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Towards System-level Simulation of an Electromagnetic Energy Harvester Model

INTRODUCTION AND MOTIVATION

Since 2015, 'Industry 4.0' has evoked the growth of 'Internet of Things', which uses wireless devices to connect the machines digitally and uses sensors to monitor physical and environmental phenomena and exchange data. However, the main challenge is the periodic replacement of drained batteries for battery-powered wireless devices or sensors.

In recent years, energy harvesting has emerged as a solution to provide a lifetime power supply to the wireless devices or sensors [1]. In this work, we start with the electromagnetic energy harvester model (see Fig.1) introduced by Beeby [2], which is reproduced in ANSYS Maxwell 3D. On basis of it, we then present the workflow of exporting an equivalent circuit model from Maxwell 3D into ANSYS Twin Builder for system-level simulations. Furthermore, in order to speed up the generation of the equivalent circuit model and the overall geometry optimization of the electromagnetic energy harvester, we adapted two alternative parametric model order reduction (pMOR) methods for effective parametric studies.

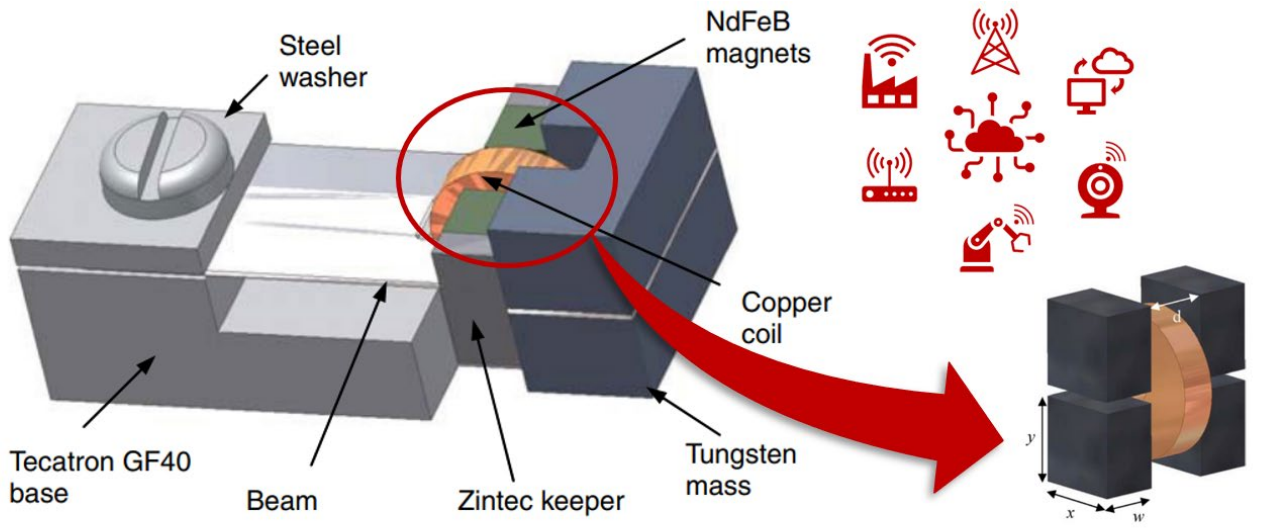

Fig. 1. To overcome the drawback of battery-powered wireless systems, energy harvesting has emerged as a solution. This figure shows a drawing of the assembled electromagnetic energy harvester model introduced by Beeby et al. [2] and the schematic of the magnets and the coil.

METHODOLOGY

In this work, four magnets and the coil were built in ANSYS Maxwell 3D as shown in Fig.2. The two magnets on each side of the coil were grouped and moved in a motion band in the z-direction. In order to establish the harmonic motion of the magnets in transient analysis, a time-dependent force was applied to each group of magnets:

$$F(t) = m\,\omega^2\,x_0\cos(\omega t)$$

where m = 22.2 µg is the mass of two magnets. $\omega = 2\pi f$ with f = 60 Hz is the excitation frequency and x_0 = 0.57 mm is the designated oscillation amplitude.

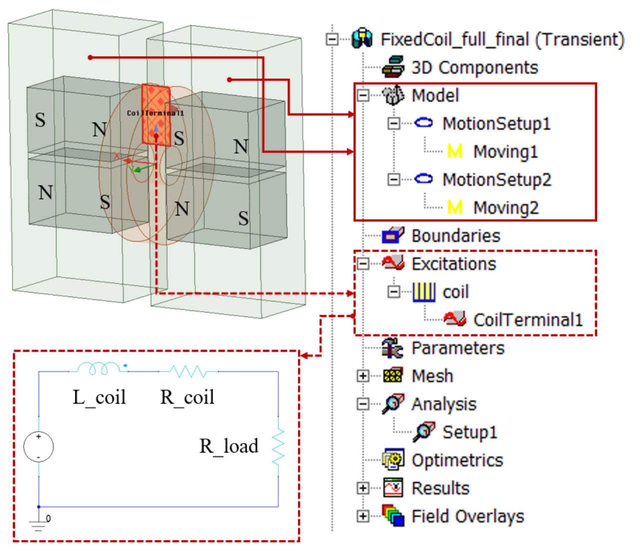

Fig. 2. Model setups in ANSYS Maxwell 3D. The oscillation of the magnets was modeled via the motion setups in two motion bands. The coil terminals were connected to an external circuit.

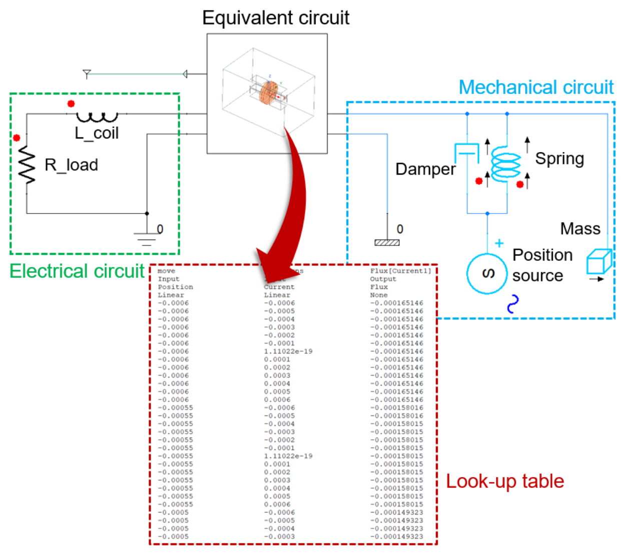

Fig. 3. The equivalent circuit model is constructed based on the look-up table of the parametric simulation results and connected to both electrical and mechanical circuits.

However, the computational cost of the transient simulation of the full-scale finite element (FE) model is relatively high. In order to reduce the computational cost, we will introduce the equivalent circuit extraction technique in ANSYS Maxwell 3D, which enables us to generate an equivalent circuit model for fast simulations at the system-level as shown in Fig.3.

Although the equivalent circuit model enables efficient system-level simulation, it still takes a long time to generate the equivalent circuit model due to the fact that it is constructed based on the parametric simulation results of the full-scale FE model in ANSYS Maxwell 3D. Therefore, in this work we suggest using two different parametric model order reduction (pMOR) methods to speed up the computational time of doing the parametric studies.

- Matrix interpolation-based pMOR method [3]: generate the local reduced order models (ROMs) at selected values of the geometrical parameter. The global parametric ROM is constructed based on interpolating the local ROMs.
- Algebraic parameterization-based pMOR method [4]: extract the geometrical parameter in front of the system matrices during the discretization process in finite element method and then apply multivariate moment-matching-based pMOR method to generate a parametric ROM.

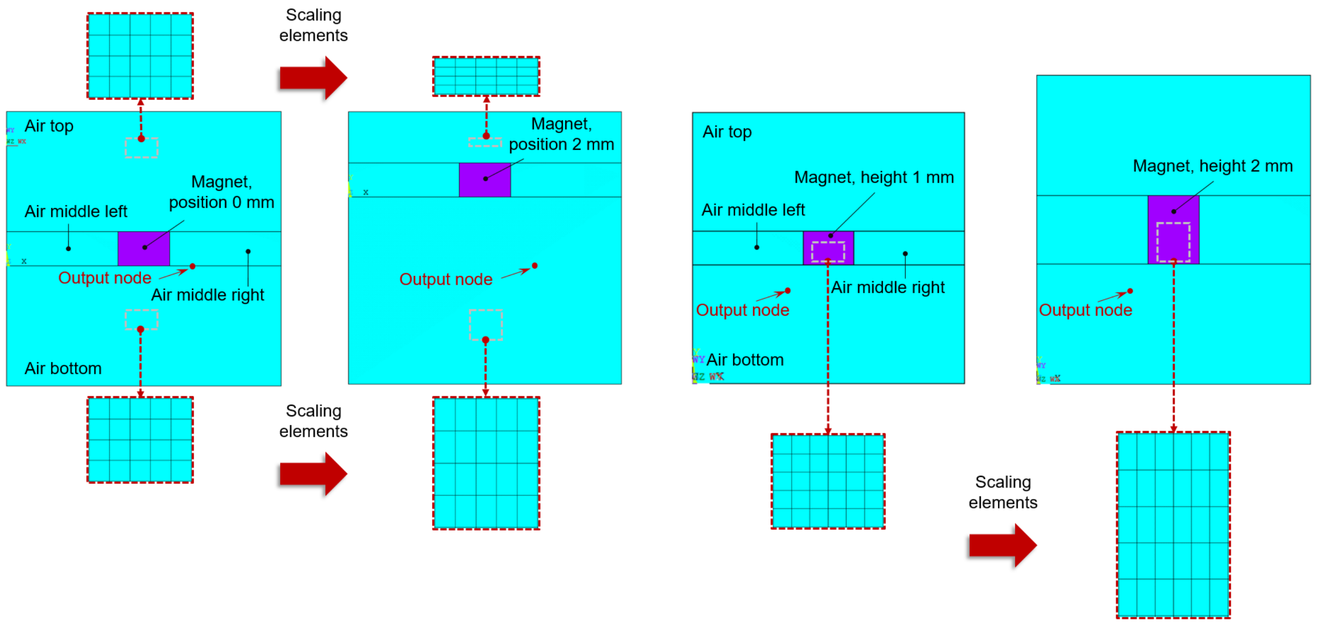

Fig. 4. Preserve the mesh topology of the 2D permanent magnet model while changing the position of the magnet via scaling the mesh in the top and bottom air regions (left); Parameterize the height of the magnet via scaling the mesh in the magnet (right).

NUMERICAL RESULTS

The simulation of the equivalent circuit model is carried out with an excitation frequency f = 60 Hz and an acceleration amplitude of a_0 = 0.59 m/s². The spring rate is calculated as $k = \omega^2 m$ =3.16 N/m. A displacement amplitude of 0.57 mm is expected. Therefore, the excitation amplitude can be calculated as follows:

$$y_0 = \frac{a_0}{\omega^2} = \frac{a_0}{(2\pi f)^2} = 4.15\ \mu\text{m}$$

The resistance of the load resistor is defined as 10 GΩ, which sets an open circuit condition. The induced voltage from the equivalent circuit model is shown in Fig.5 left. It takes only 19 s to perform the simulation of the equivalent circuit model compared to running the simulation of the full-scale FE model in 2 hours.

Then the parametric studies of the load resistance in the electrical circuit could be performed efficiently on the basis of the equivalent circuit model as shown in Fig.5 right. The maximum power output of 4.28 µW is obtained.

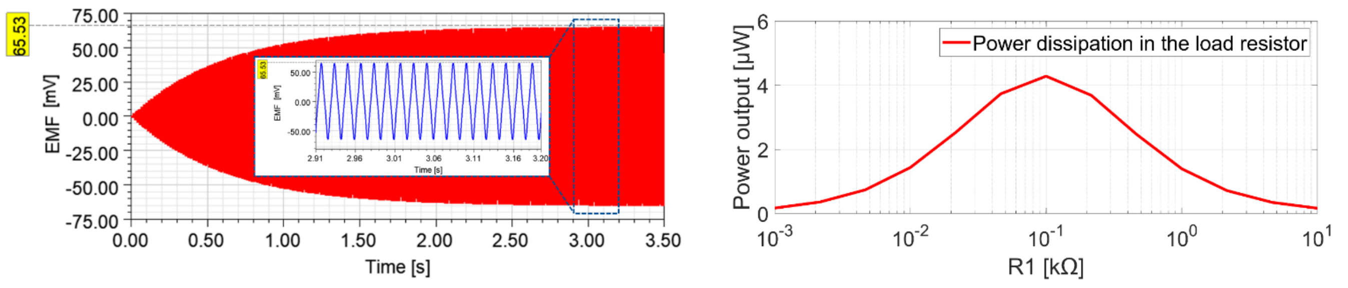

Fig. 5. Voltage output from the equivalent circuit model in an open circuit condition (left); Power dissipation in the load resistor with the varying load resistance (right).

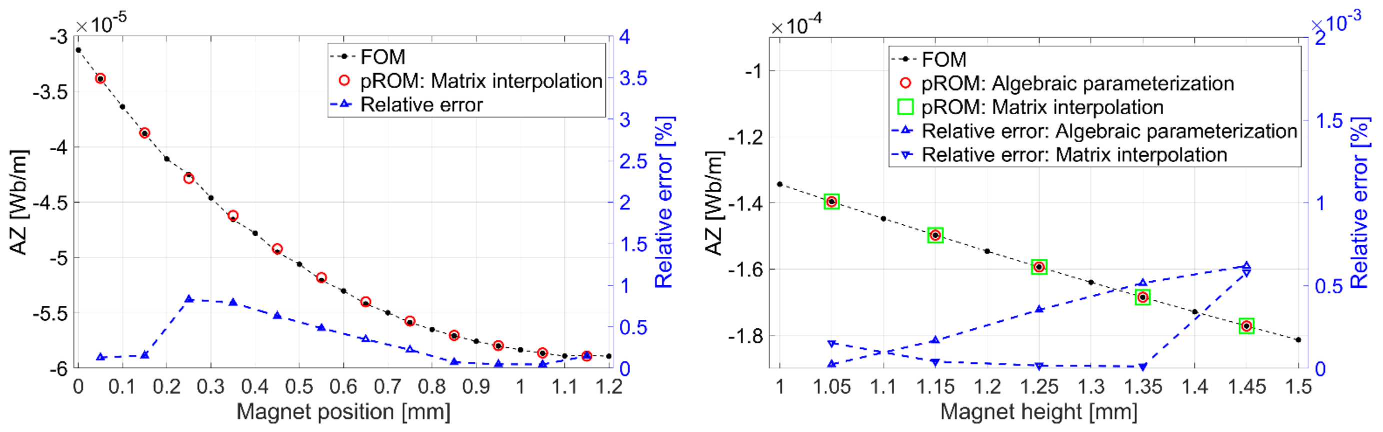

Fig. 6. Magnetic vector potential (AZ) results from the parametric ROM obtained via matrix interpolation-based pMOR method. Change the position of the 2D magnet between 0 and 1.2 mm (left); Comparison of the results from the parametric ROMs obtained via matrix interpolation and algebraic parameterization-based pMOR methods. Change the height between 1 and 1.5 mm (right).

LITERATURE

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