Harmonic Analysis of Inverter-Based Resources Subject to Unbalance

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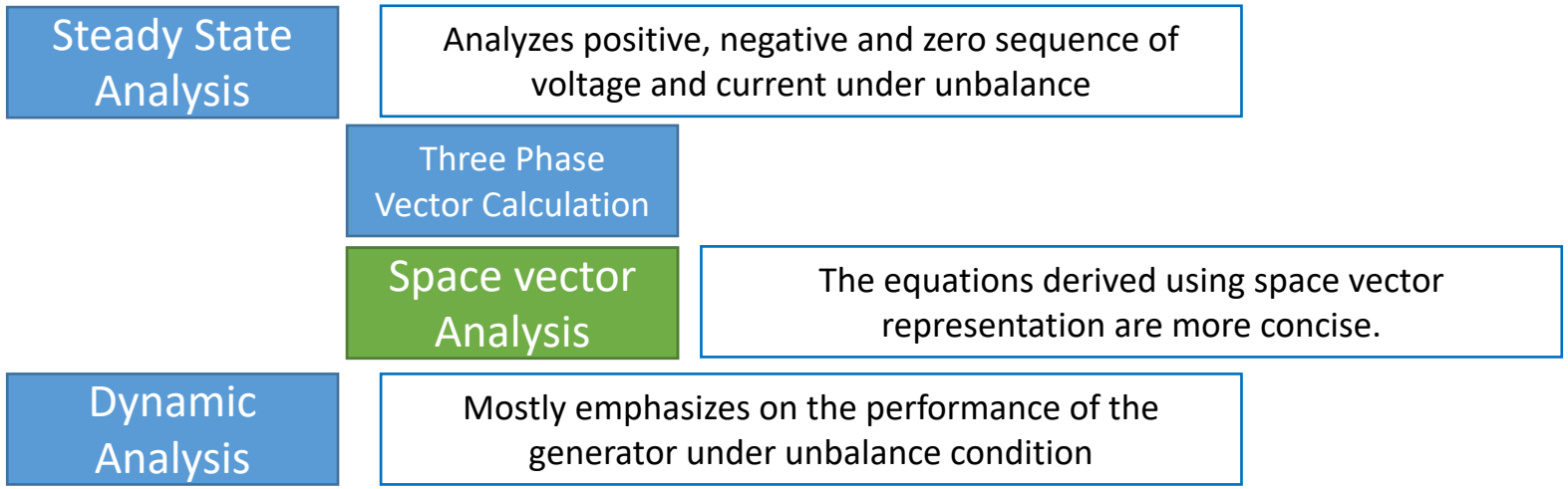
Overview

- Introduction
- Space Vector Representation
- Process of space vector analysis
- Outcome from EMT testbed
- Results
- Conclusion

Introduction

- There are multiple ways to analyze an unbalanced system.
- The types of analysis of an unbalanced system in a wind turbine can be broadly classified into,



Space Vector Representation

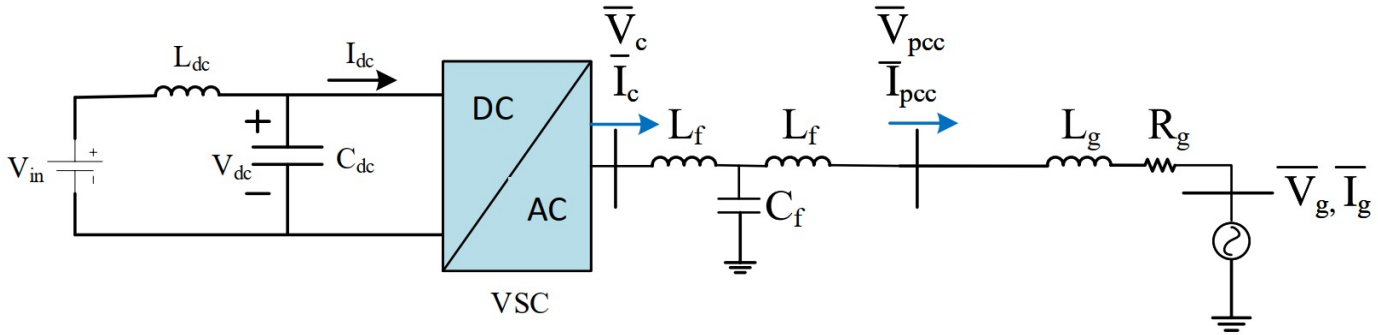


Fig: System under observation

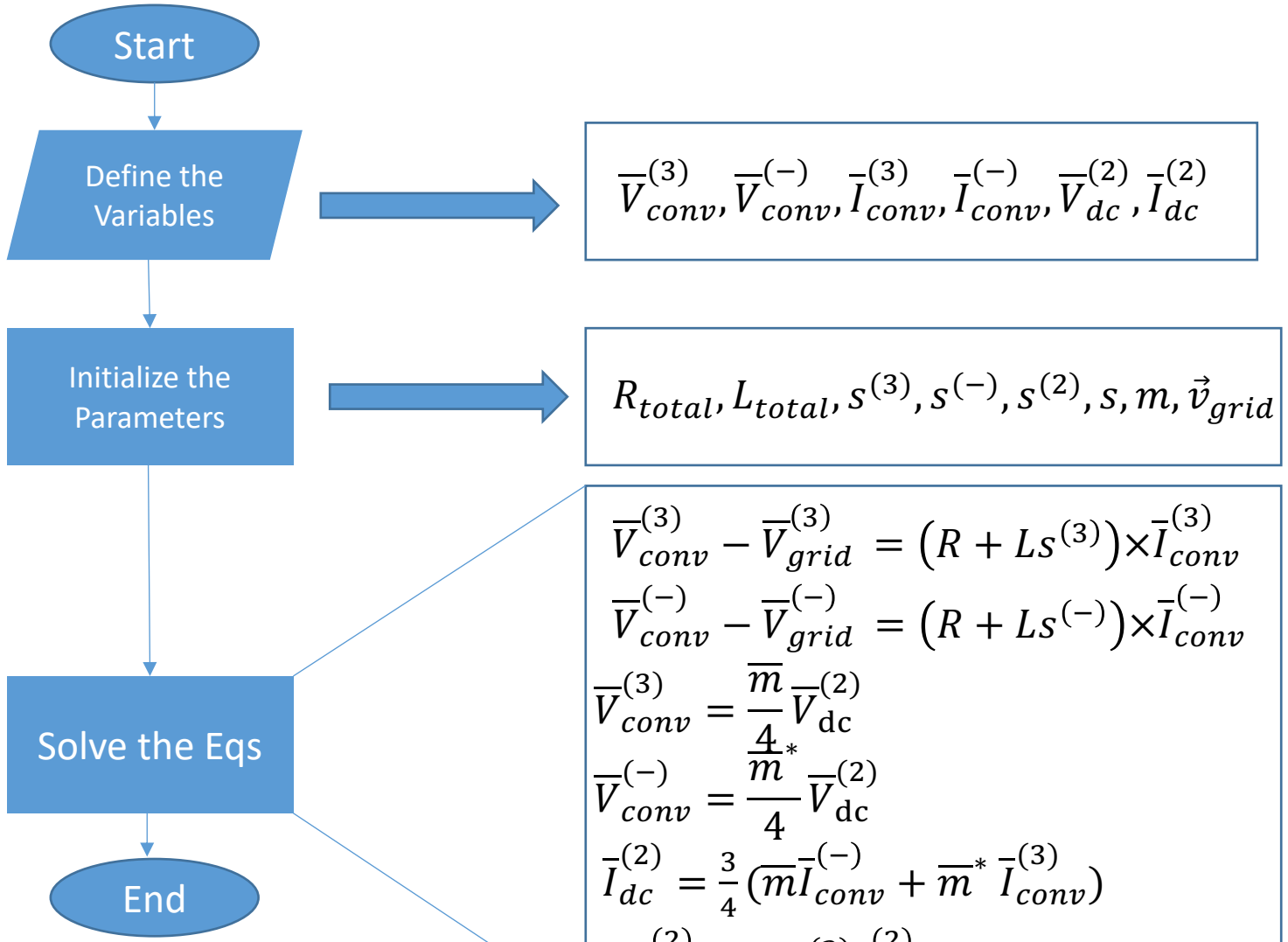
- Under unbalance condition, voltages and current can be represented as,

$$\vec{v}_{grid} = \overline{V}_{grid}^{(+)} e^{j\omega_0 t} + \overline{V}_{grid}^{(-)*} e^{-j\omega_0 t}$$

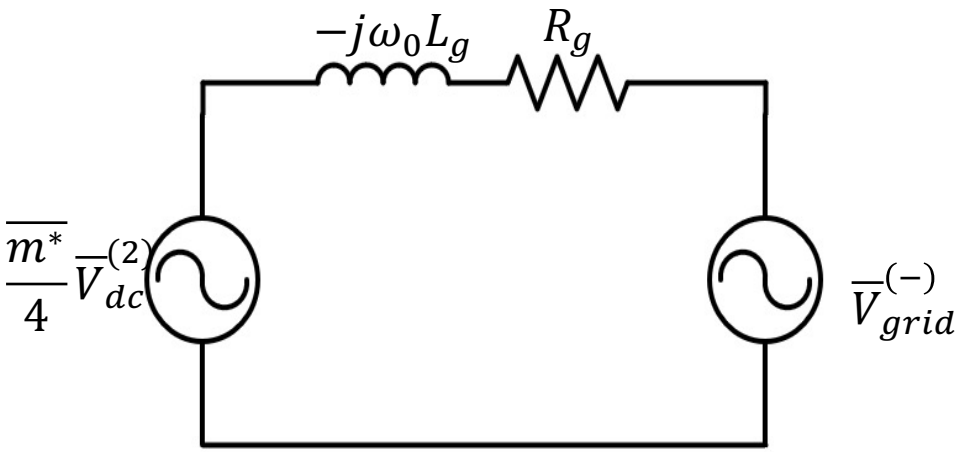
$$\vec{v}_{conv} = \overline{V}_{conv}^{(+)} e^{j\omega_0 t} + \overline{V}_{conv}^{(-)} e^{-j\omega_0 t} + \overline{V}_{conv}^{(3)} e^{j3\omega_0 t}$$

$$\vec{i}_{conv} = \overline{I}_{conv}^{(+)} e^{j\omega_0 t} + \overline{I}_{conv}^{(-)} e^{-j\omega_0 t} + \overline{I}_{conv}^{(3)} e^{j3\omega_0 t}$$

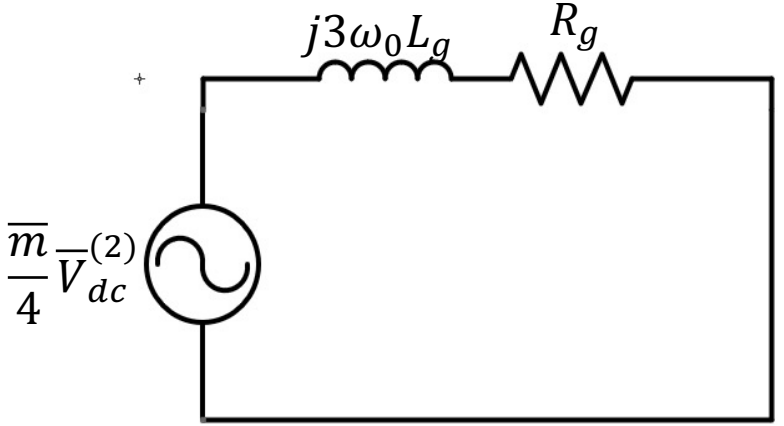
Process of space vector analysis



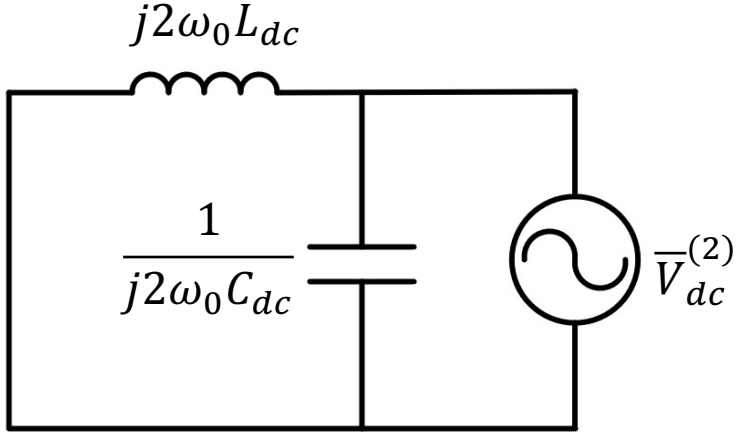
Equivalent circuit for the system in Negative sequence and 3rd Harmonic Component



Equivalent circuit in negative sequence seen from the AC side

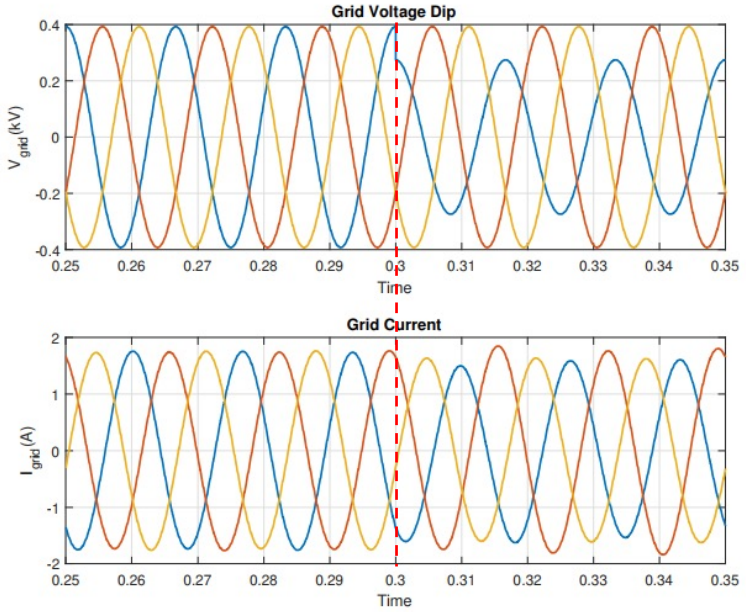


Equivalent circuit in positive sequence 3rd harmonics circuit seen from the AC side

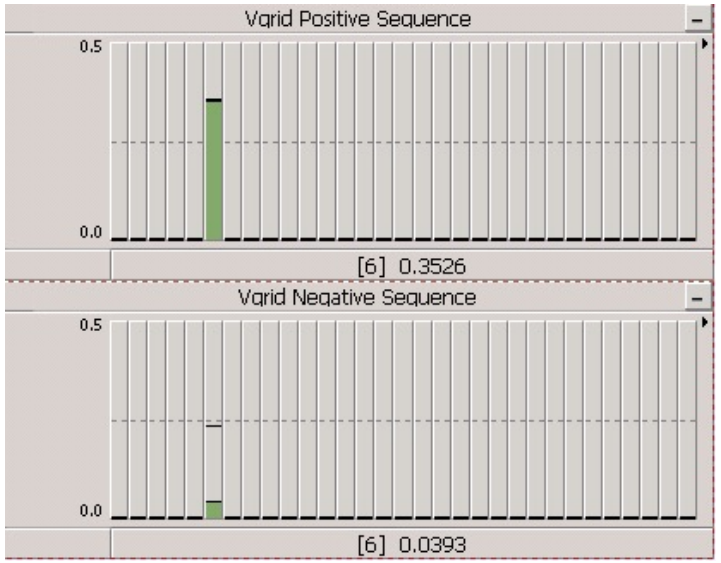


Equivalent circuit in 2nd Harmonics seen from the DC side

Outcome from EMT testbed

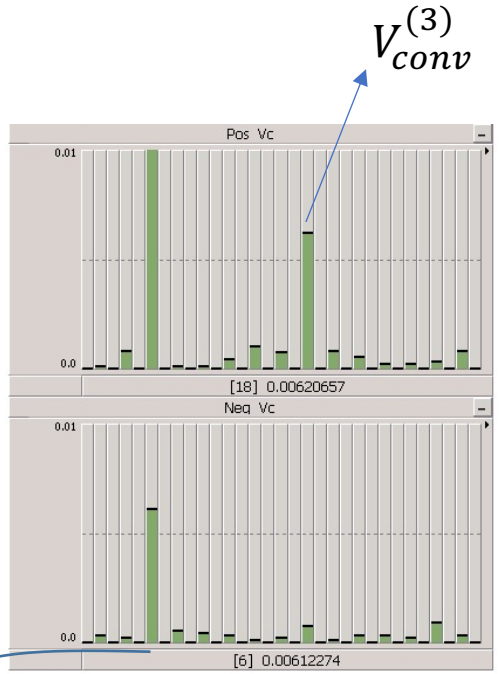


Instantaneous grid voltage and current plot showing unbalance event at 0.3 secs

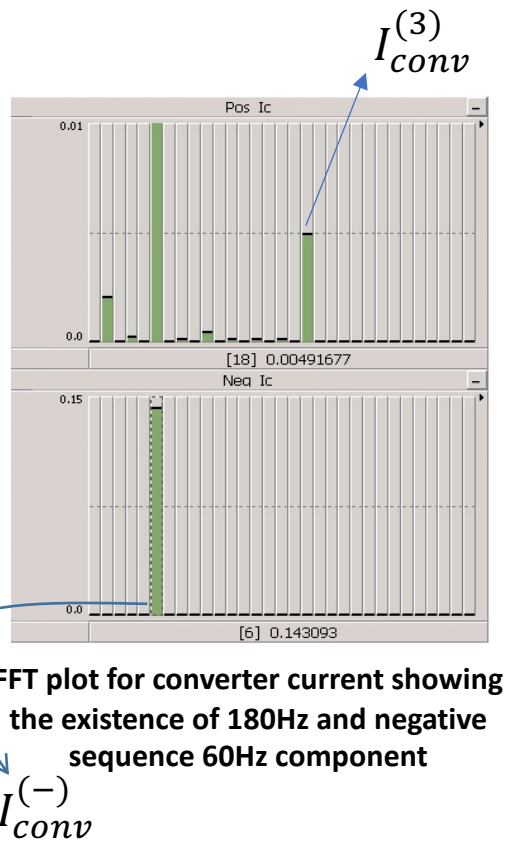


FFT plot of grid voltage showing the existence of positive and negative sequence voltage

Comparison of the analysis with the EMT testbed on AC side with m = $1\angle 1.57$



FFT plot for converter voltage showing the existence of 180Hz and negative sequence 60Hz component

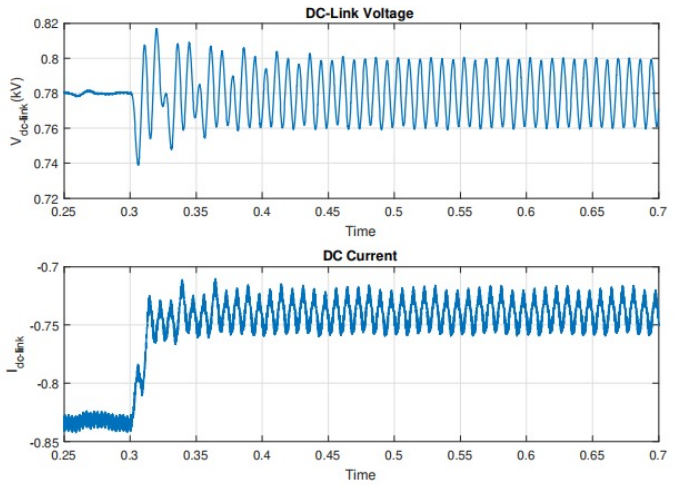


FFT plot for converter current showing the existence of 180Hz and negative sequence 60Hz component

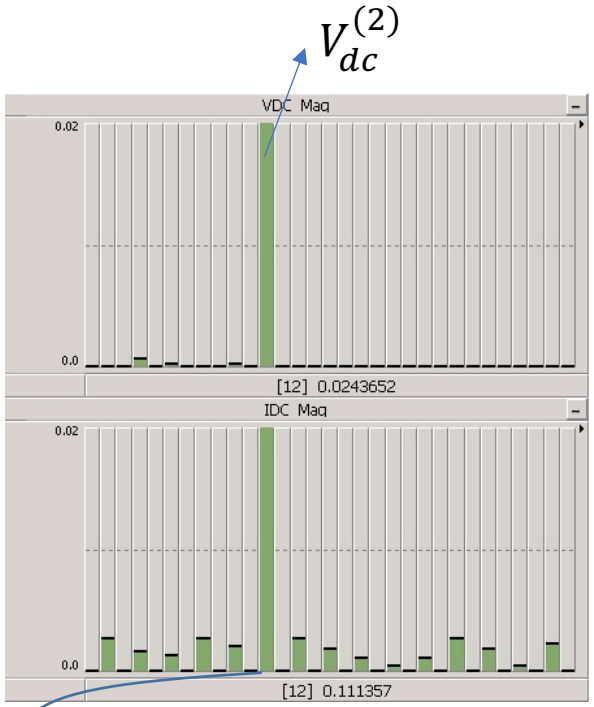
	EMT Testbed	Analysis
$\overline{V}_{\text{conv}}^{(3)}$	$0.0062\angle 2.9776$	$0.0056\angle 3.04$
$\overline{V}_{\text{conv}}^{(-)}$	$0.0061\angle -0.155$	$0.0056\angle -0.09$
$\overline{\text{I}}_{\text{conv}}^{(3)}$	$0.0049\angle -1.42$	$0.0054\angle -1.63$
$\overline{\text{I}}_{\text{conv}}^{(-)}$	$0.143\angle -1.67$	$0.1092\angle -1.66$

The table shows the comparison of the EMT model output with the analysis results

Comparison of the analysis with the EMT testbed on DC side with m = $1\angle 1.57$



Instantaneous DC side voltage and current plot showing 120Hz oscillation after the unbalance

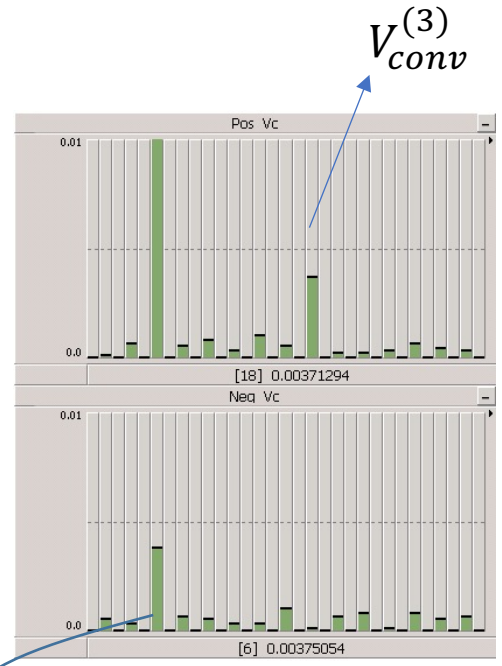


FFT plot showing the magnitude of 120Hz component for DC voltage and current

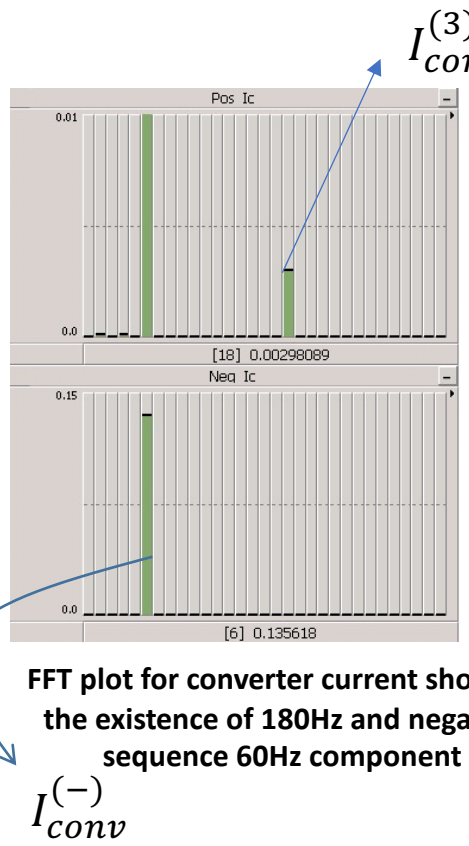
	EMT Testbed	Analysis
$\overline{V}_{dc}^{(2)}$	$0.0243\angle -1.46$	$0.0227\angle -1.663$
$\overline{I}_{dc}^{(2)}$	$0.1113\angle 3.043$	$0.1017\angle 3.045$

The table shows the comparison of the EMT model output with the analysis results

Comparison of the analysis with the EMT testbed on AC side with m = $0.8\angle 1.57$



FFT plot for converter voltage showing the existence of 180Hz and negative sequence 60Hz component

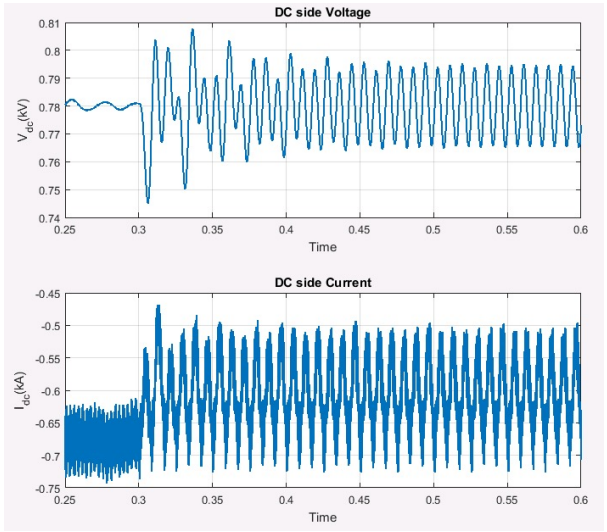


FFT plot for converter current showing the existence of 180Hz and negative sequence 60Hz component

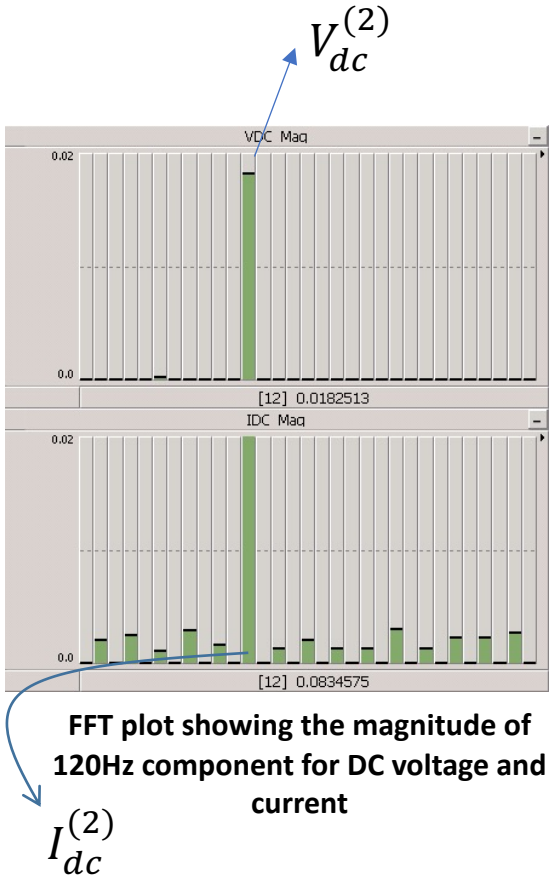
	EMT Testbed	Analysis
$\overline{V}_{\text{conv}}^{(3)}$	$0.0037\angle 3.02$	$0.0035\angle 3.05$
$\overline{V}_{\text{conv}}^{(-)}$	$0.0037\angle -0.25$	$0.0037\angle -0.13$
$\overline{\text{I}}_{\text{conv}}^{(3)}$	$0.0029\angle -1.42$	$0.0029\angle -1.63$
$\overline{\text{I}}_{\text{conv}}^{(-)}$	$0.135\angle -1.673$	$0.135\angle -1.66$

The table shows the comparison of the EMT model output with the analysis results

Comparison of the analysis with the EMT testbed on DC side with m = $0.8\angle 1.57$



Instantaneous DC side voltage and current plot showing 120Hz oscillation after the unbalance



FFT plot showing the magnitude of 120Hz component for DC voltage and current

	EMT Testbed	Analysis
$\overline{V}_{dc}^{(2)}$	$0.018\angle -1.4664$	$0.0173\angle -1.66$
$\overline{I}_{dc}^{(2)}$	$0.083\angle 3.0366$	$0.0787\angle 3.05$

The table shows the comparison of the EMT model output with the analysis results

Conclusion

- The approach is using a space-vector modeling technique to do the steady state circuit analysis for an unbalance system

- The problem formulation is validated with the EMT simulation and the current and voltage has a close match with the output of EMT-testbed.

Thank you