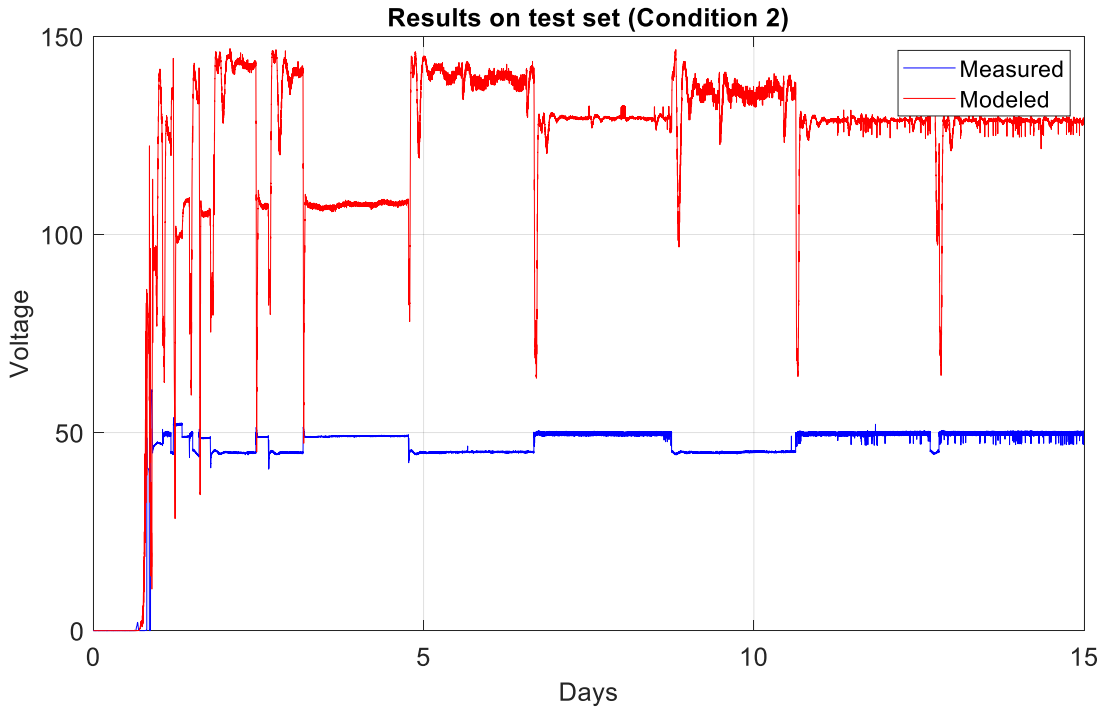
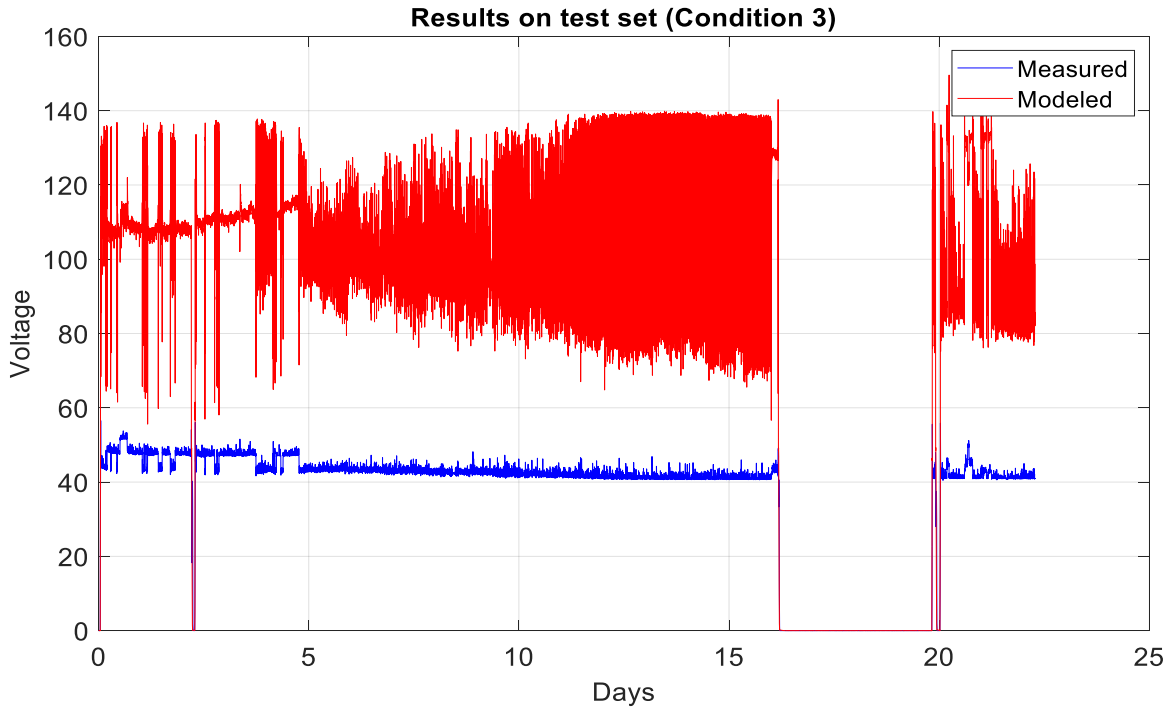
Performance evaluation 2/2

…A DEGREE OF GENERALIZABILITY TOO LOW TO MAKE THE MODEL APPLICABLE UNDER THE OTHER CONDITIONS





IT IS NECESSARY TO INTRODUCE TECHNIQUES TO INCREASE GENERALIZABILITY WITHOUT CRITICALLY REDUCING ACCURACY

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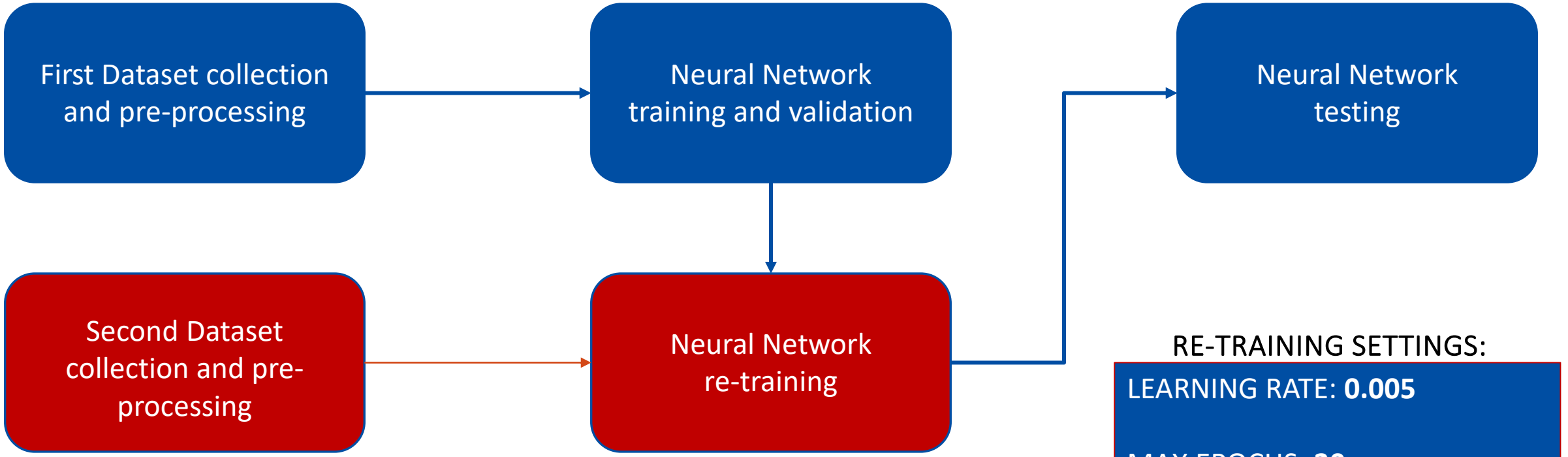
Fine Tuning of the FFNN



RE-TRAINING SETTINGS:

LEARNING RATE: **0.005**

MAX EPOCHS: **30**

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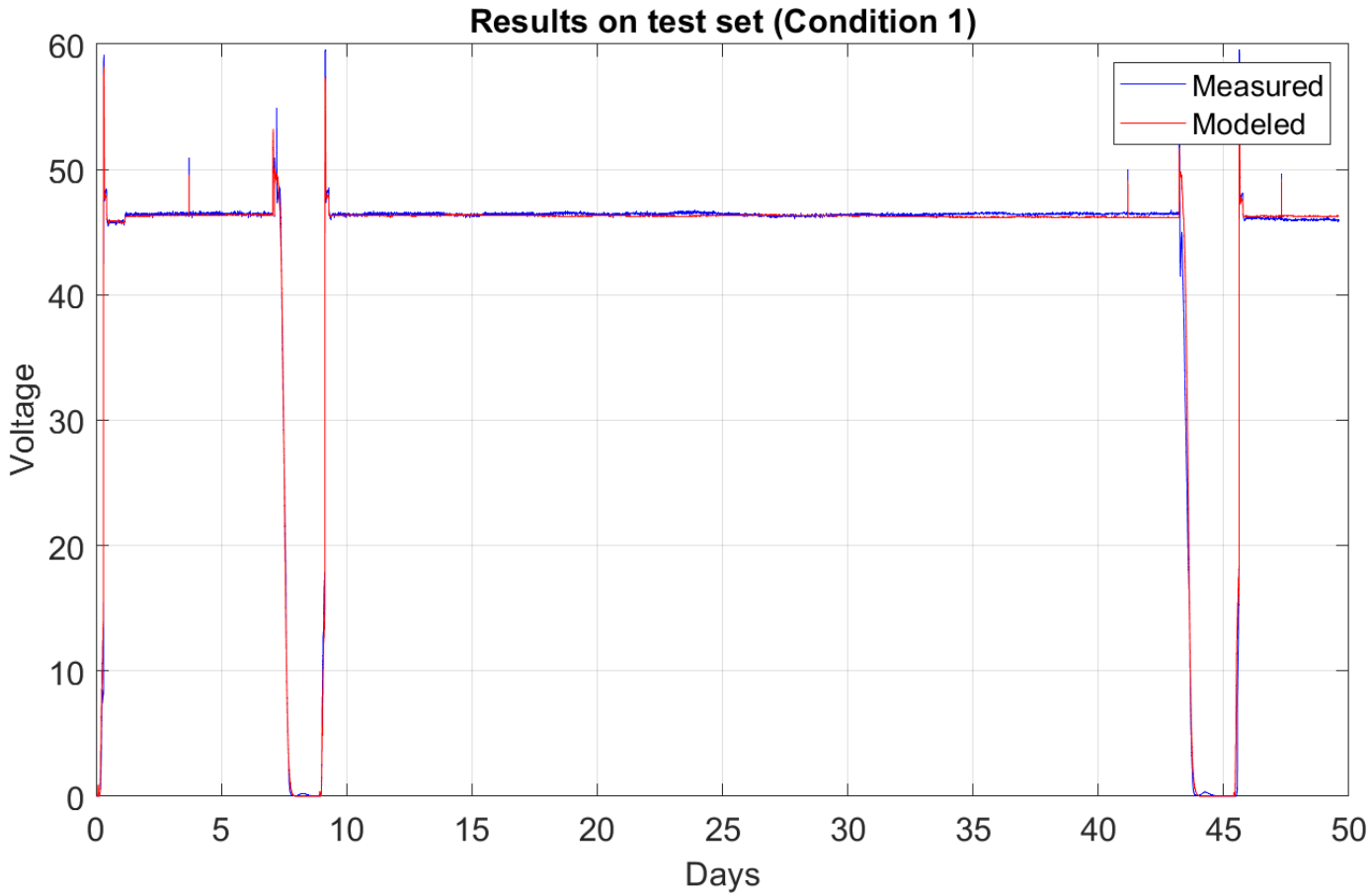
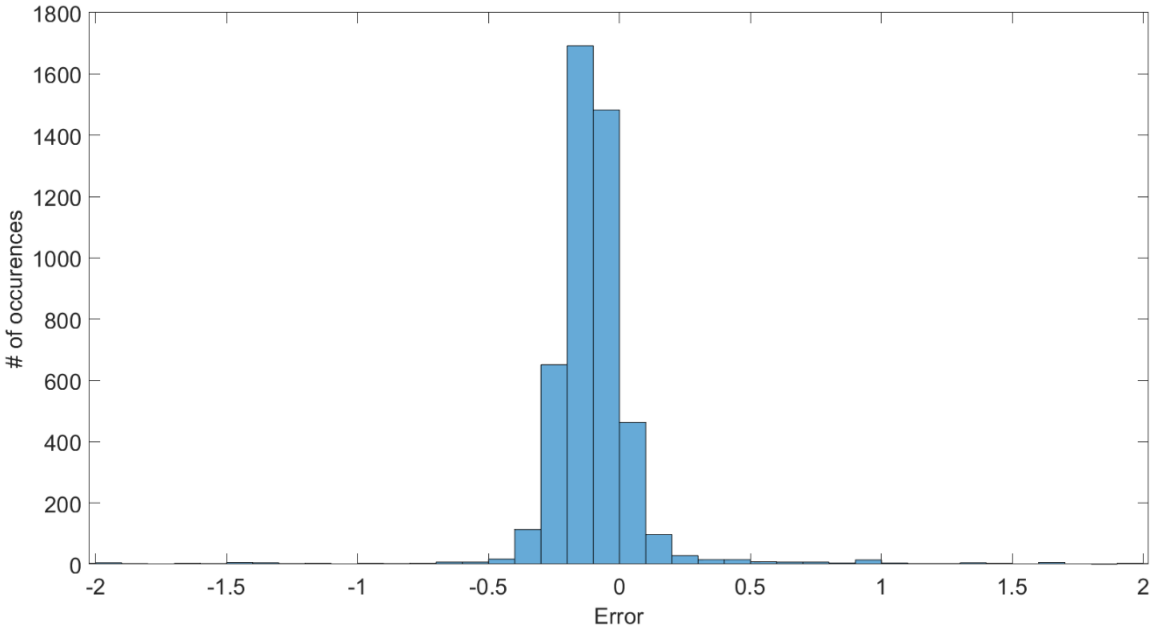
Results 1/3 – Condition 1



On the first condition dataset a **normal distribution** of the error can be observed.



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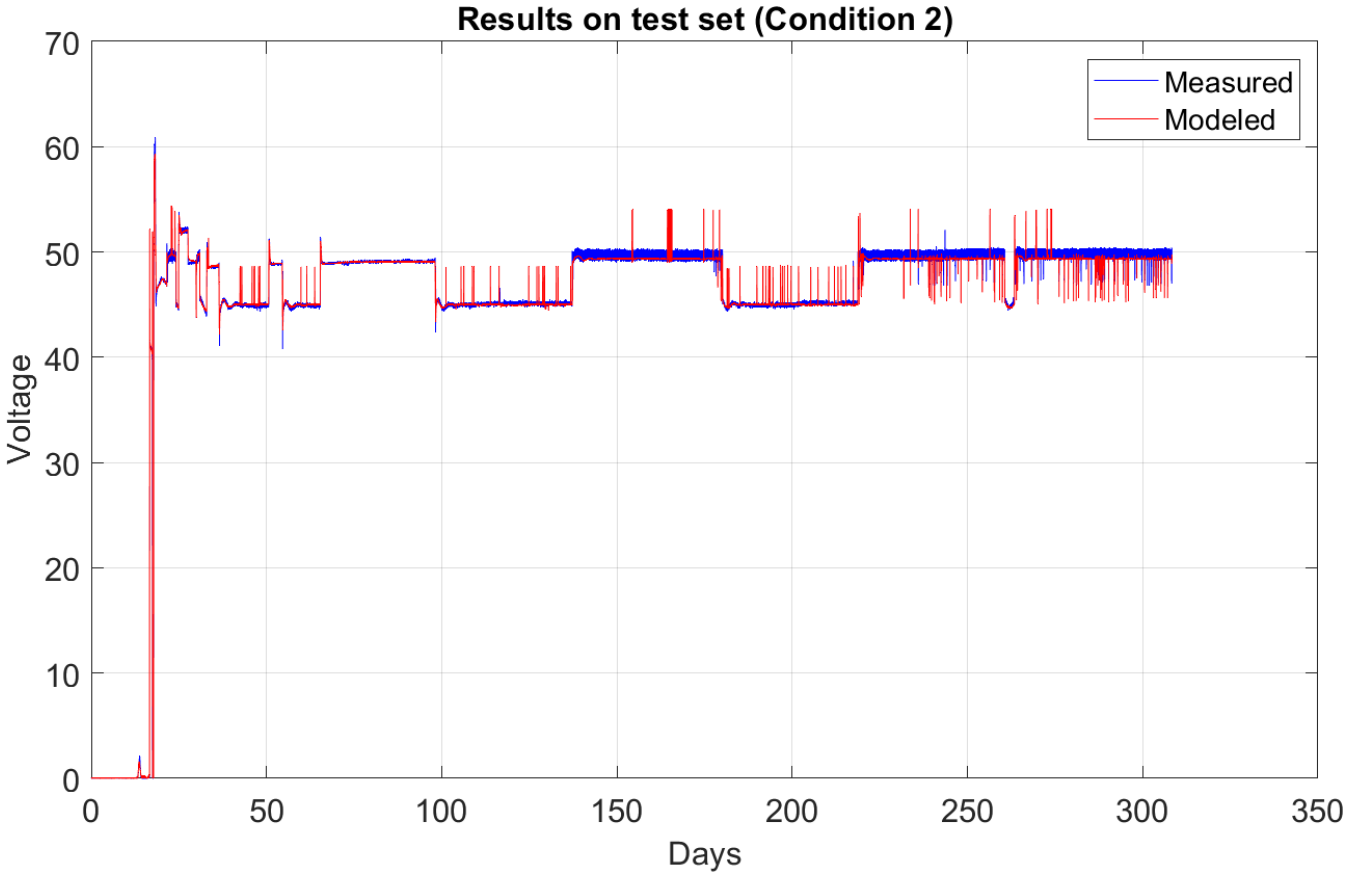
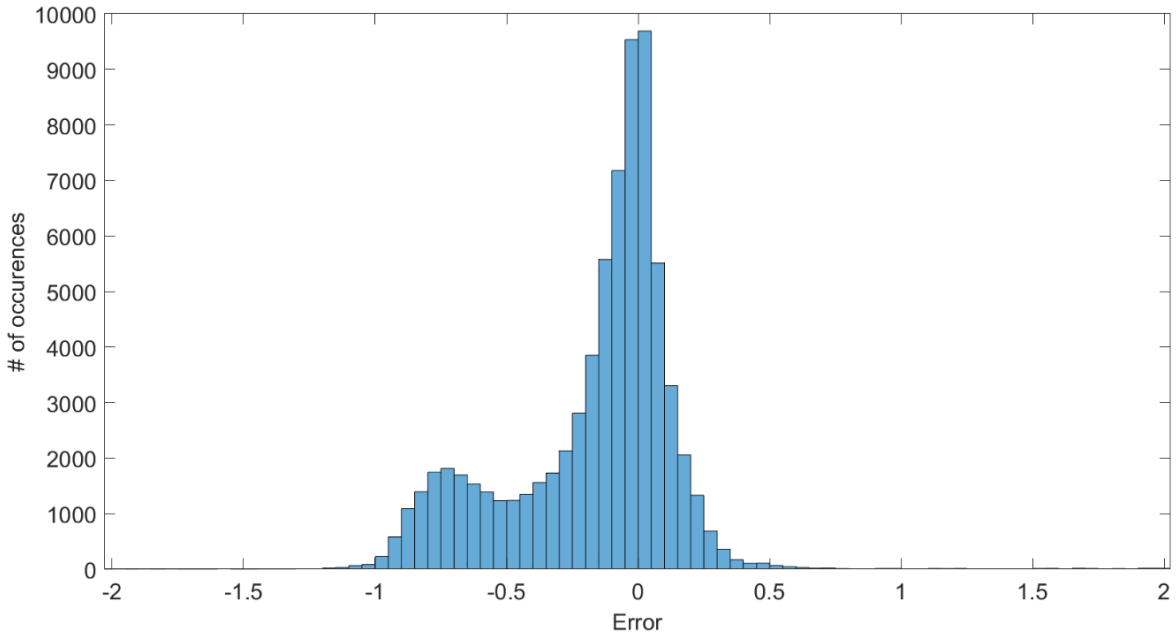
Results 2/3 – Condition 2



Worst performances on the other condition dataset can be observed



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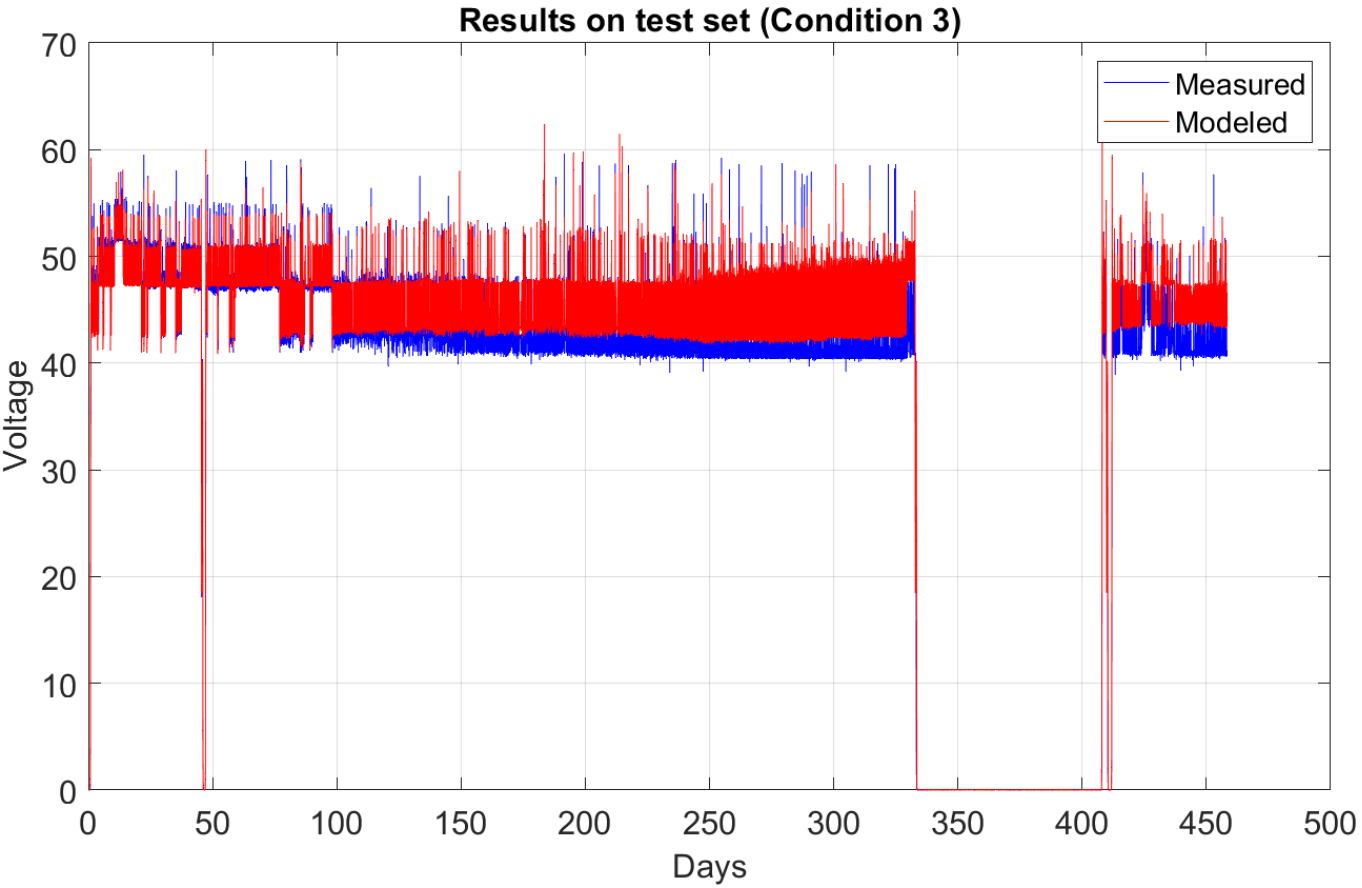
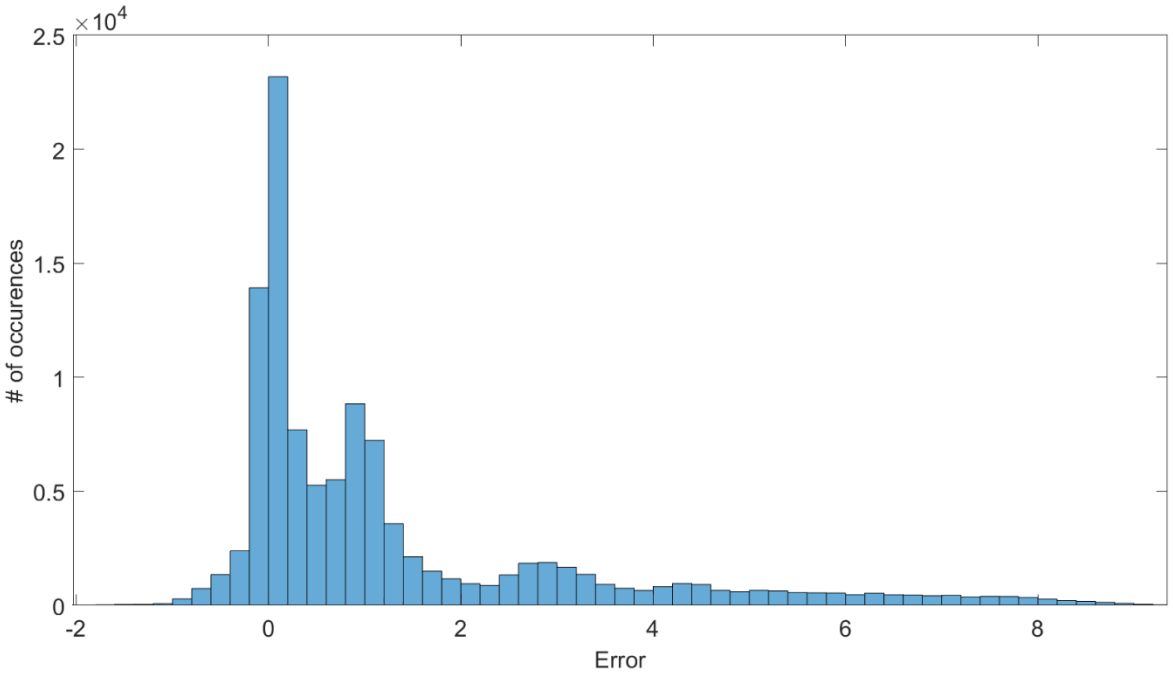
Results 3/3 – Condition 3



Worst performances on the other condition dataset can be observed



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RNN methodology

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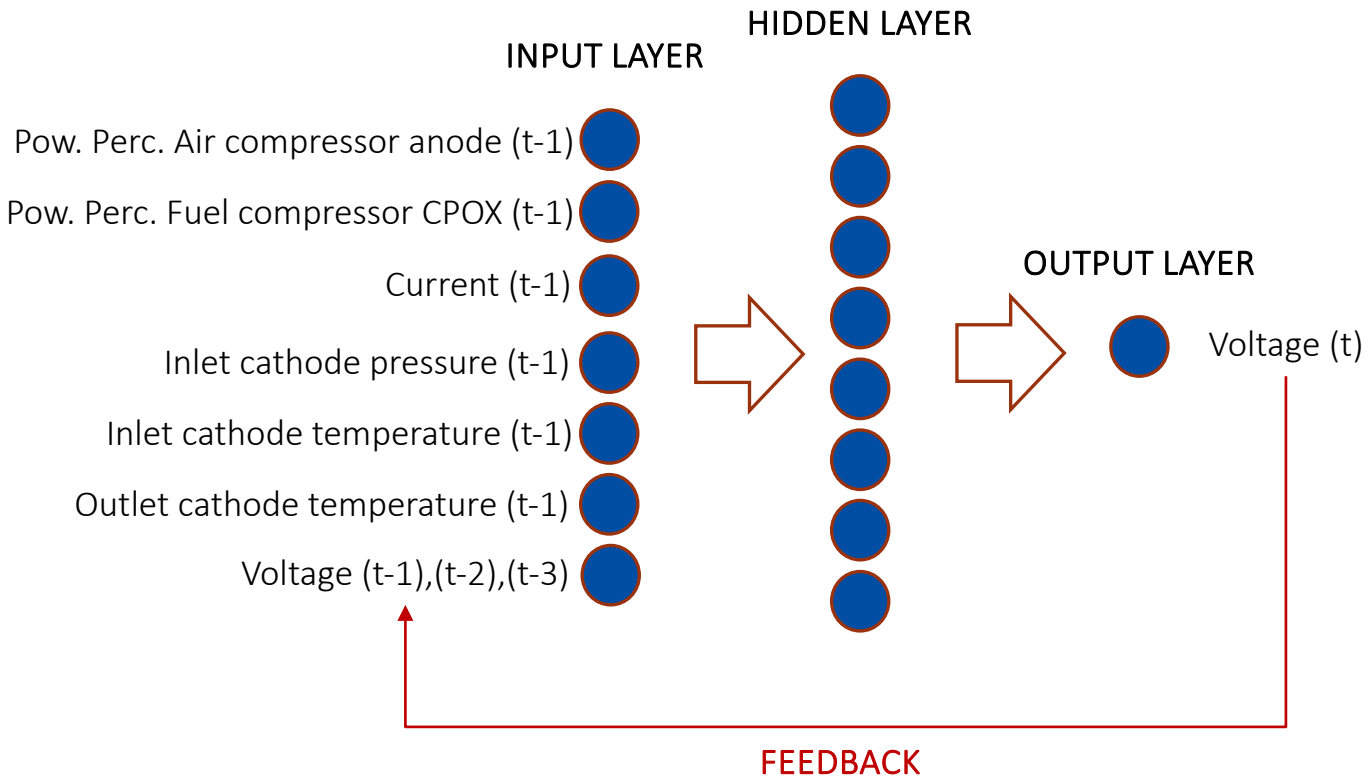
Recurrent Neural Network (RNN)



NETWORK SETTINGS:

INPUT PRE-PROCESSING:
Normalization
INPUT:
6 Variables + 3 Time Step Feedbacks
OUTPUT:
1 Variable
HIDDEN LAYER:
1 Hidden Layers with 10 neurons
TRAINING ALGORITHM:
Levenberg-Marquardt
ACTIVATION FUNCTION:
Hyperbolic Tangent (HL) & Linear (O)

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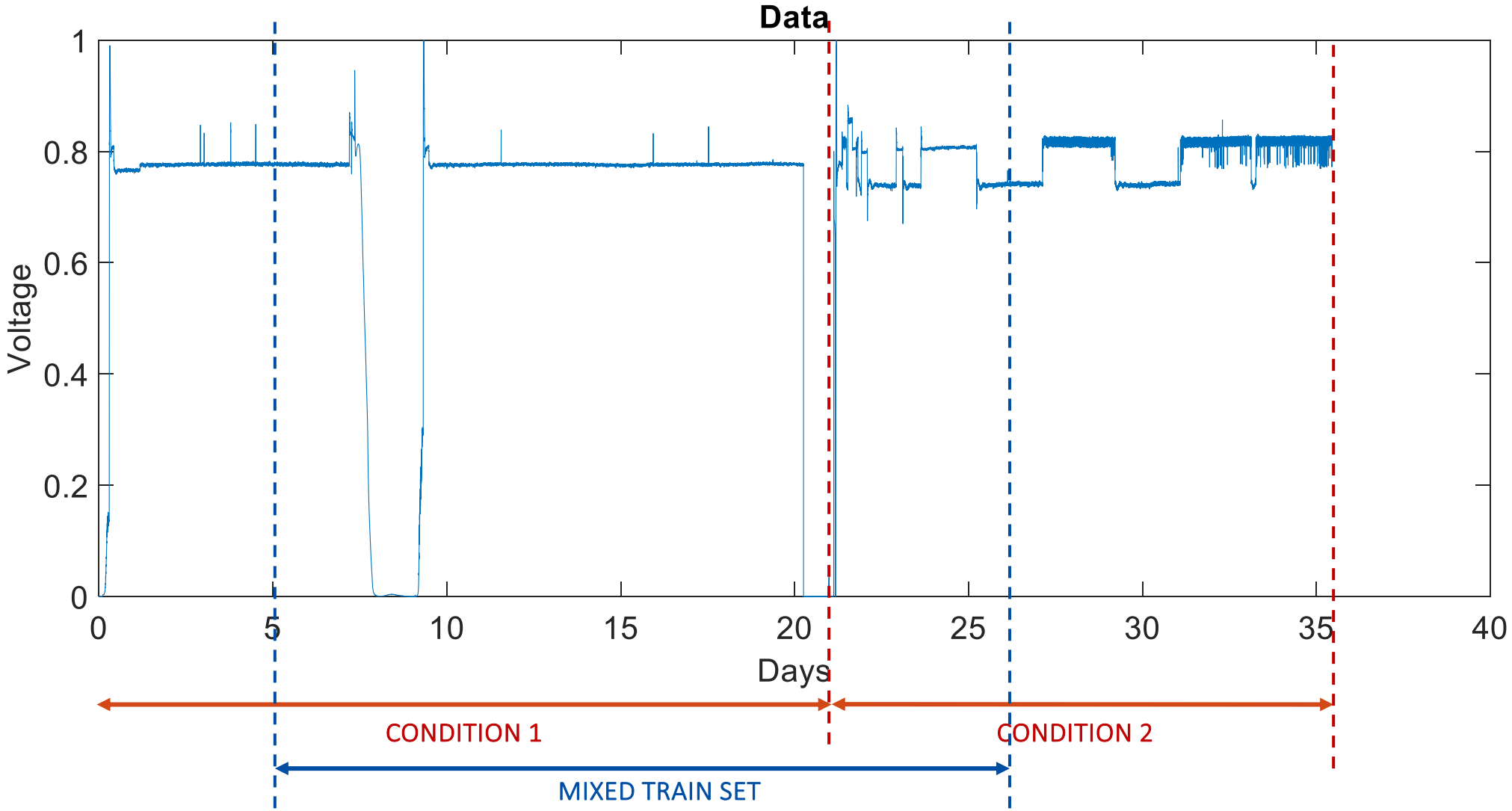
Increasing generalizability



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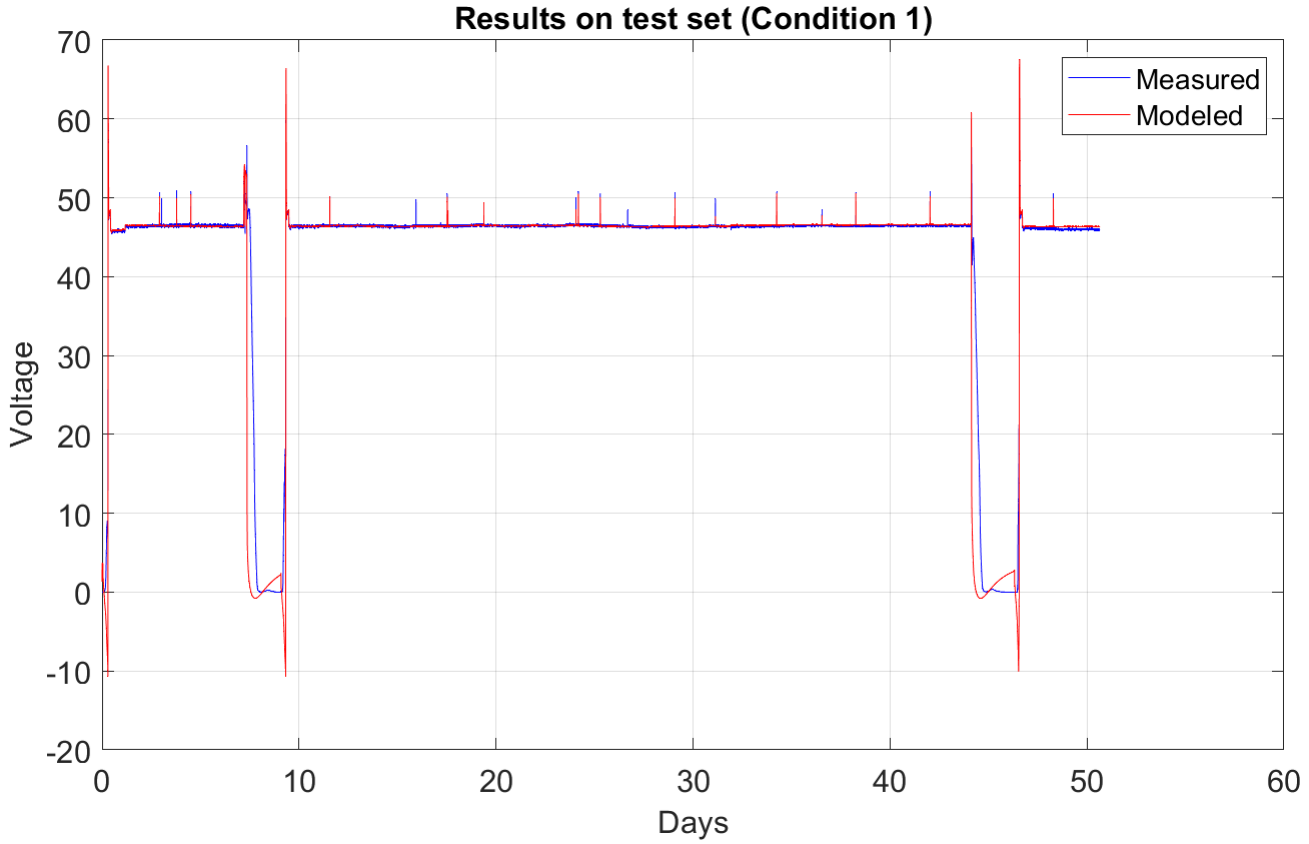
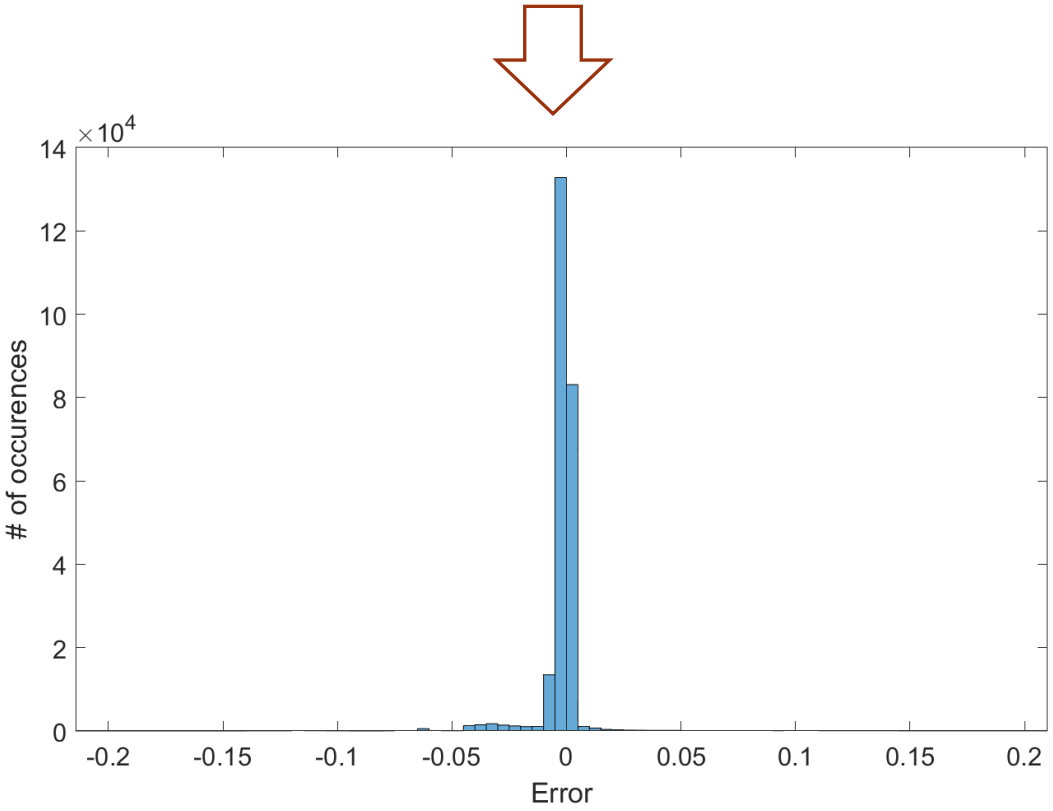
Results 1/3 – Condition 1



Improved performances can be observed



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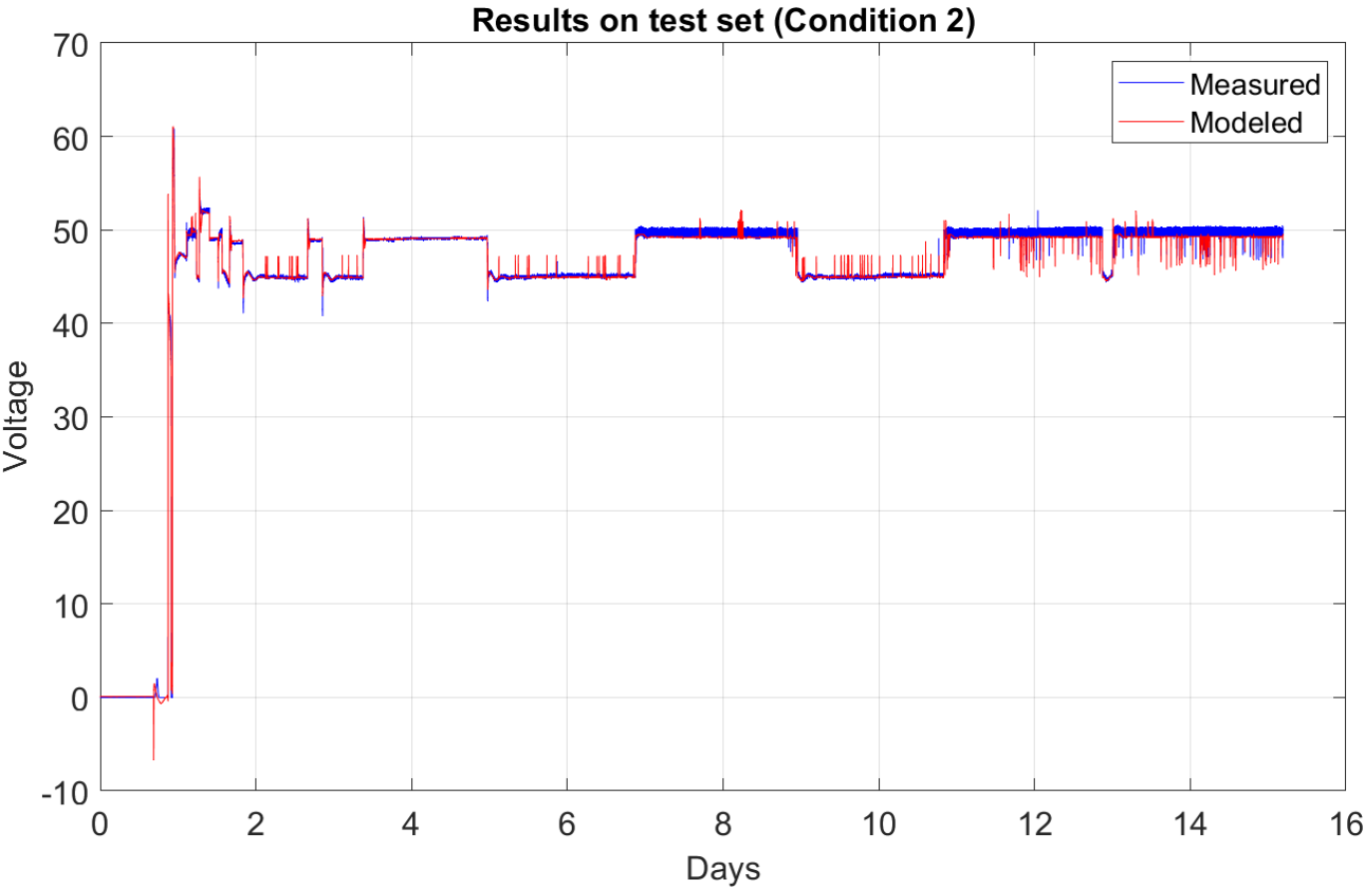
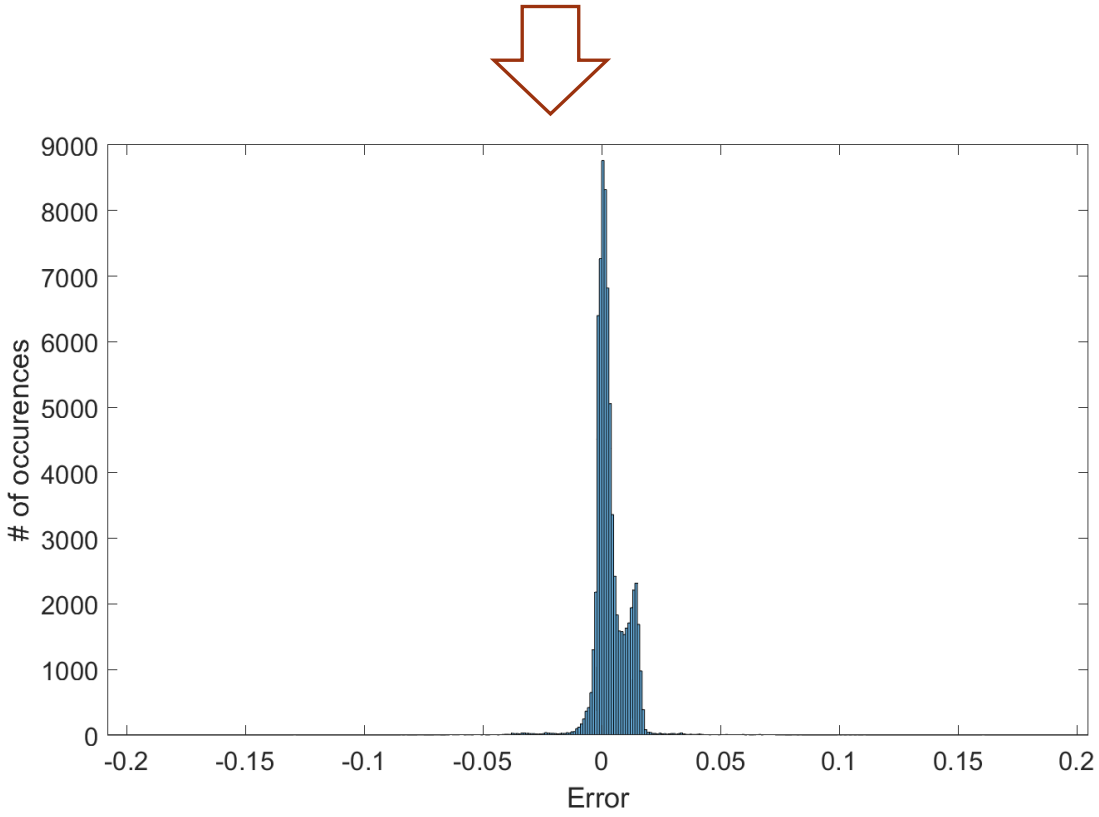
Results 2/3 – Condition 2



Improved performances can be observed



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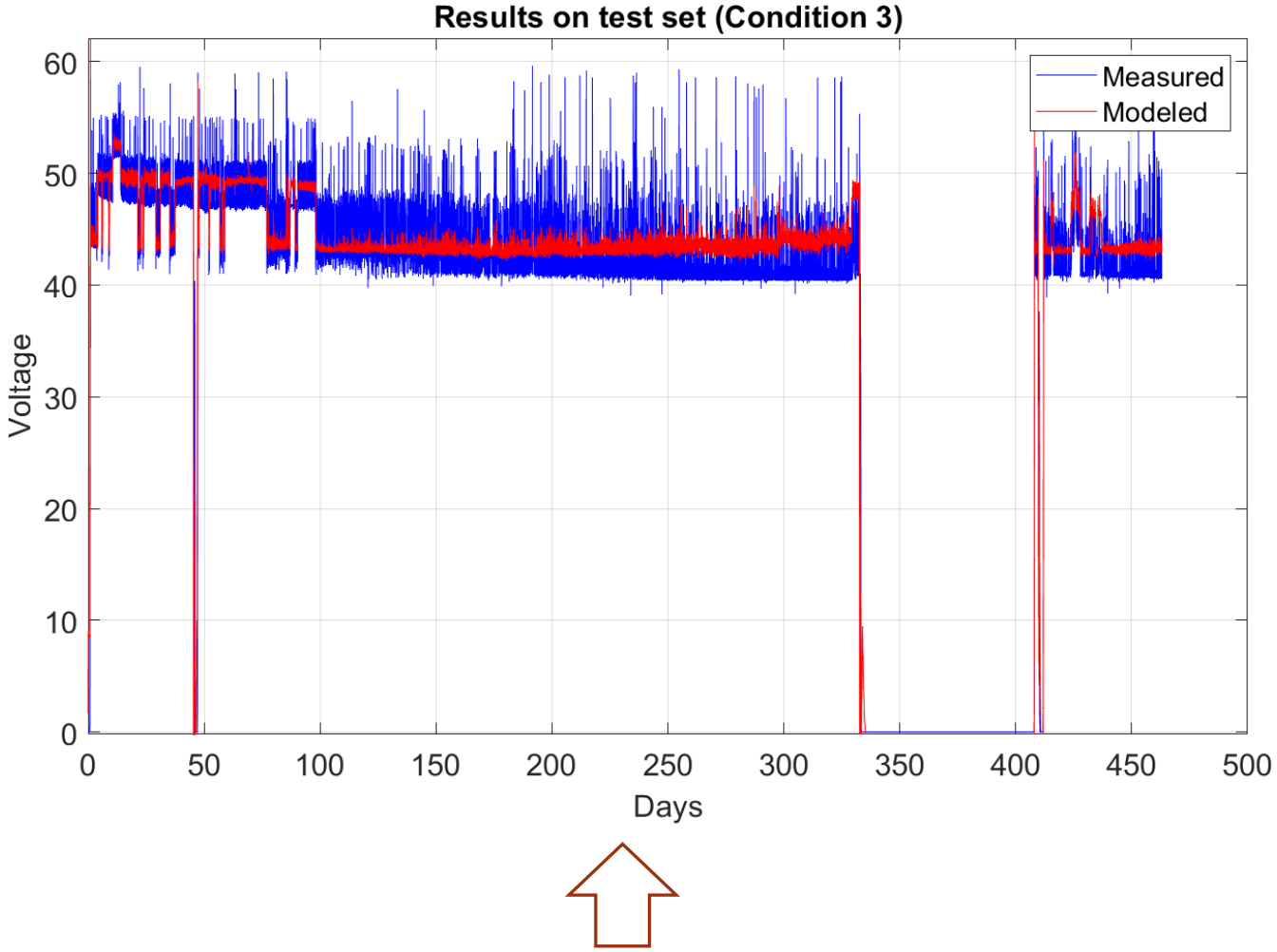
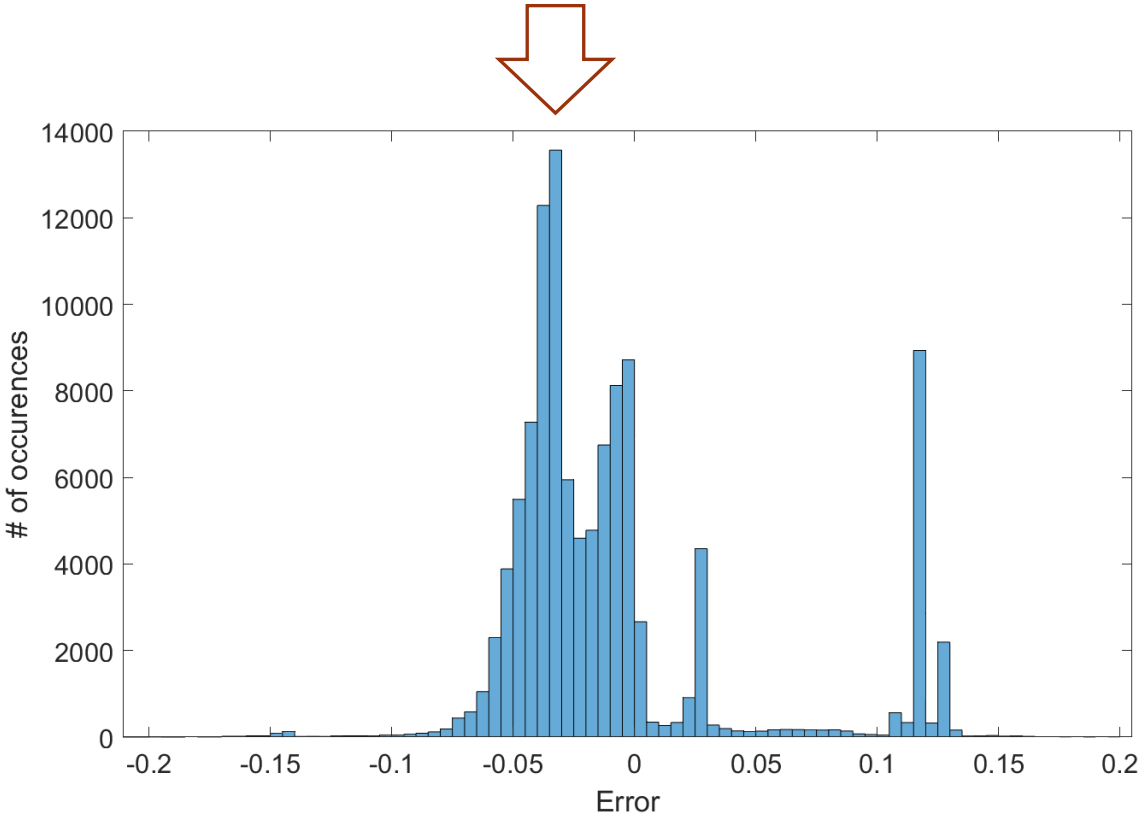
Results 3/3 – Condition 3



Adapting inputs to the voltage decay

Improved performances can be observed



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Conclusions

- The developed neural network models were updated in order to achieve better performance in terms of generalizability.

- The recurrent neural network (RNN) showed generally more satisfactory performance than the classic feed forward neural network (FFNN).

- Further implementations are being evaluated in order to improve accuracy: a pruning process could eliminate the connections responsible for transmitting the error.

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