Ferromagnetic Material Modeling with an Equivalent Circuit Model

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BACKGROUND

- The process of magnetization and losses experienced by a material is very difficult to predict and varies vastly between individual material structures/compounds.
- Current modeling tools are not intuitive or easily accessible to many power electronics engineers, thus prompting a circuit-based solution.

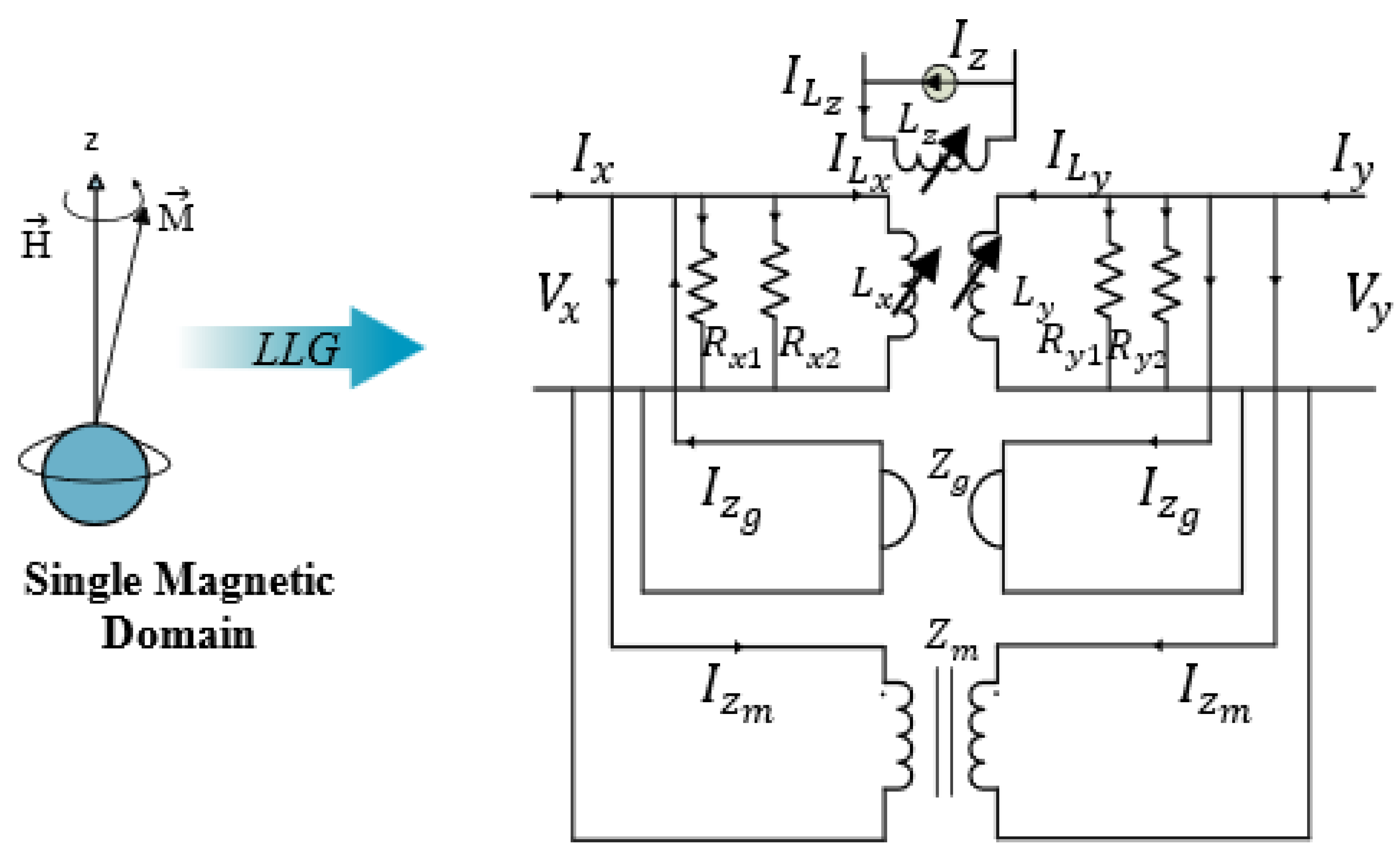
OBJECTIVES

- Derive applicable circuit-based equations from existing magnetic-dynamic modeling foundations (LLG equation)
- Design a circuit model which includes circuit parameters to equivalent physics parameters associated with the magnetization process

CONCLUSION & FUTURE WORK

- Using an equivalent circuit model is viable method of describing hysteresis.
- The model has the capability to be tested against existing and accepted models describing the complex behaviors of magnetic materials.
- Future work includes adding more levels of complexity to the model including:
    - anisotropic behaviors with multiple preferred axes, exchange interaction between domains, and temperature dependence.

CIRCUIT MODEL



PARAMETER CONVERSION

Physics Parameter	Circuits Parameter
M (magnetization)	V (Voltage)
H (applied field)	I (current)
γ (gyromagnetic ratio)	Z_g (gyrator)
α (damping factor)	R (resistor)
$M_{x,y,z}$ (mutual coupling)	$L_{x,y,z}$ (non-linear inductor)

These parameters were derived by the Landau-Lifshitz-Gilbert (LLG) equation:

$$\frac{d\overline{M}}{dt} = \gamma\,\mu_0(\overline{M} \times \overline{H}) - \frac{\alpha}{Ms}\left(\overline{M} \times \frac{d\overline{M}}{dt}\right)$$

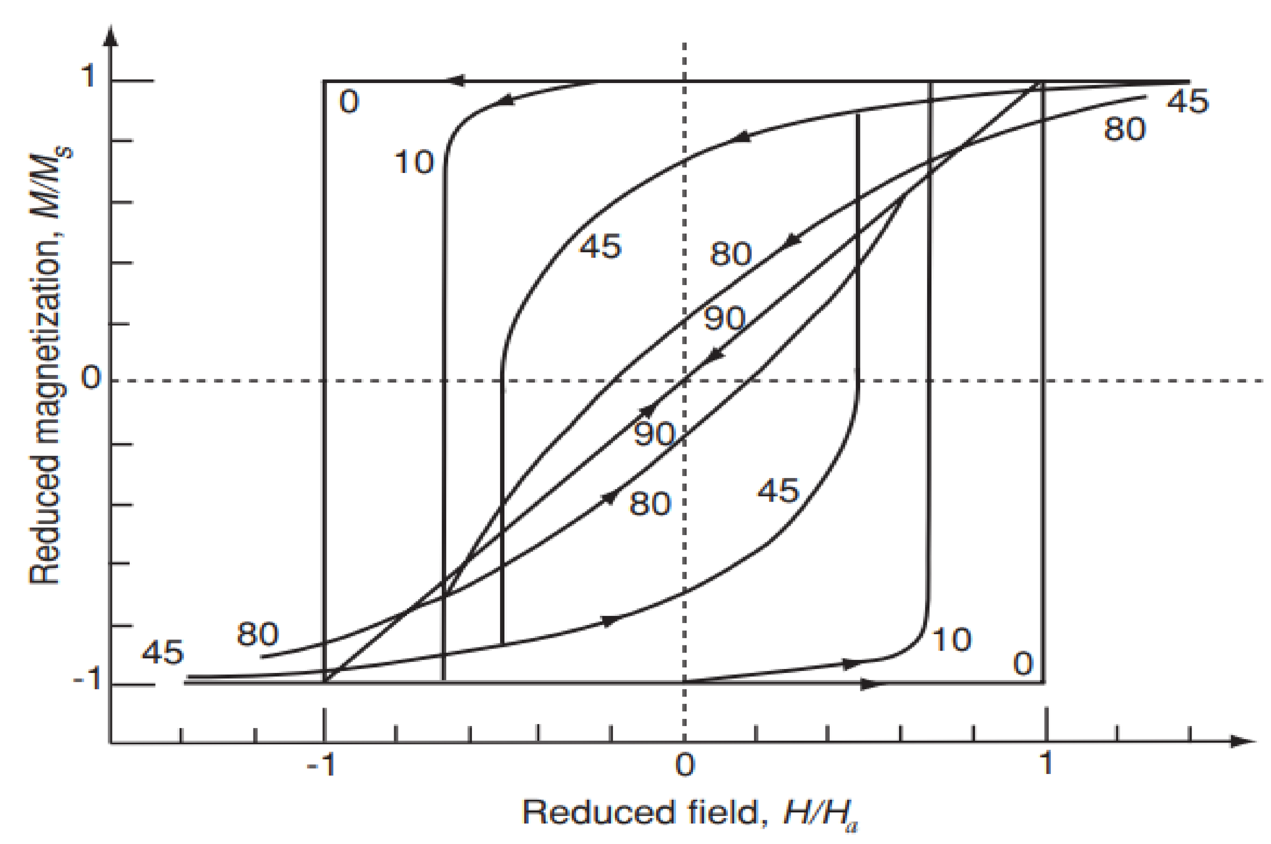
Describing magnetization dynamics – the motion of **M** within a solid.

With voltage and current being guided by the following relationships:

$$V_x = \mu_0 \Delta y \Delta z \frac{dM_x}{dt},\ V_y = \mu_0 \Delta x \Delta z \frac{dM_y}{dt},\ V_z = \mu_0 \Delta y \Delta x \frac{dM_z}{dt}$$

$$I_x = H_x \Delta x,\ I_y = H_y \Delta y,\ I_z = H_z \Delta z$$

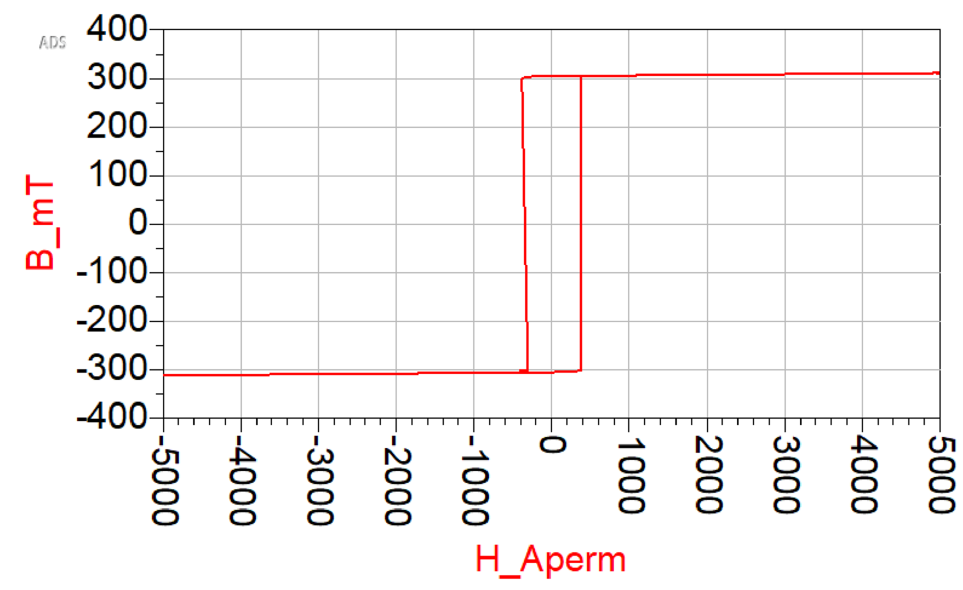
STONER-WOHLFARTH MODEL



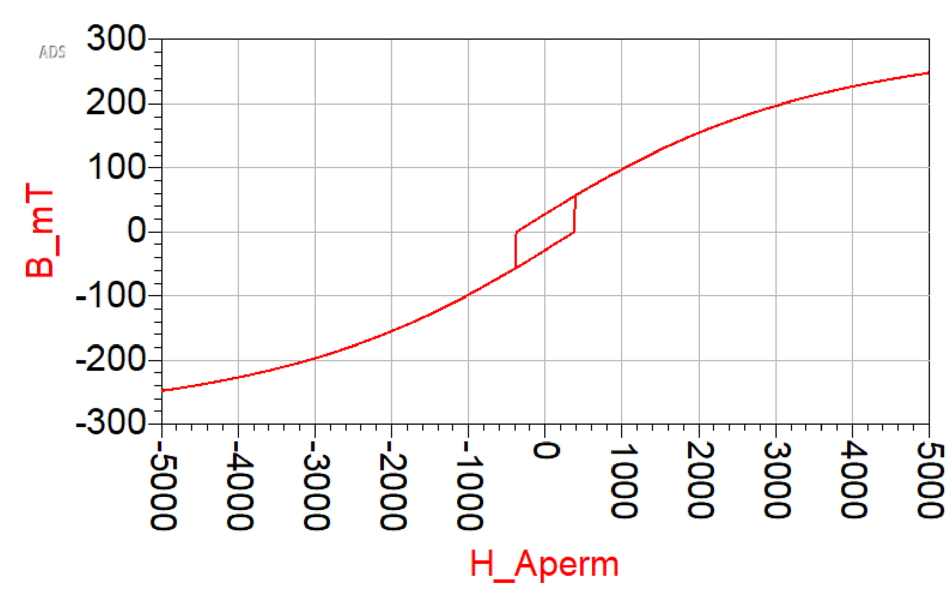
- This graph depicts magnetization curves for the S-W model.
- The size and shape of the hysteresis loops are determined by the angle between the material's **easy axis** and the **applied field (H).**
- When **H** is parallel (0°) to the to the easy axis, the loop is largest and square. When **H** is perpendicular (90°) to the easy axis, the loop is smallest and there is no loop.

SIMULATION VERFICATION

The circuit model was first implemented in the Advanced Design System (ADS) software. There have also been successful efforts to cross-reference the model in LTSpice - one of the most used software by electrical engineers.



The resulting B-H loop when orienting the applied field ***parallel*** *to the anisotropy field. (The angle between* ***H*** *and* ***H*** *anis very close to 0°)*



The resulting B-H loop when orienting the applied field ***perpendicular*** *to the anisotropy field. (The angle between* ***H*** *and* ***H*** *anis very close to 90°)*

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