Finite Element Analysis of a Nine-Phase Induction Generator

Alford Sibanda

Supervisor: Dr N. Gule

Stellenbosch University

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Outline

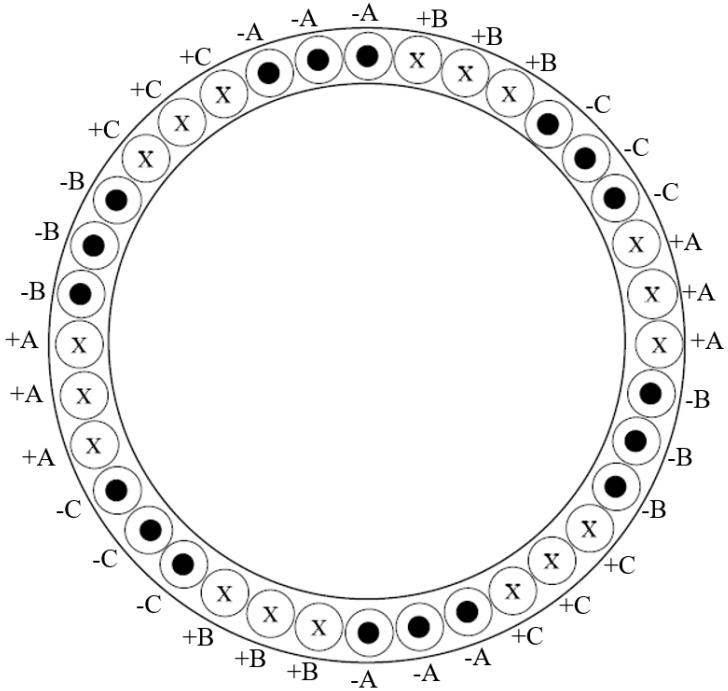
Introduction

- Induction machines - Three phase
- Power limited by cost of components
- Multi-phase machines provide same power but with lower current rated components
- Applications include; electric ship propulsion and generation, traction drives, more electric aircraft
- Growing interest in renewable and sustainable energy sector

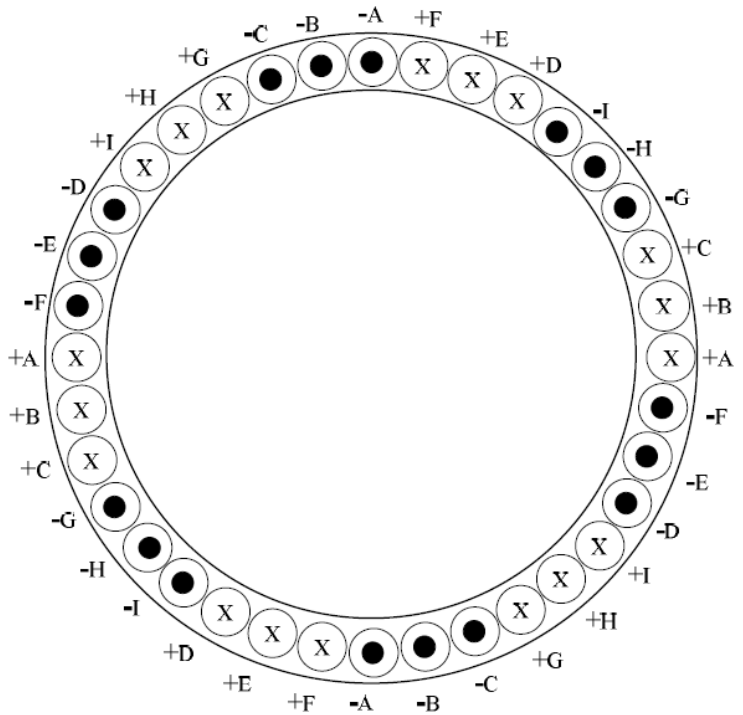
Multi-phase induction machines

- Squirrel-cage used in wind energy conversion systems (WECS) under fixed speed conditions
- Variable frequency drives (VFDs) - advanced control of induction machines
- **Objective: FEA of Nine-phase Induction Generator**

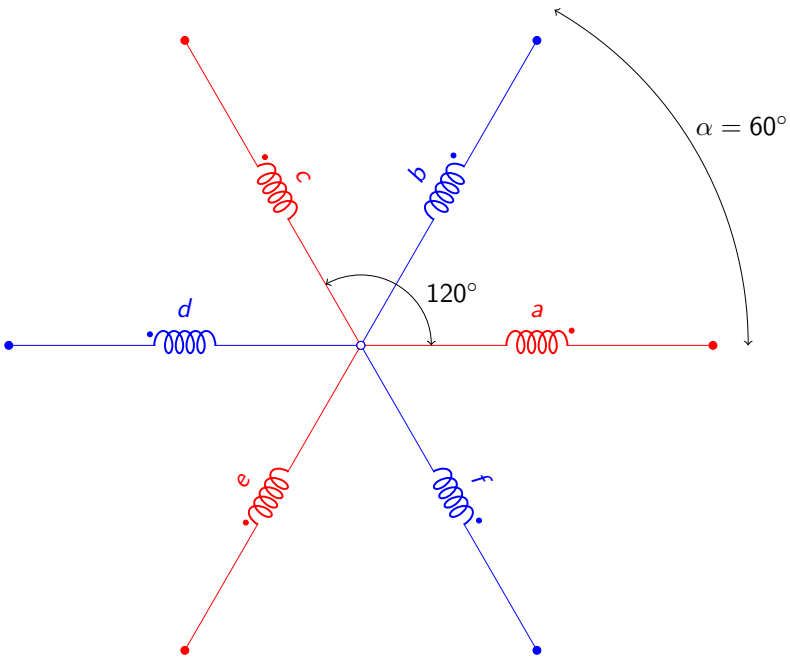
Construction



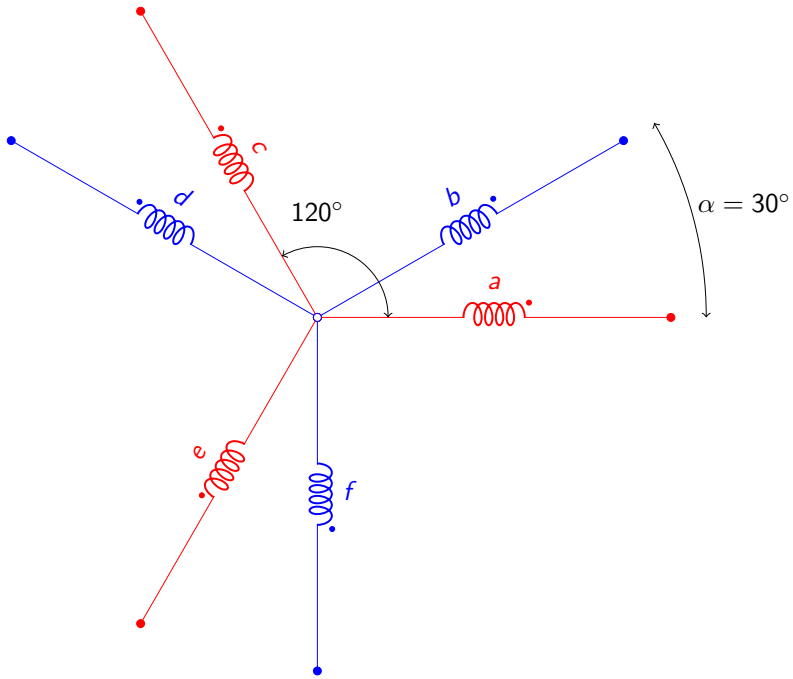
Three-phase stator



Nine-phase stator

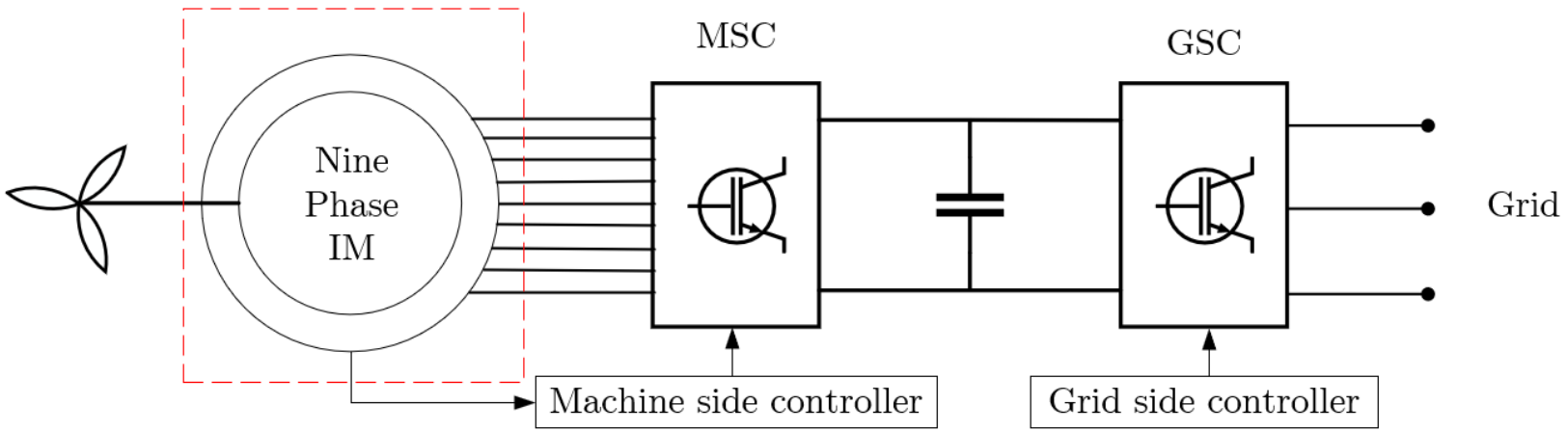


Symmetrical Six-phase



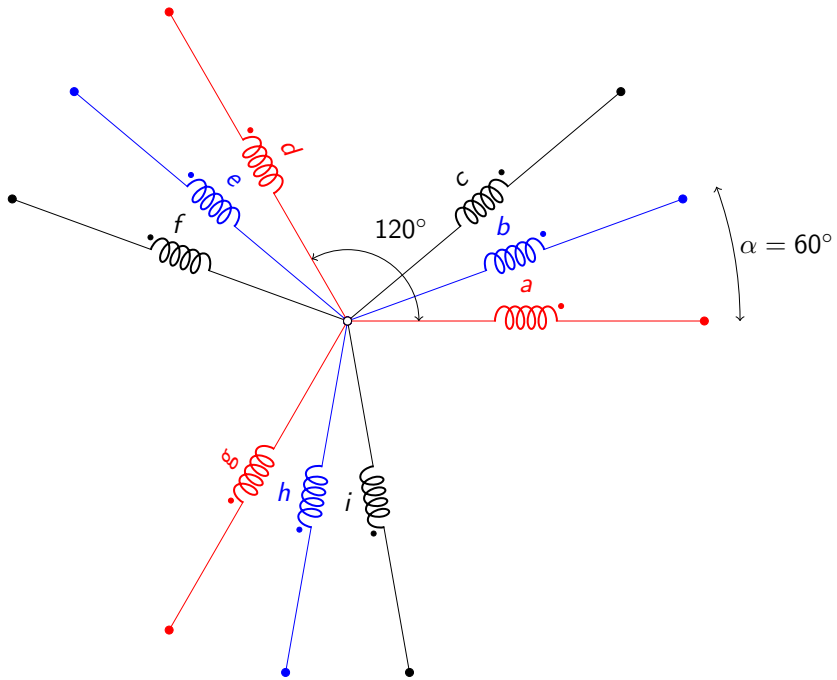
Asymmetrical Six-phase

Machine Model



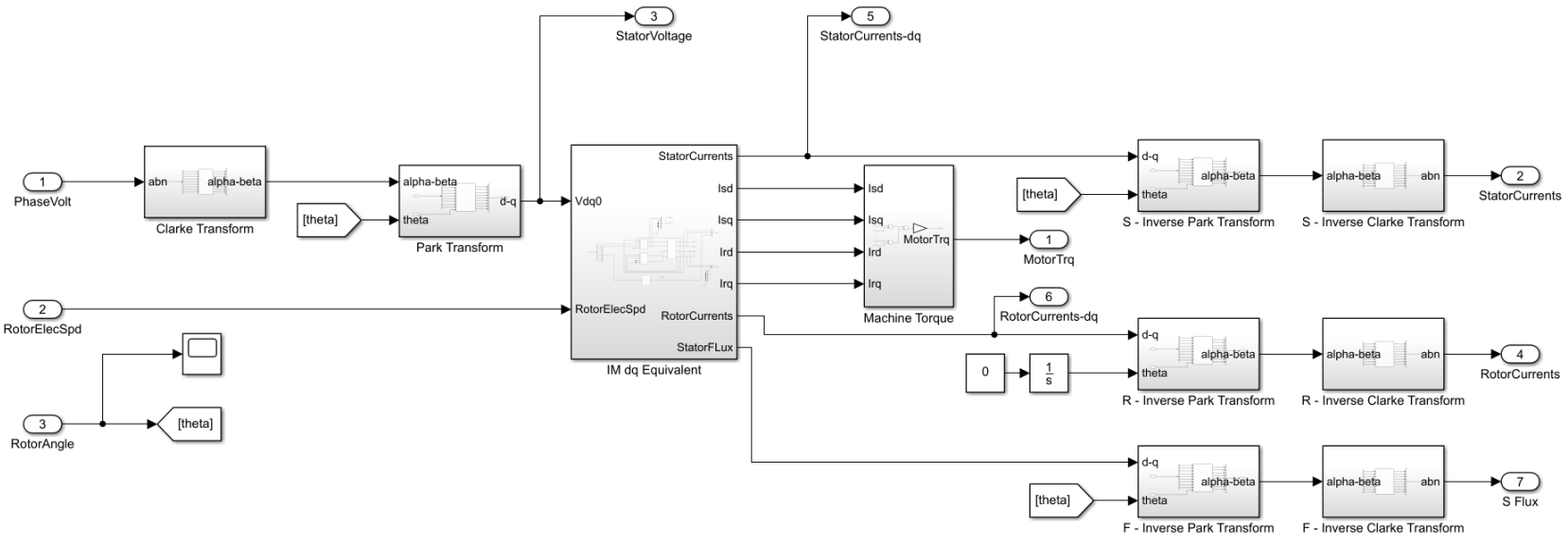
Parameter	Value
Poles	4
Stator slots	36
Rotor slots	28
Rated voltage	400 V
Rated torque	72 Nm
Rated speed	1534 RPM
Rotor length	127 mm
Air-gap radius	84.75 mm
Air-gap length	0.5 mm
Stator material	M43_29G
Rotor material	M43_29G
Stator winding material	Copper
Stator winding resistance	1 Ω
Stator leakage inductance[a]	35 mH
Rotor leakage inductance[a]	1.75 mH
Magnetizing inductance[a]	150 mH

[a] Only used in the SIMULINK model

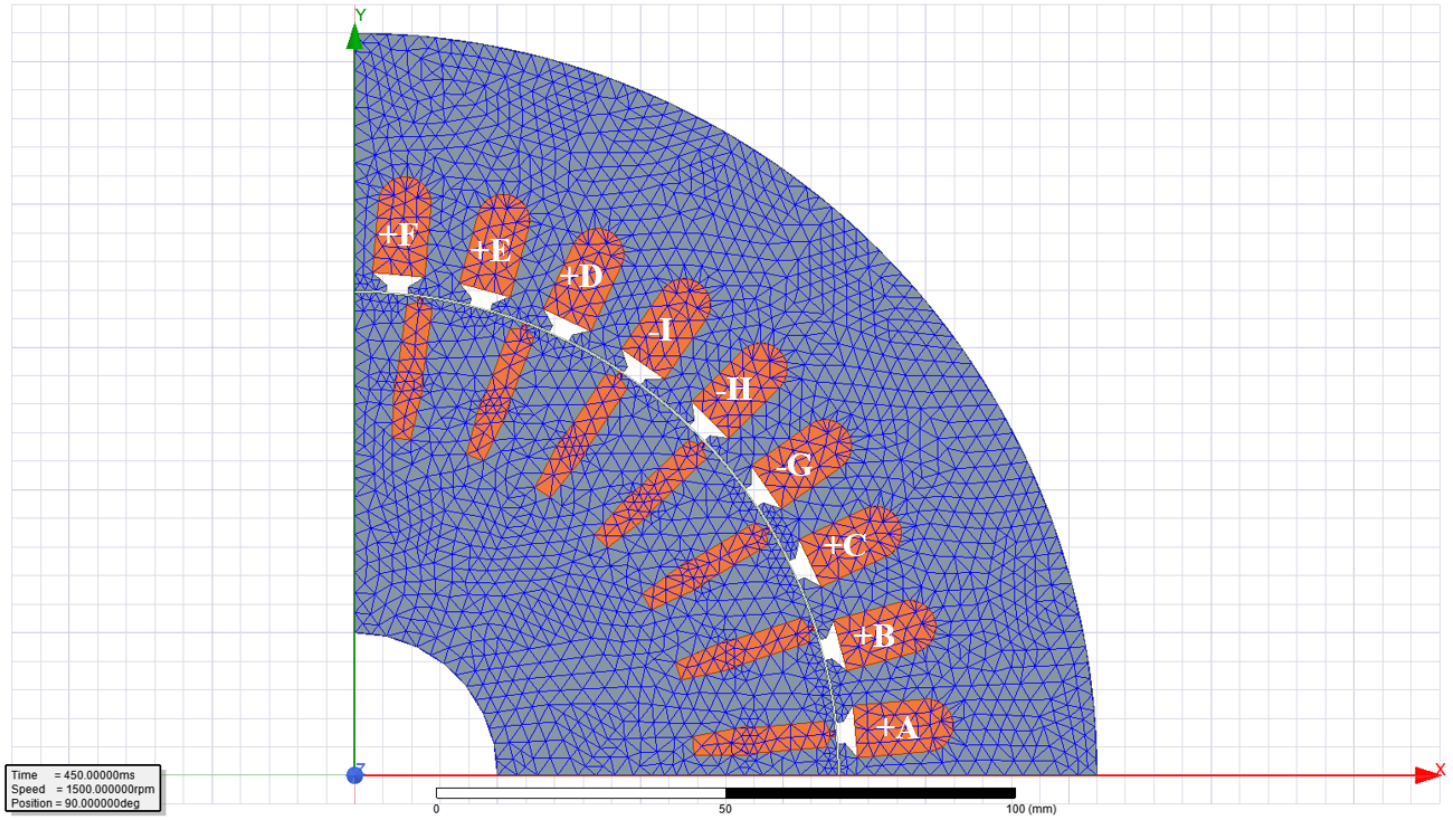


Nine-phase winding layout

MATLAB SIMULINK Model



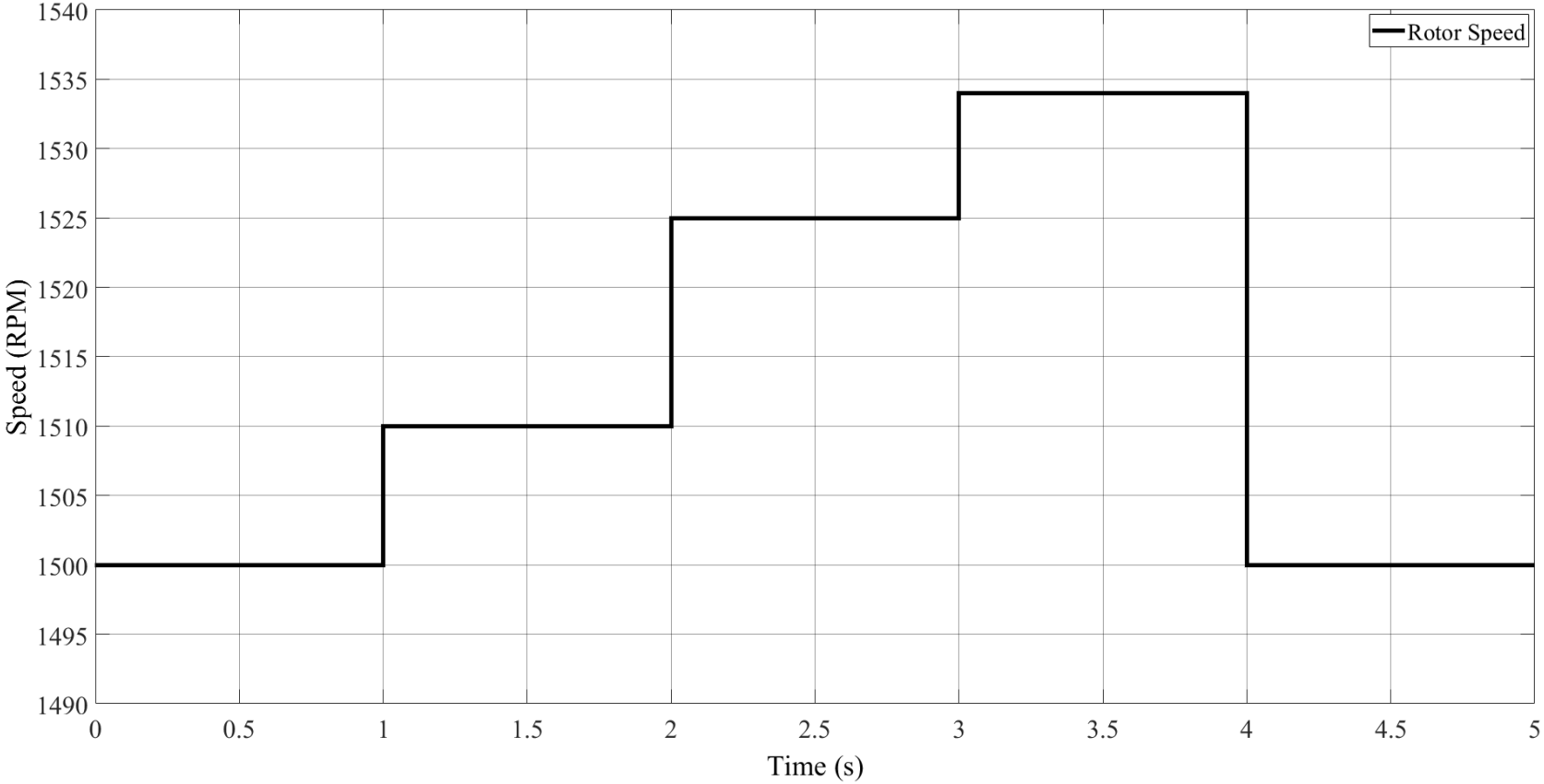
Finite Element Analysis



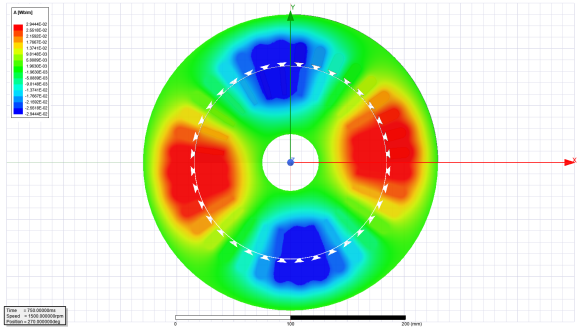
Comparison of Results

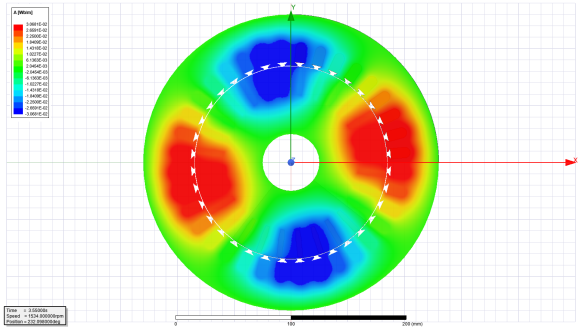
- Experiment Setup
- FEA Flux distribution
- Torque
- Current
- Flux Linkage
- Power

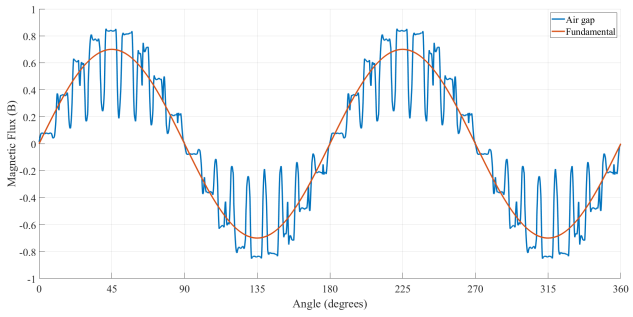
Experiment Setup



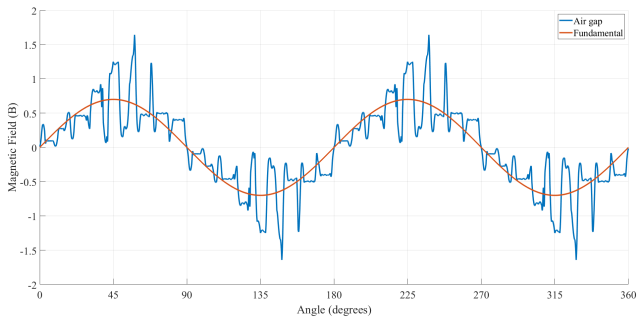
FEA Flux Distribution





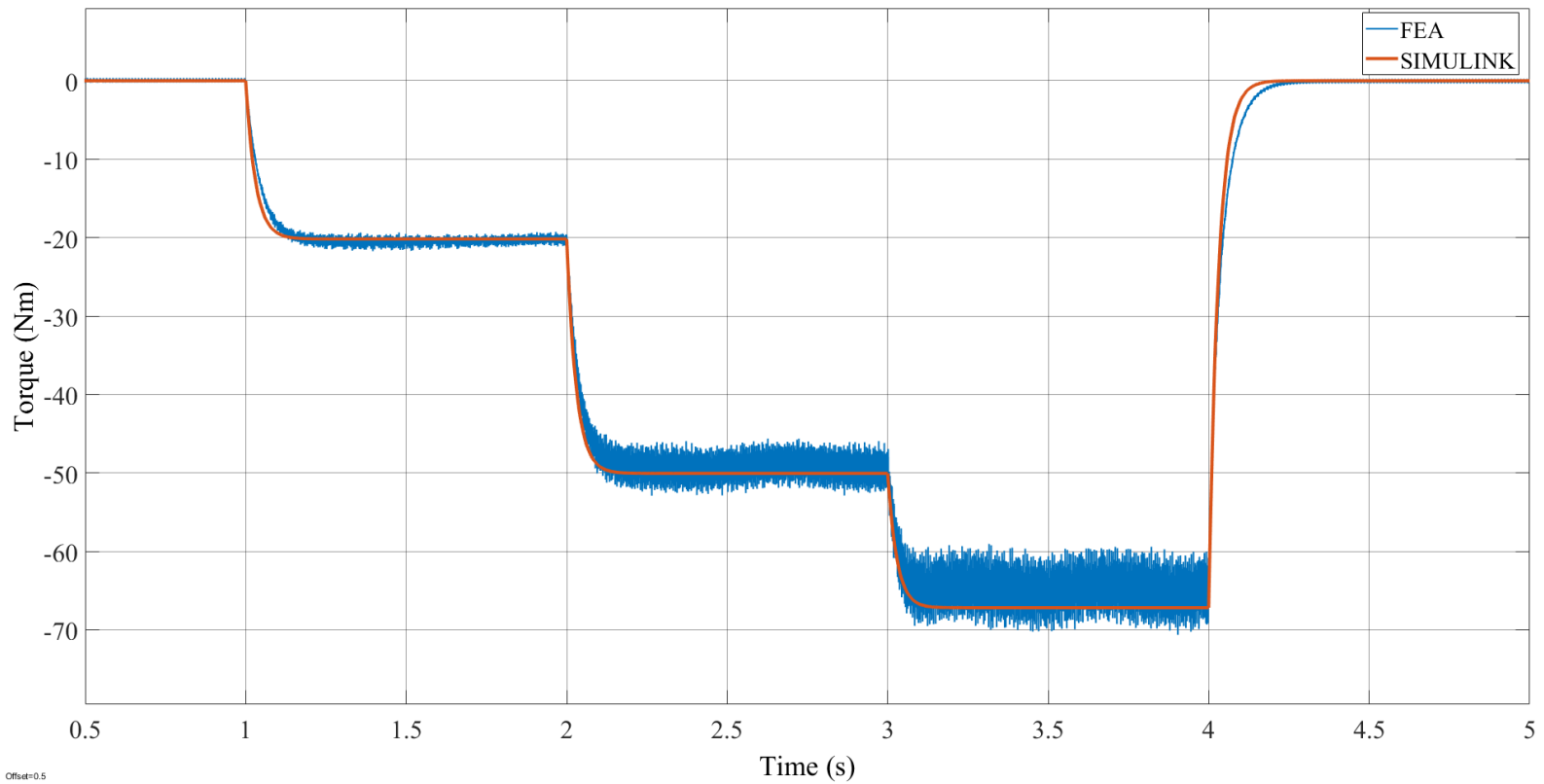


Synchronous Speed (1500 RPM)

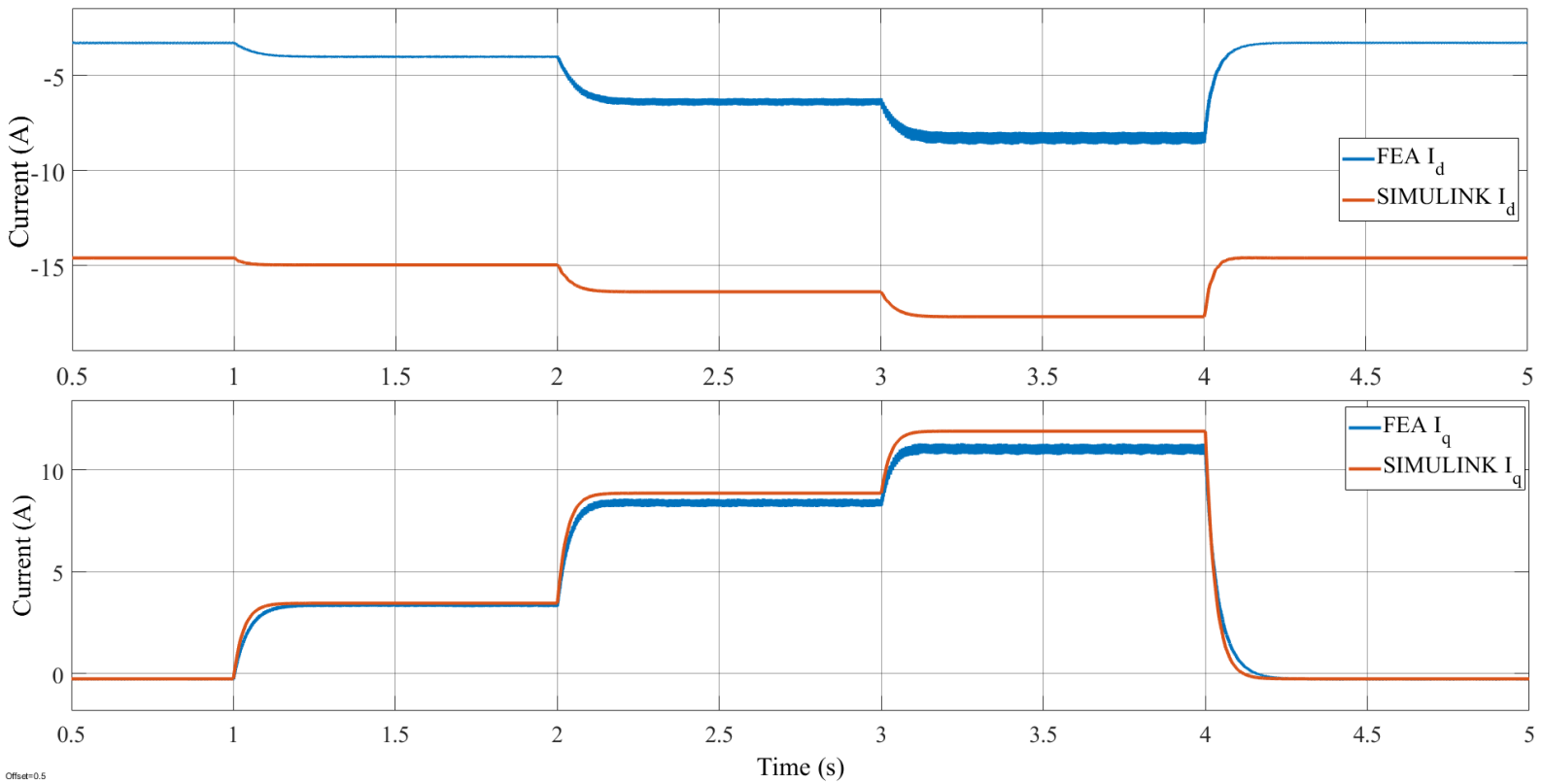


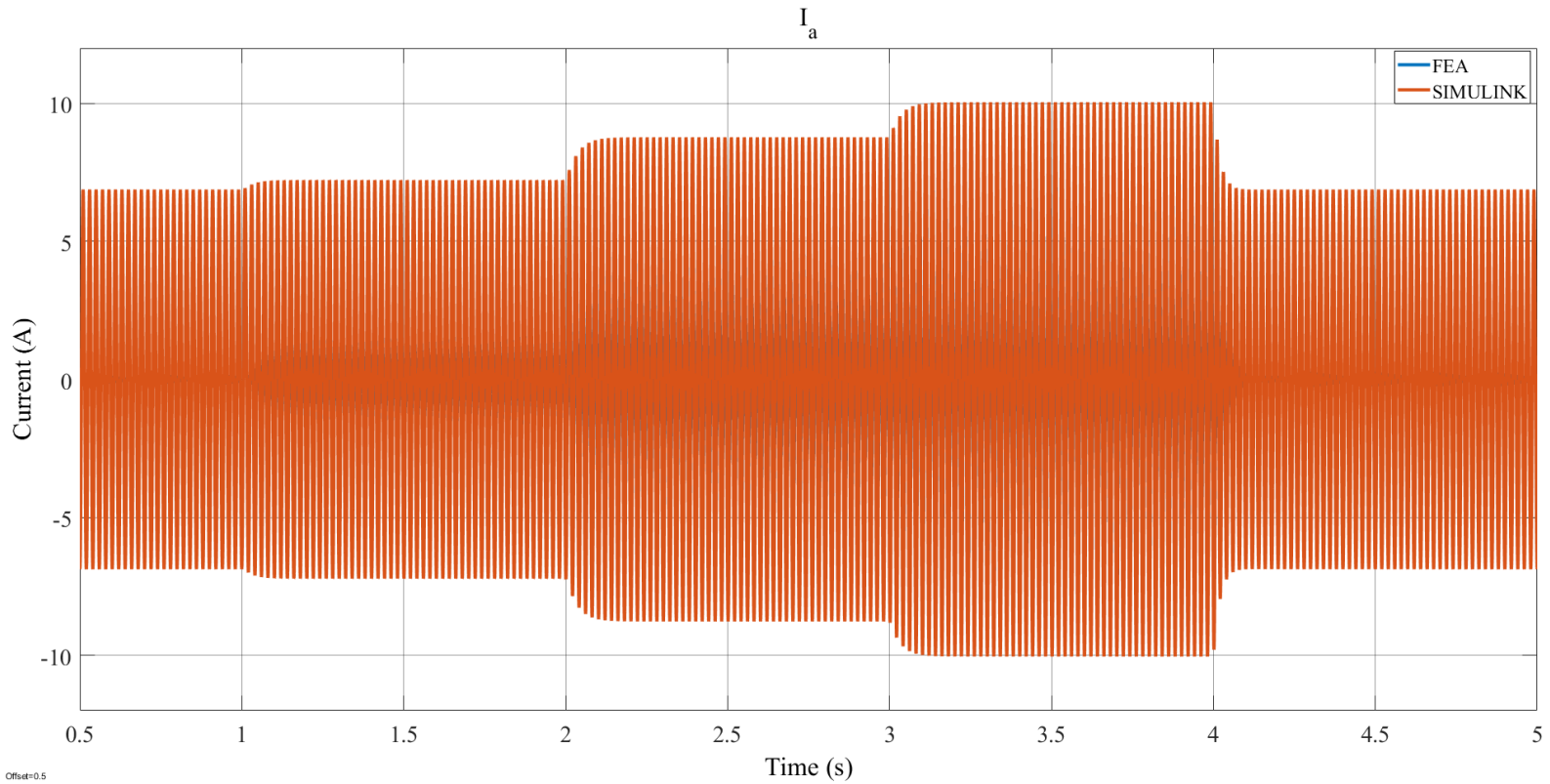
Rated Speed (1534 RPM)

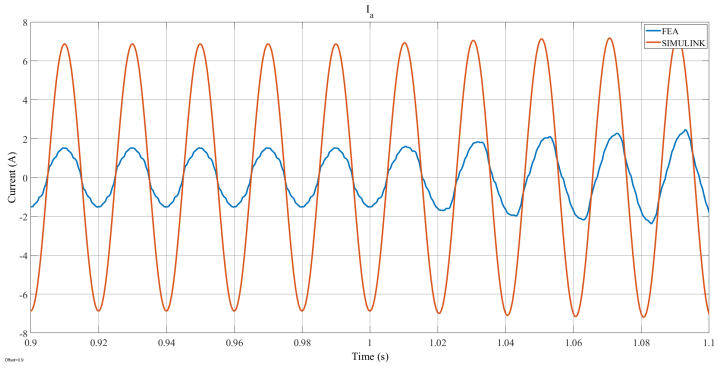
Torque


FEA
SIMULINK
0
-10
-20
-30
-40
-50
-60
-70
Torque (Nm)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (s)
Offset=0.5

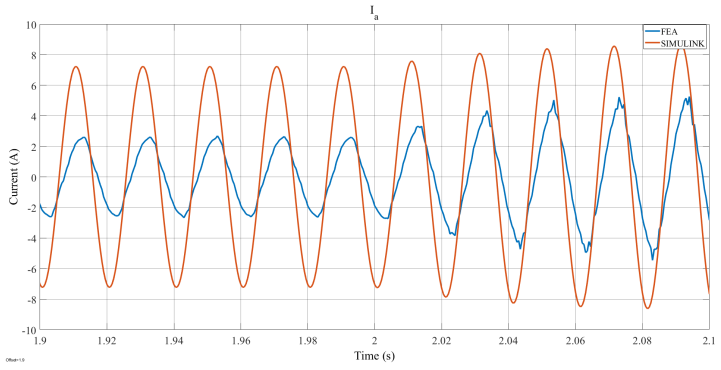
Current


Current (A)
-5
-10
-15
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
FEA I d
SIMULINK I d
Current (A)
10
5
0
FEA I q
SIMULINK I q
Time (s)
Offset=0.5

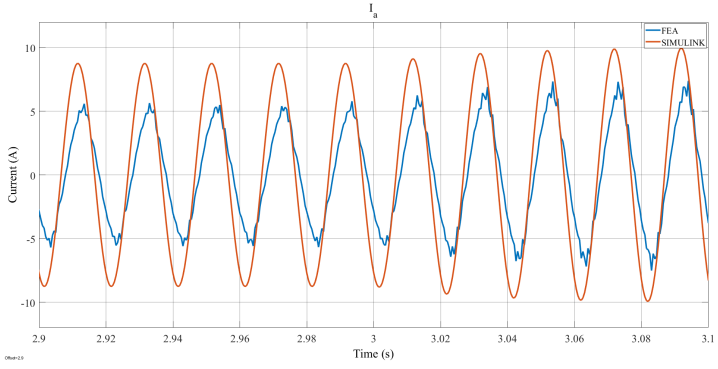

I a
FEA
SIMULINK
10
5
0
-5
-10
Current (A)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (s)
Offset=0.5



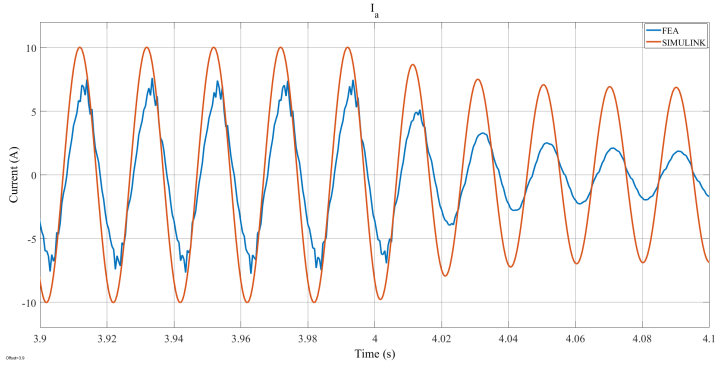
$0.9 < t\ (s) < 1.1$



$1.9 < t\ (s) < 2.1$

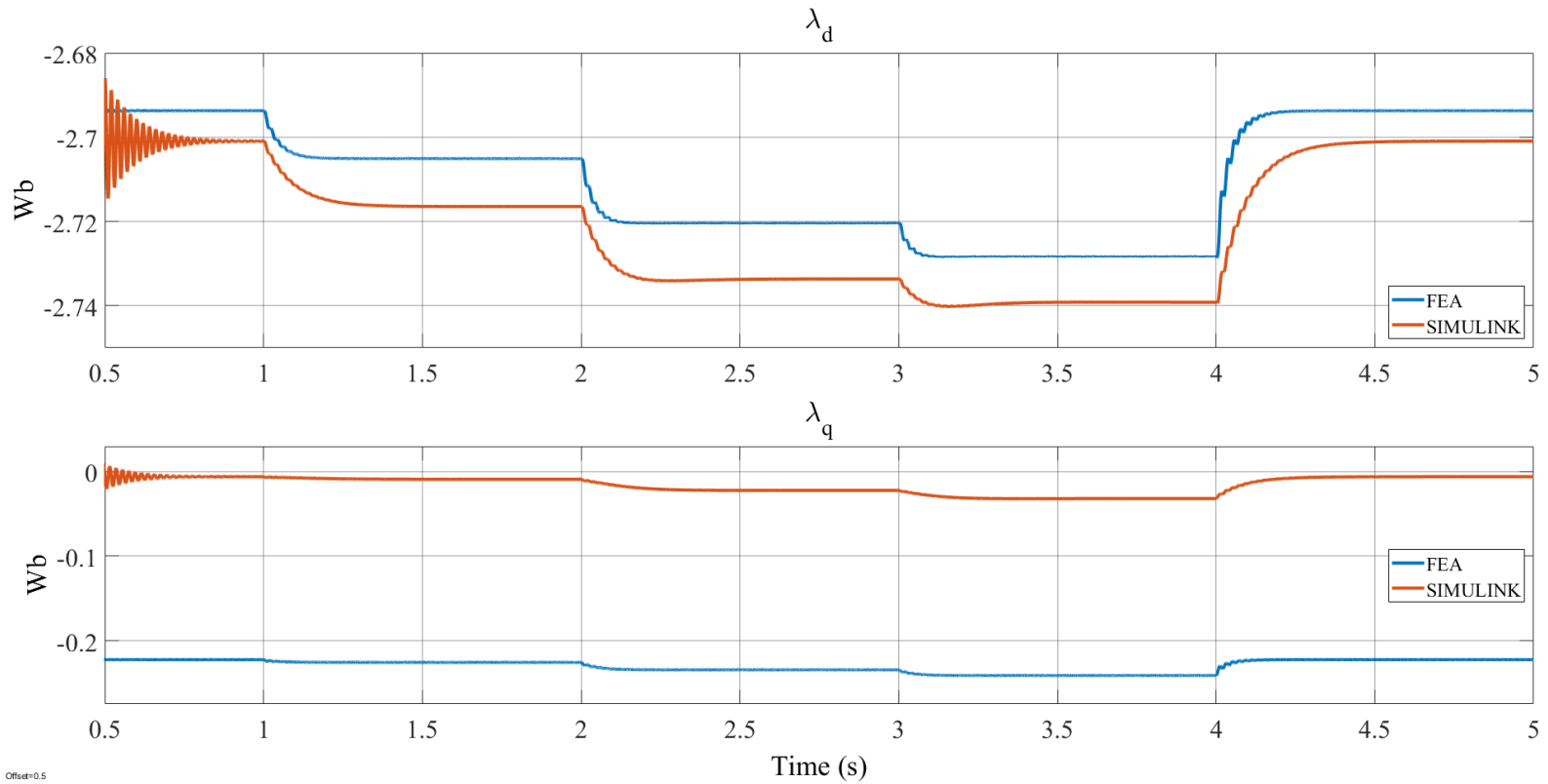


$2.9 < t\ (s) < 3.1$

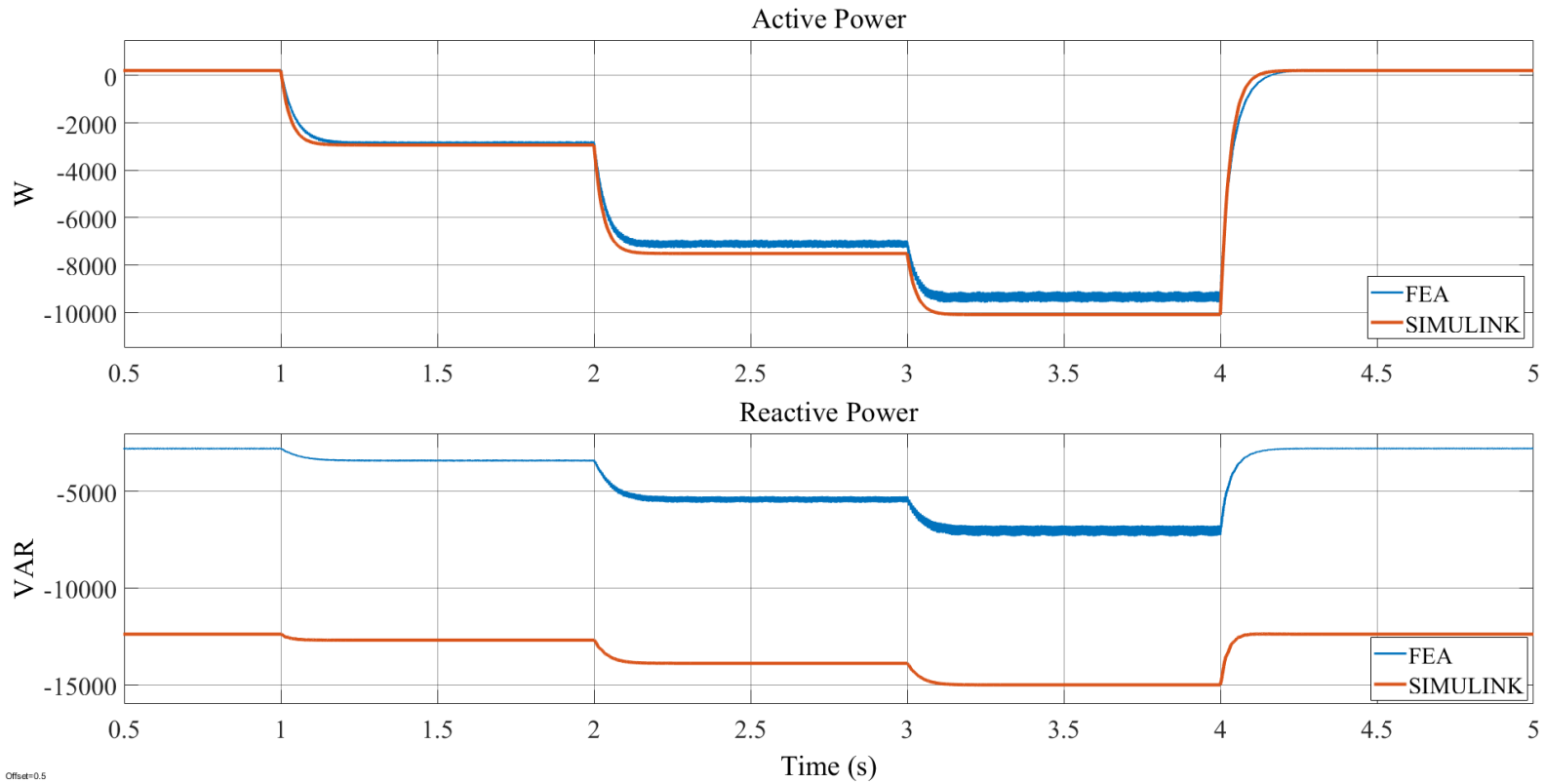


$3.9 < t\ (s) < 4.1$

Flux Linkage



Power


Active Power
W
0
-2000
-4000
-6000
-8000
-10000
FEA
SIMULINK
Reactive Power
VAR
-5000
-10000
-15000
FEA
SIMULINK
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (s)
Offset=0.5

Conclusions

- FEA: Accurate in modelling but computationally intensive
- SIMULINK: Quick and robust for controller design but inductance values require re-calculating
- **Future work**: Investigate inductance values further and how they can be improved. Back-to-back converter design for a nine-phase induction generator