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Transient Modelling of Induction Machine Using Artificial Neural Networks

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Abstract

A start-up transient model of an induction machine (IM) is developed using an artificial neural network. The model is suitable for direct-on-line and converter fed induction machines. Different inputs and model configurations are investigated to find an optimal solution in developing the transient model. The datasets required by the development process are generated with a finite element-based model of induction machine. The transient model can be used to estimate the current and torque at any given time accurately in real time, which makes it suitable to use in digital twin services.

Introduction

- Performance assessment of IMs is important as most industrial pumps are run by direct-on-line induction motors
- Analytical models are used in real time applications to simulate transient behaviour of IMs but they ignore
  - the effects of different spatial harmonics of the machine
  - the eddy current in the rotor bar
  - the saturation of the iron core makes
- Can an artificial neural network (ANN) learn the time-dependent start-up transient behaviour of an IM from finite element (FE) simulations?
  - Which inputs an ANN needs?
  - Is the current needed in the model?
    → Does the prediction accuracy decrease if its excluded?

Induction Machine Modelling

- 45 kW double-cage induction motor
- Data: 2D FE transient simulations from standstill condition to different power levels
  - Initial current and speed is zero
  - A load profile is used to accelerate rotor to attain a specific steady speed to generate required power level
  - 11 power levels from 10 to 60 kW with 5 kW steps
    → ANN training, validation, and testing datasets

ANN Surrogate Model Development

- ANNs are created with Tensorflow (Python)
  - Structure and learning parameters optimised with Hyperopt
- Model input options:
  - Three-phase voltage *U*
  - Shaft speed *ω*
  - First backward finite difference of shaft speed *Δω*
  - Three-phase current *I*
- Studied input configurations (Table 1):
  - M1 → current in the input. Reference model to which we compare the next, currentless configurations
  - M2 → M1 but without current in the input
  - M3 → M2 but *Δω* and more previous timesteps in the input

Table 1. ANN input configurations. K is the present timestep, k-1 is the previous timestep, etc.

Abbrev.	*I*	*U*	*ω*	*Δω*
M1	k-1	k	k, k-1	-
M2	-	k	k, k-1	-
M3	-	k, k-1, …, k-4	k, k-1, …, k-4	k, k-1, …, k-4

Performance of ANN Surrogate Models

- ANN accuracy with the three input configurations (Table 2)
  - M1: Current in the input → low error
  - M2: Current dropped from the input → large error
  - M3: *Δω* added to the input → similar error as with M1 but without current in the input

Table 2. Torque prediction error of the ANNs.

	Torque			Current		
Configuration	RMSE (Nm)	NRMSE	MAE (Nm)	RMSE (A)	NRMSE	MAE (A)
M1	26.3	0.7 %	15.6	1.3	0.1 %	0.9
M2	107.4	3.0 %	67.2	8.9	0.6 %	6.3
M3	23.7	0.7 %	15.8	3.1	0.2 %	2.3

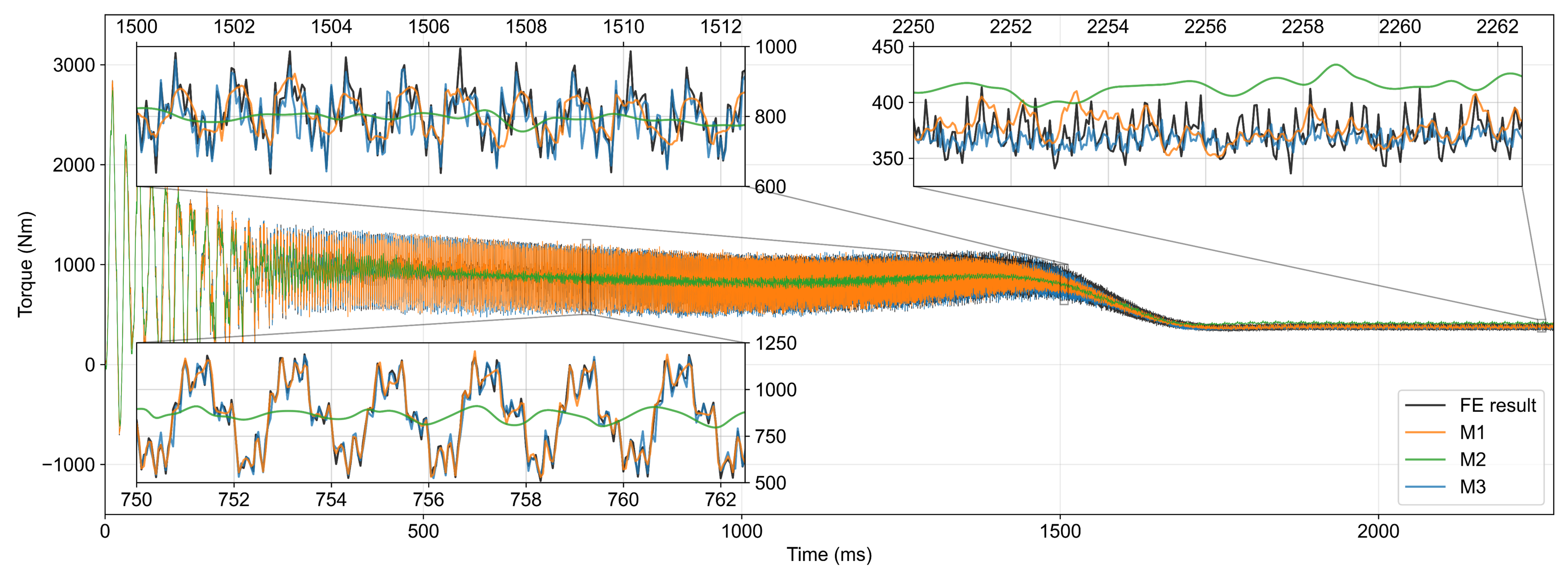

Figure 1. Torque predictions of the ANNs. An extrapolation test case with 60 kW power level.

- Run-time speed (per sample)
  - Analytical model: 8 µs
  - FE model: 12 ms
  - ANN (M3): 25 µs
    → 500x faster than FE

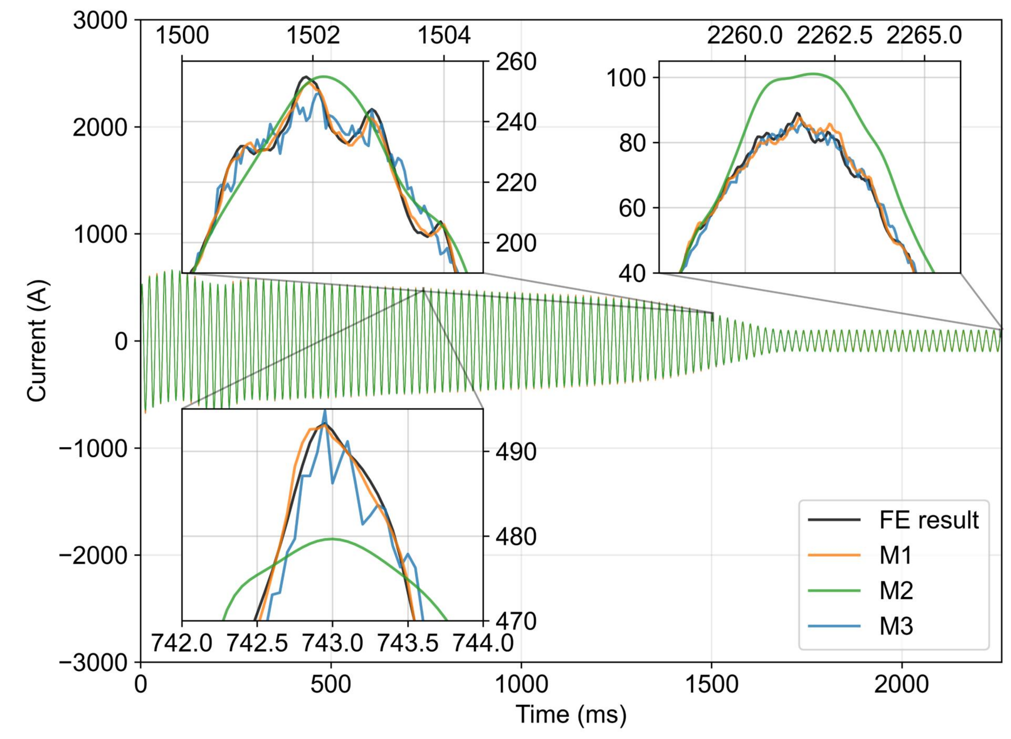

Figure 2. Current predictions of the ANNs . An extrapolation test case with 60 kW power level.

Conclusion

- ANN can predict time-dependent start-up transient behaviour of an IM accurately and in real time
- Measuring voltage and shaft speed is only required
- The model can be used for real time optimization of IM start-up behaviour
  - Loss and torque estimation for more intelligent control
  - Thermal management

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