Elmer

Open source finite element software
for multiphysical problems

ELMER WEBINAR (22.04.2021)

CONVERTER-FED INDUCTION MACHINE ELMER FEM COMPUTATIONS COMPARISON WITH MEASUREMENT AND COMMERCIAL FEA

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Acknowledgements:

Dr. Lassi Aarniovouri (LUT)

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OUTLINE

- Open-source software
- Why ELMER?
- Machine model
- Experimental and Computational Results from Publications
- Further work

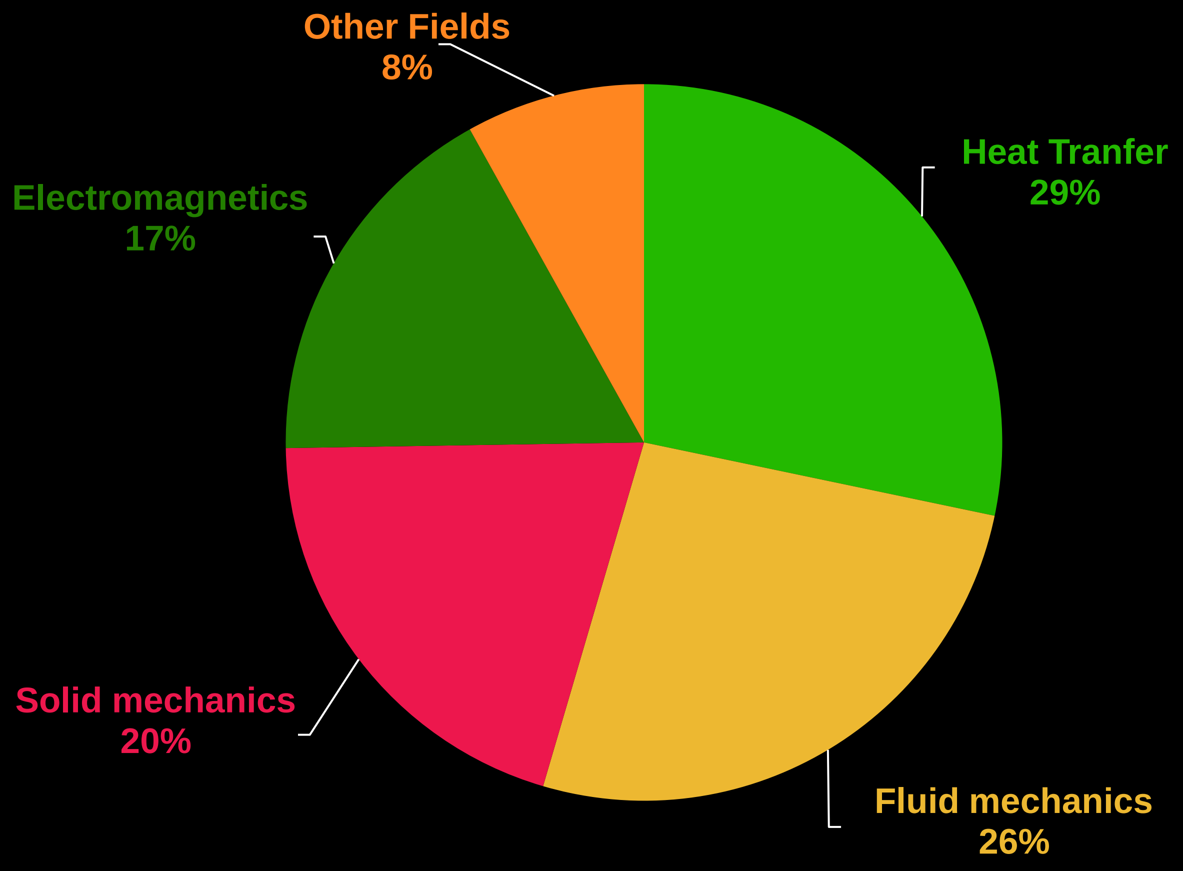
OPEN-SOURCE SOFTWARE

- Transparency of all features of the software
- license-free usage
- Some platforms enables flexible modification of the modelling features
- It is possible to include attributes that do not exist in commercial software, for example, the open-source platform supports alternatives for pre-processing and post-processing.
- Some open-source softwares like 'FEMM', 'getDP', 'SMEKlib' and 'Pyleecan (Python Library for Electrical Engineering Computational Analysis) are available but having some limitations

WHY ELMER?

- Multi-physics computational tool
- Message passing interface (MPI) standard is used for fast parallel computation.
- External resource (CSC supercomputers) can be used for heavy simulations
- Research and Development is very fast in collaboration with universities and industry

ELMER APPLICATIONS

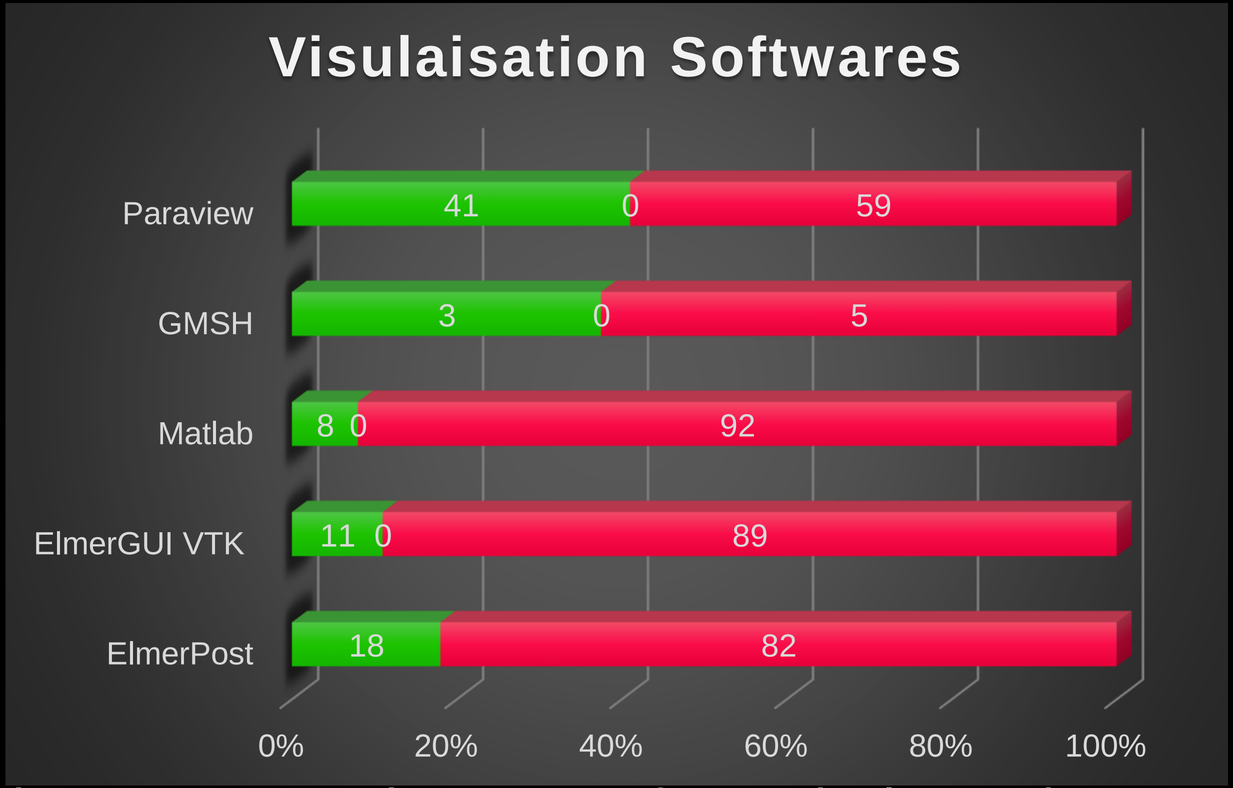


MULTIPLE PLATFORMS

Pre-processing → Import mesh in ElmerGrid → Elmer solver

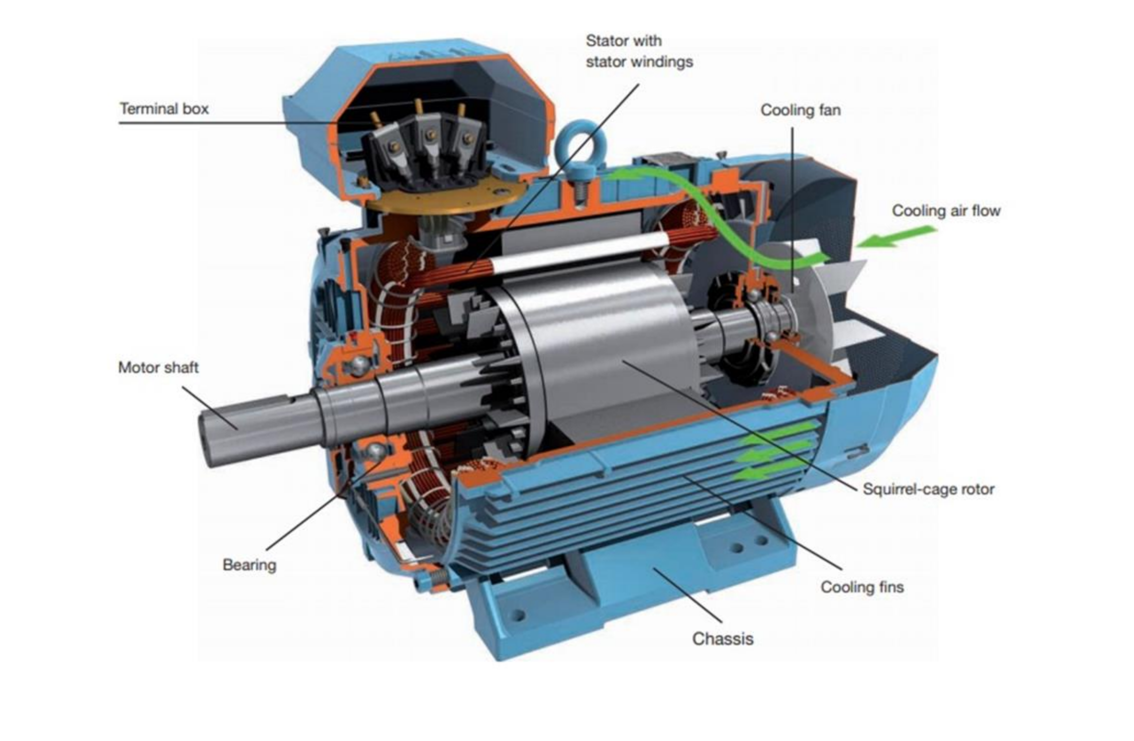
- 2D and 3D mesh structure can be built in Ansys, Abaqus, Fidap, Comsol, Gmsh, Solidworks etc
- People mostly use Gmsh, Salome, and Netgen for creating and meshing structures.
- To run the model in Elmer FEA the mesh is converted into Elmer mesh by ElmerGrid
- Post-processing in Paraview, MATLAB, Python etc.

ELMER POST



- Green bar represents the usage of a particular package.

MACHINE MODEL



- Induction machine cut section. Figure taken from (A. Anttila, “STATOR-BASED THERMAL MODEL FOR INDUCTION MOTOR BEARING,” Lappeenranta-Lahti University of Technology LUT, Lappeenranta, 2019) and ABB’s machine (https://www.slideshare.net/ELIMENG/1sdc007106g0201) .
- These machines are widely used in variable-speed applications such as for powering conveyor belts, robots, electrical vehicles, cranes, elevators and home appliances.

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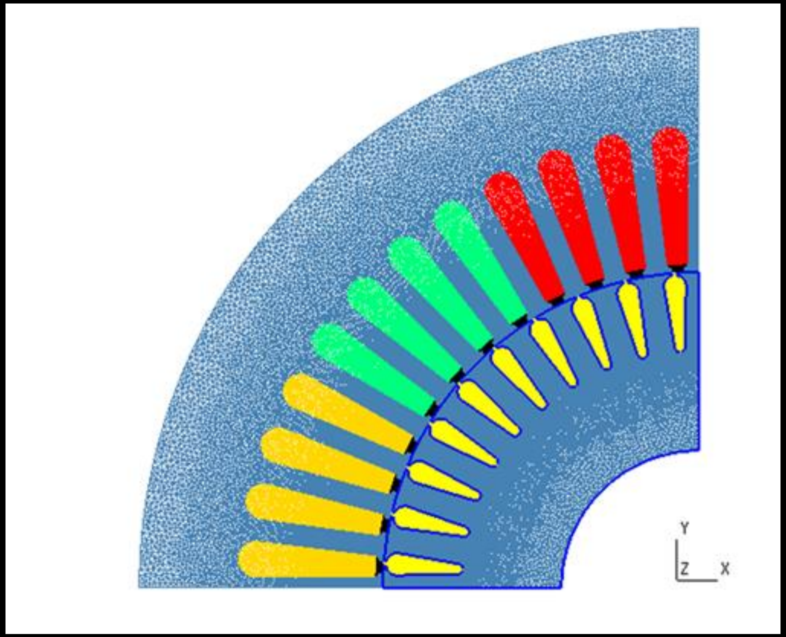
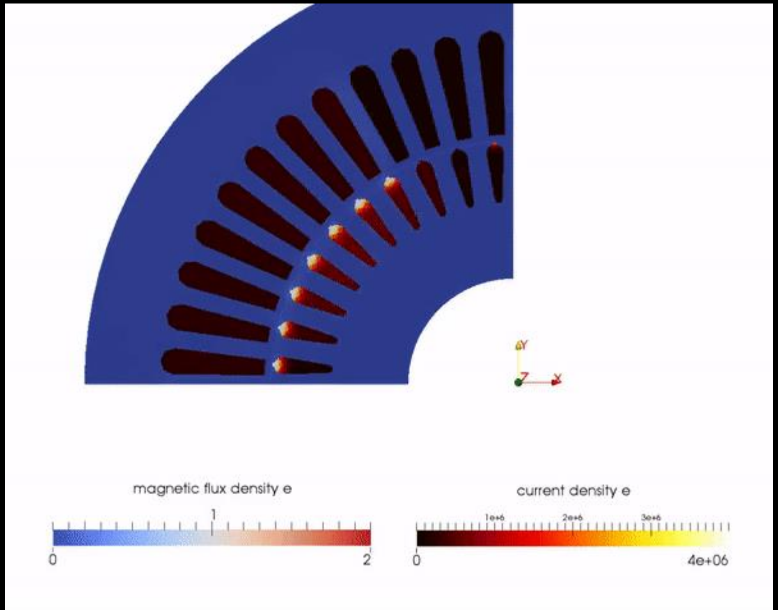
FEM MODEL

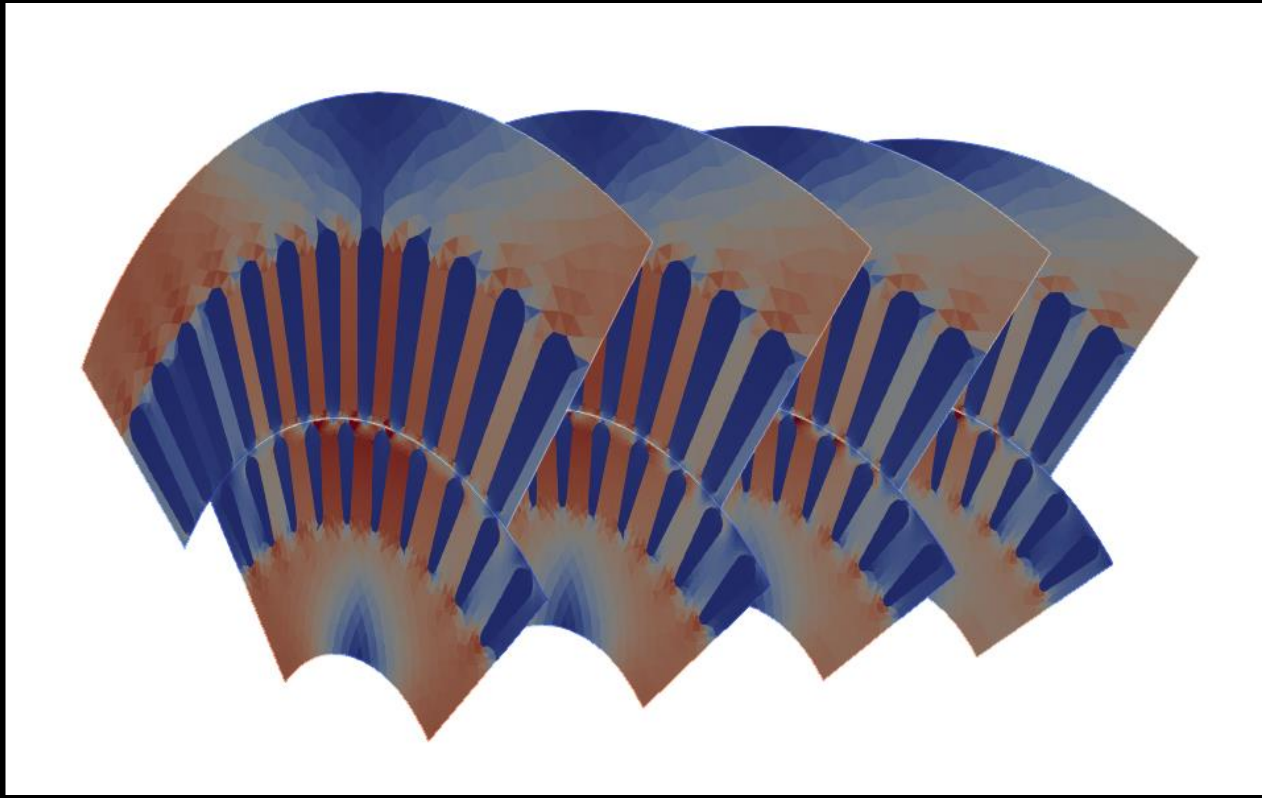


- GMSH 2D model.



- Elmer simulation model. (done by P. Ponomarev also https://www.youtube.com/watch?v=HI6ICoWC4B8)

FEM 2.5D MODEL



- The distance between slices is 0.04
- The motor has 8.5 degrees skew along the rotor length 160 mm
- Number of slices are 4
- The identified practical number of slices is 4–6 for practically acceptable level of precision to account for skewing effect in 2.5D radial flux machine models (from below mentioned reference).

P. Ponomarev, L. Aarniovuori and J. Keränen, "Selection of optimal slice count for multi-slice analysis of skewed induction motors," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, 2017, pp. 2149-2153, doi: 10.1109/IECON.2017.8216361.

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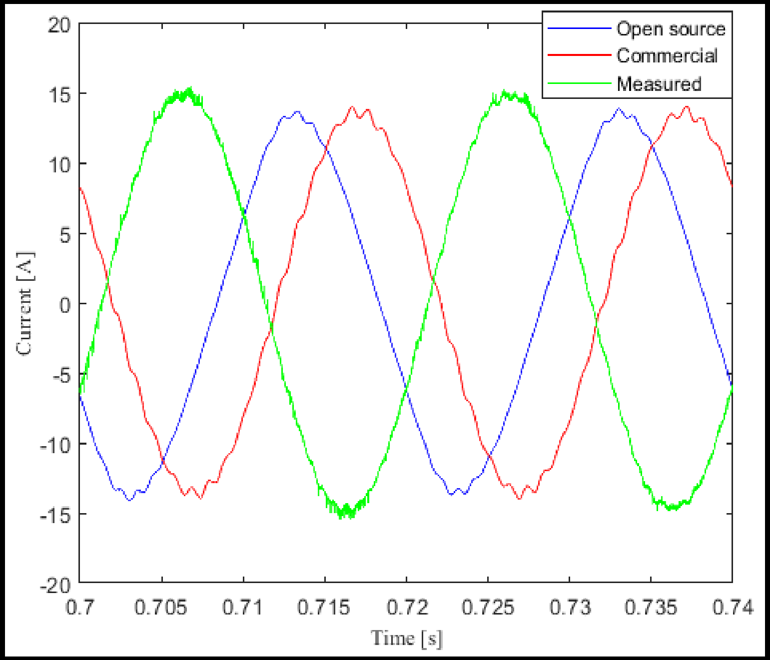
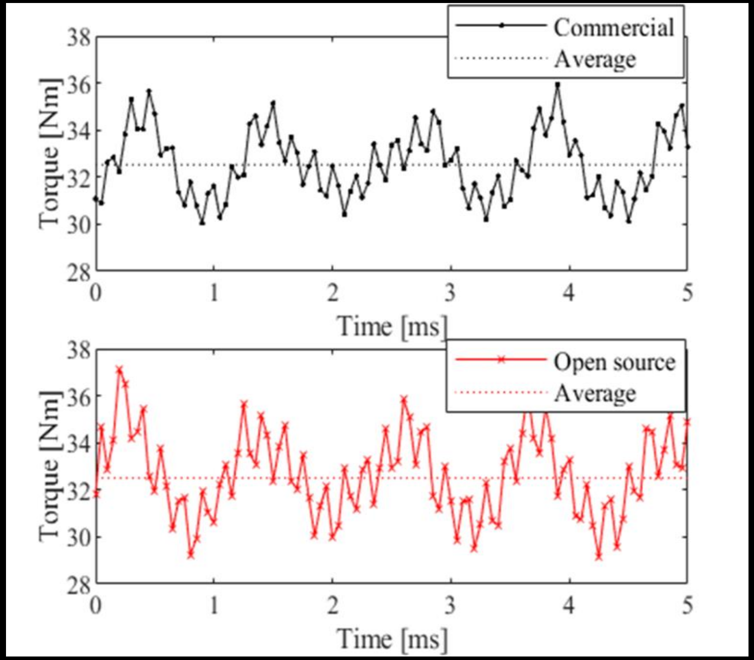
COMMERCIAL AND ELMER FEM PRAMETERS

FEA	Maxwell Equation	Bertotti model	MPI	Cores limit	External resources
Commercial	✓	✓	✓	6	✗
Open-source	✓	✓	✓	520	✓

LABORATORY MEASUREMENTS COMPARED WITH COMMERCIAL AND ELMER FEM





- Figures from

M. Zaheer, P. Lindh, L. Aarniovuori and J. Pyrhönen, "Comparison of Commercial and Open-Source FEM Software: A Case Study," in IEEE Transactions on Industry Applications, vol. 56, no. 6, pp. 6411-6419, Nov.-Dec. 2020.

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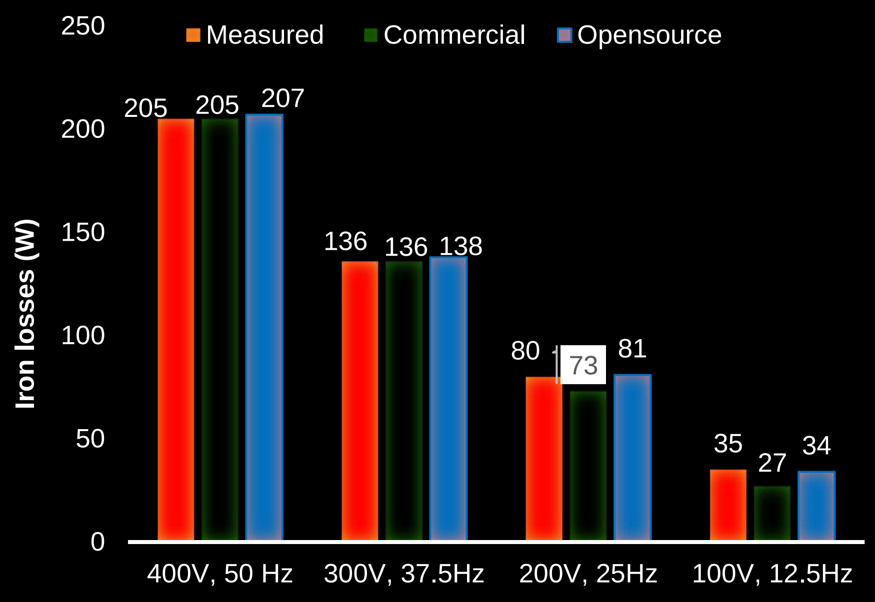

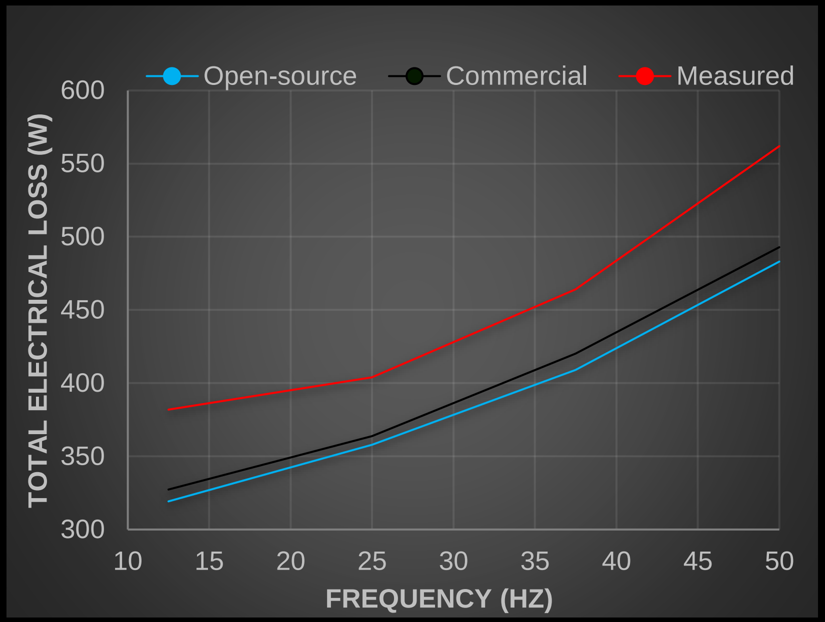

» Figures from

M. Zaheer, P. Lindh, L. Aarniovuori and J. Pyrhönen, "Comparison of Commercial and Open-Source FEM Software: A Case Study," in IEEE Transactions on Industry Applications, vol. 56, no. 6, pp. 6411-6419, Nov.-Dec. 2020.

P. Lindh, L. Aarniovuori, H. Kärkkäinen, M. Niemela and J. Pyrhonen, "IM Loss Evaluation Using FEA and Measurements," 2018 XIII International Conference on Electrical Machines (ICEM), Alexandroupoli, 2018, pp. 1220-1226.

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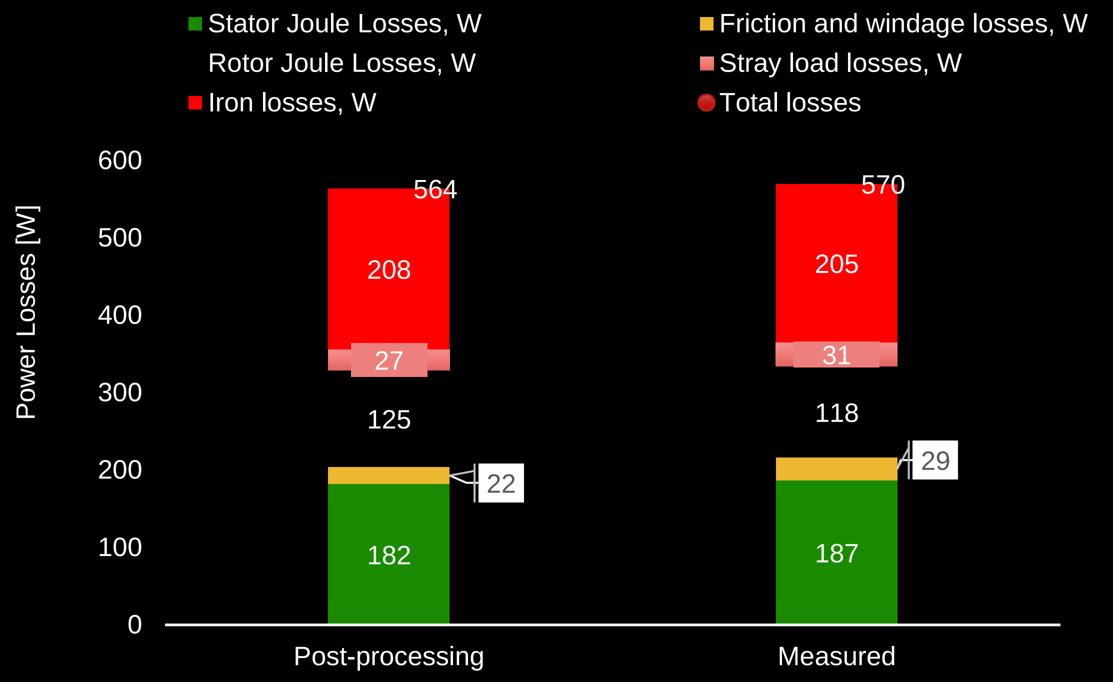
LABORATORY MEASUREMENTS COMPARED WITH ELMER FEM



- Figures from

  M. Zaheer, A. Anttila, P. Lindh, L. Aarniovuori and J. Pyrhönen, "Emulating Induction Machine Loss Segregation Procedure with FEM ," ACED 2021 (In Review)

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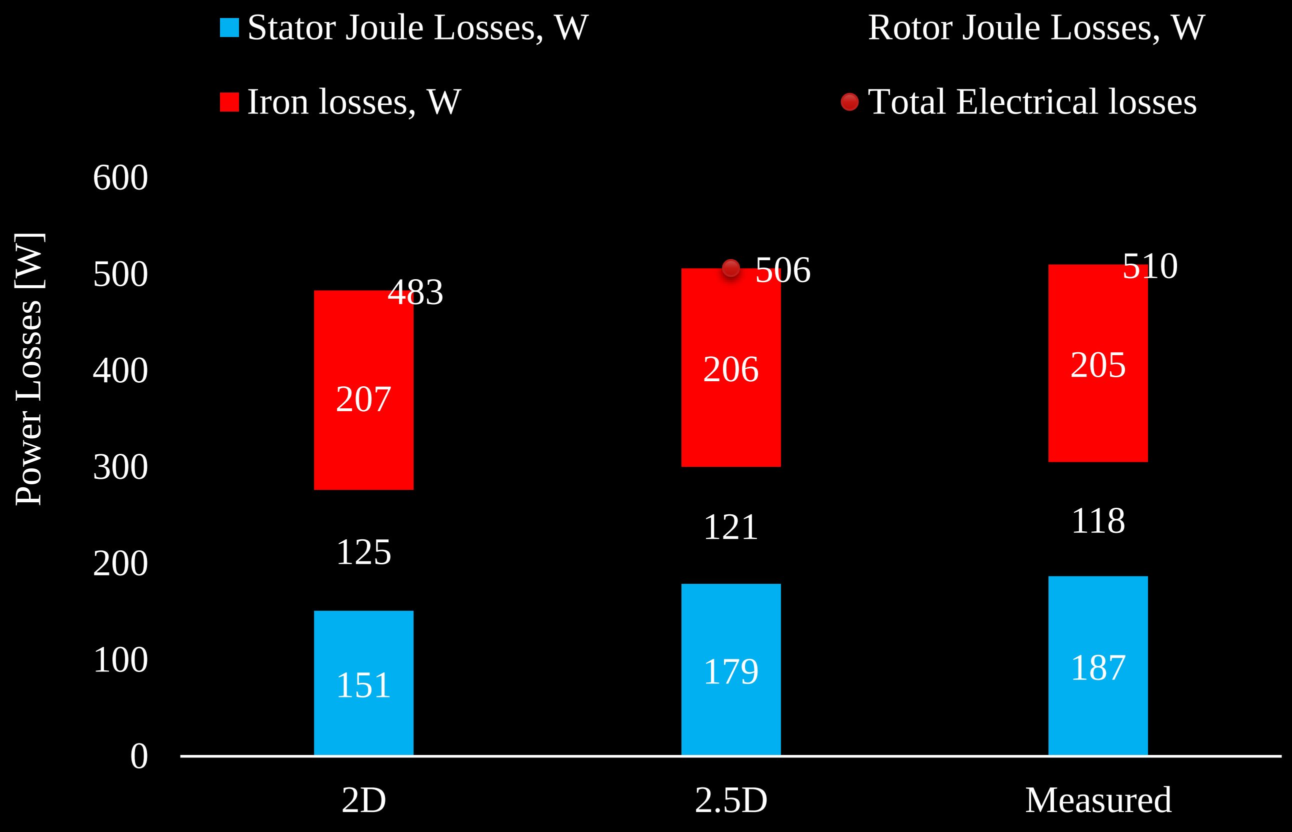
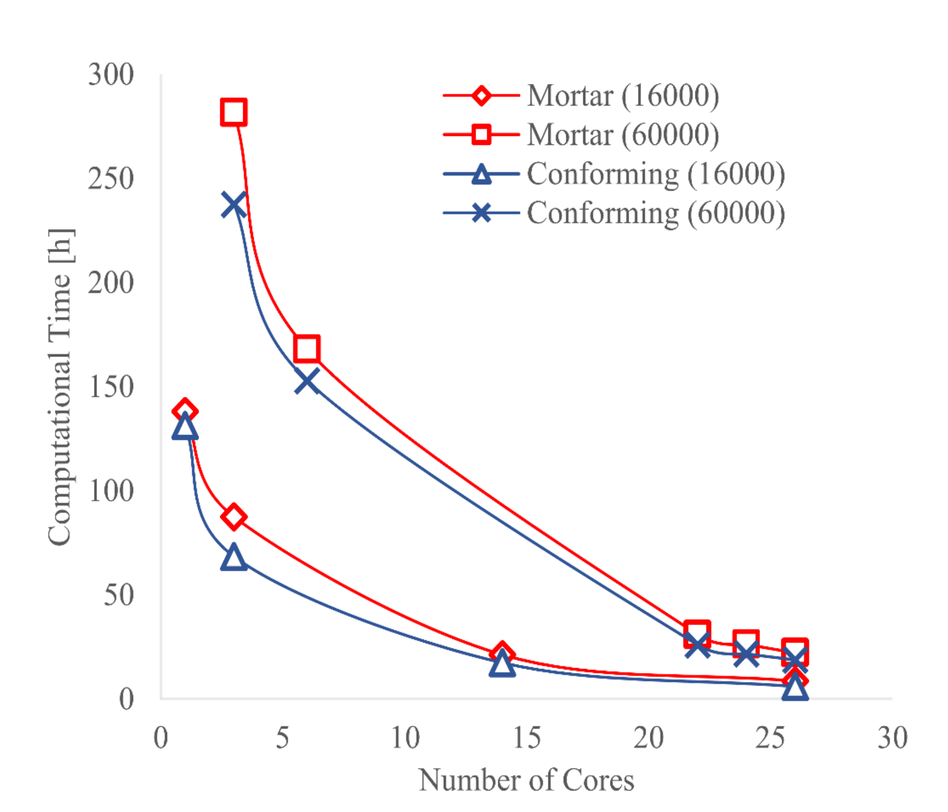
2D, MULTI-SLICED AND MEASURED REULT COMPARISON



ELMER AND COMMERICAL FEA COMPUTATIONAL TIME

- In Elmer for 2D simulation Computational time comparison between mortar and conforming boundary conditions is shown as function of the number of cores.
- The relation of the computation time to the number of cores is not linear.
- Computational time decreases more than 50% when increasing the number of cores from 14 to 26 for 16,000 intervals.
- Conforming BC require less computation time than the mortar boundary conditions at lower cores however, with increase in number of cores the computational time is almost same.



ELMER AND COMMERICAL FEA COMPUTATIONAL TIME

FEA	Time size (s)	Mesh nodes	Time step (μs)	Cores limit	Local computing system	Computational time (h)
Commercial	0.8	120000	50	6	✓	33
Open-source	0.8	120000	50	6	✗	33 (app.)

- The local system simulation total time depends partly on the computer-unit having processor Intel Xeon W-2135 3.7GHz, 6 cores and NVIDIA Quadro P2000, 5GB.
- While Elmer was using Taito CSC servers for computation.

ELMER AND COMMERICAL FEA COMPUTATIONAL TIME

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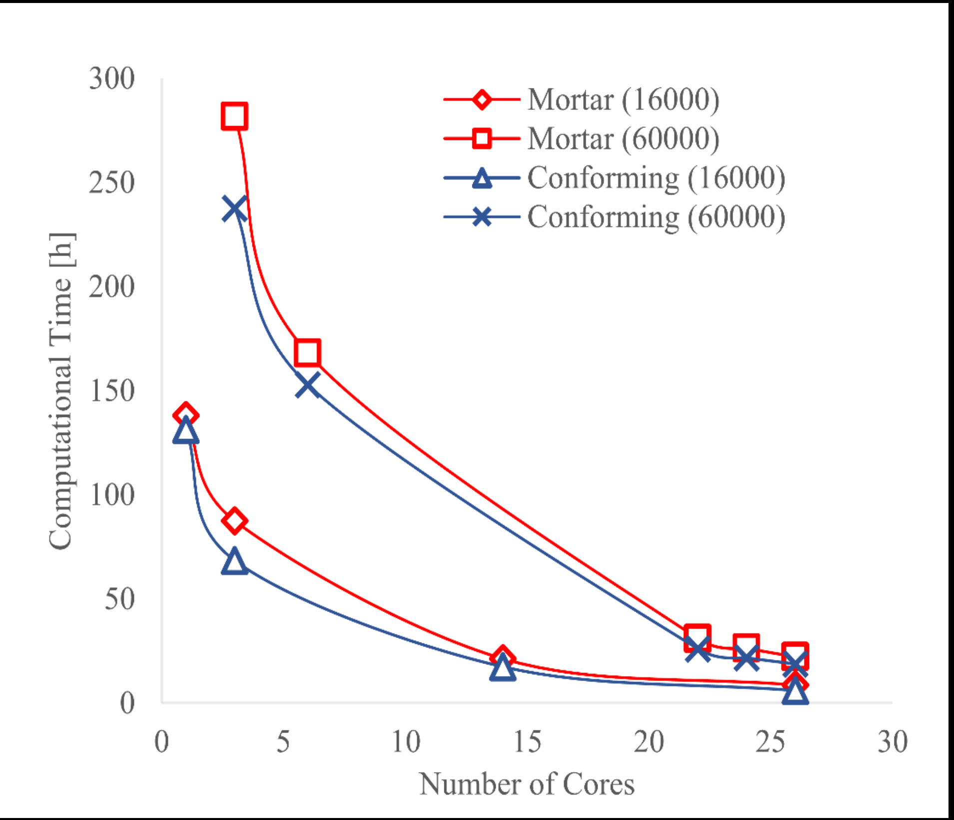
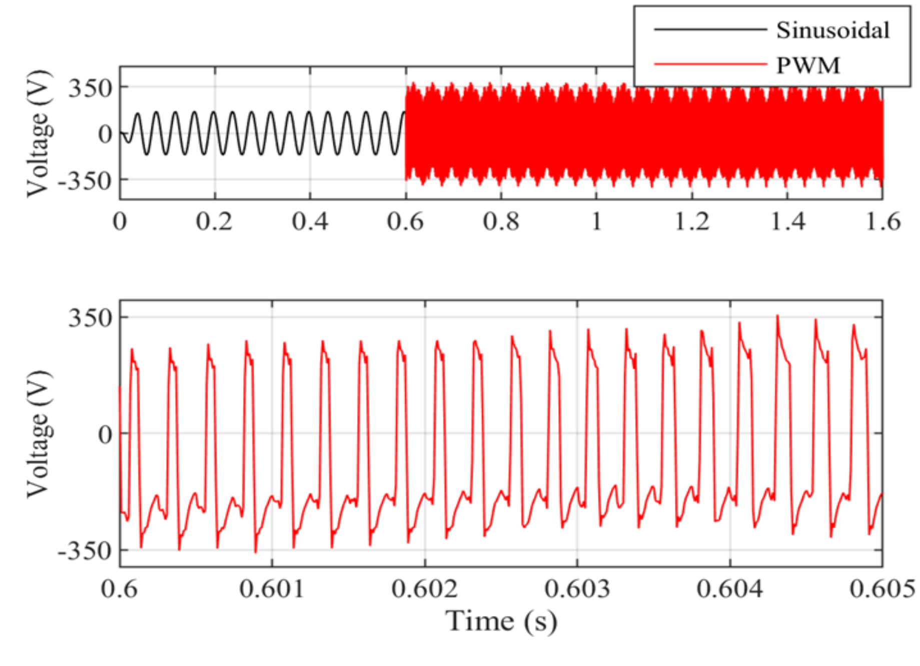


FEA AND MEASURED RESULTS FOR CONVERTER FED IM WITH PWM SUPPLY

- In the experiments, the recorded voltage sampling interval is 1 µs to include all the PWM – induced harmonic content in the data.
- If 1 µs is used in FEA it would take much longer time to compute the results. So, voltage data was down sampled to 10, 50 and 100 µs
- In transient phenomena, the sinusoidal voltage supply is supplied to start motor and changed to PWM voltage supply after the sinusoidal outcome is steady (Can be done in 2 ways making script phase.f90 and calling it in circuit body or adding data phases data to .dat file and than call that file in circuit body).
- An example of Recorded voltage down sampled data fed to Elmer is shown in Figure



SIMULATED RESULTS

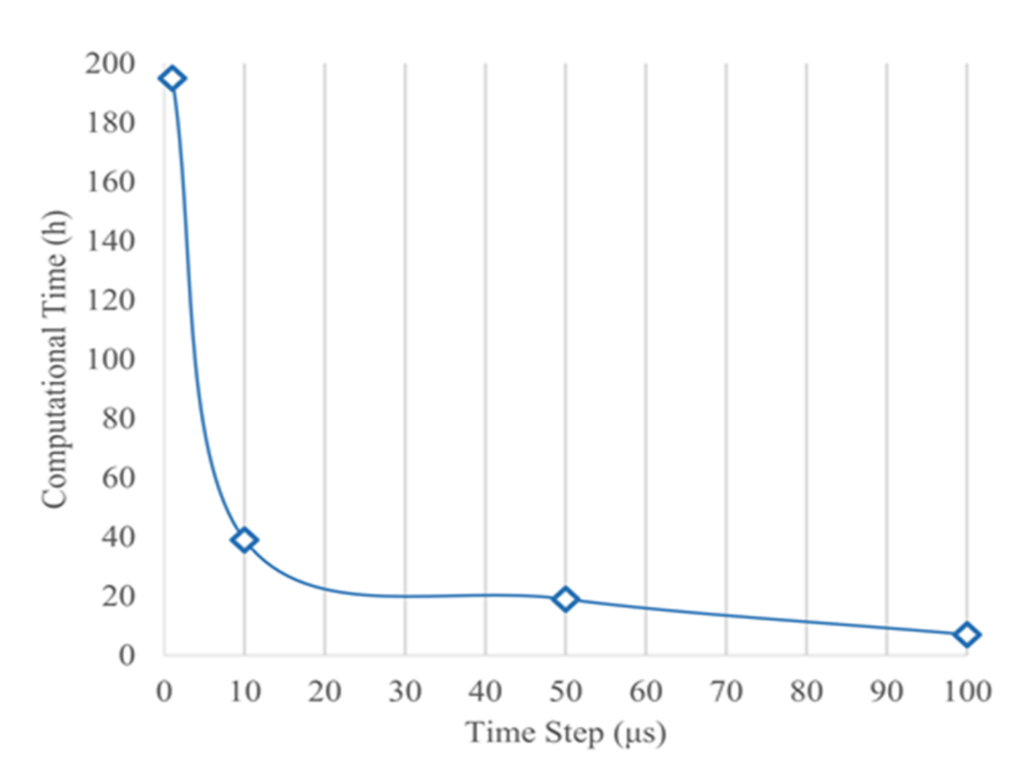
- Transient solution takes several supply periods to reach a steady state. Therefore, reducing the simulation time for IMs is an important issue, while using a higher mesh density.
- Elmer FEM results showed that 1 µs were too time consuming but the current THD %, electrical losses and input power are closer to the measured results.
- Better and fast results were obtained using 10 µs which are closer to 1 µs measured results.

Taken from Publication

M. Zaheer, P. Lindh, L. Aarniovuori and J. Pyrhönen, "Converter-Fed Induction Motor Finite Element Analysis With Different Time Steps," 2020 XI International Conference on Electrical Power Drive Systems (ICEPDS), Saint Petersburg, Russia, 2020, pp. 1–7.

COMPUTATIONAL TIME EVALUATION

- To check the time consumed by different time step, transient computation is performed with 1-second simulation, mesh 120000 nodes, and 25 cores.
- The relation between the computation time and time step is not linear.
- The time was reduced by more than 400% when the step size was changed from 1 μs to 10 μs.



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PWM INDUCED LOSS RISE IN A 5-KW CONVERTER-FED IM

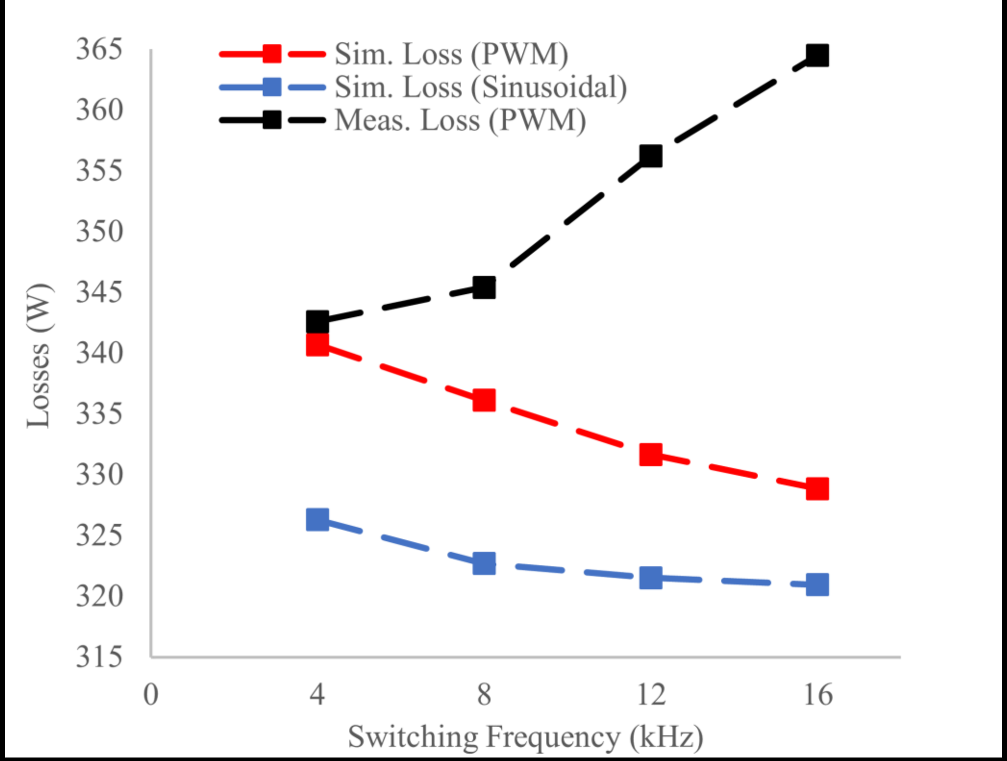
- The motor losses with a PWM voltage supply are higher than in sinusoidal supply because of distorted current.
- In PWM supply the machines experience higher temperatures and a reduction in insulation lifetime .
- Typically, the electrical machine losses decrease as a function of the switching frequency but in this case the opposite behavior is reported during the laboratory experiments.
- Motor supply using the different switching frequencies; 4, 8, 12 and 16 kHz and power losses were examined.
- Recorded voltage for different switching frequencies during measurements was supplied to Elmer to see exact behavior.

Taken from Publication

M. Zaheer, P. Lindh, L. Aarniovuori and J. Pyrhönen, "Analysis of PWM induced loss rise in a 5-kW induction machine," (In Final stages of EPE 2021 conference)

PWM INDUCED LOSS RISE IN A 5-KW CONVERTER-FED IM

- The losses in the machine start increasing as a function of carrier frequency when keeping the torque value content.
- In Elmer FEA as expected the losses decreases as carrier frequency is increased.
- It is somehow observed that FEA is lagging to model high frequency phenomena and therefore measurement results can be only verified with a temperature rise in machine.



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FUTURE WORK

- In further research the behavior of power, flux densities and iron losses as function of the switching frequencies will be studied considering 3D model.
- 1 µs fast computations required to exactly see the losses behavior at different switching frequencies.
- Rotating machine heat transfer problems that involve FEM for rotor and stator and CFD/PDE for airgap & case-ambient thermal interfaces will be studied.
- Our colleague Dr. Chong Di (LUT graduate) is also working on designing high-speed solid-rotor induction machine.

THANKS ALL FOR LISTENING