

Abstract

Energy harvesting (EH) is a process of converting readily and freely available ambient energy into usable electrical energy. Magnetic energy harvesting (MEH) demonstrates superior performance in terms of both the harvested energy level and its predictability compared to other ambient energy harvesting methods. As a result, it emerges as a suitable power supply for self-powering low-power devices like embedded systems, sensor nodes, Internet-of-Things (IoT) devices, and cyber-physical systems (CPS).

MEH can be categorized based on how magnetic fields are generated. The first category is vibration-based MEH, where the changing magnetic field is generated by the kinetic motion or vibration of permanent magnets. However, the output voltage of this method is typically extremely low unless coils with a very large number of turns are used. To achieve usable voltages for microcontrollers and wireless sensors, it is essential to involve a step-up conversion, which in turn complicates the circuit and increases its size. Another preferred category is the current-transformer-based (CT-based) MEH. Here, the magnetic field is induced by an AC-current-carrying wire inserted in a magnetic core with high permeability. This CT-based energy harvesting approach can produce usable voltages directly, thereby shrinking system size and reducing circuit complexity.

Conventional CT-based energy harvesting approaches typically rely on toroidal cores, which aim to create tightly enclosed magnetic loops and achieve maximum energy extraction. The optimal energy harvesting is achieved when magnetic cores are slightly saturated or manipulated in a proper saturated state whenever feeding a resistive load or a constant voltage load. Despite its effectiveness and simplicity, the traditional MEH circuit presents two notable limitations. The first limitation arises from the necessity for an extremely high magnetic permeability, mandating the use of a gapless magnetic core. This requirement imposes a significant constraint on the installation process: integrating a single-core harvester into an existing system necessitates breaking the primary system's wiring, leading to potential downtime of the mother system. The second limitation is that the

previous saturation strategy for maximal energy harvesting assumes a single EH window in every half AC cycle. Although it indeed maximizes energy harvesting, it does so only under the strong constraint of a single harvesting window. Apparently, a single window indicates not the entire cycle is utilized and once saturation occurs, the process of energy harvesting electrically ceases.

This installation challenge was first addressed through the innovation of a cascaded core structure. This structure combines a clampable core with an ungapped core, striking a balance between non-intrusive installation and optimal power harvesting. A clampable core is used in the first stage to facilitate a non-intrusive mounting of the energy harvester onto the current-carrying wire. An ungapped toroidal core with high permeability is then cascaded as the second magnetic stage to maximize the harvested power. This two-stage cascaded structure opens a door for electromagnetic energy harvesting to be employed in a wide range of applications. Finally, to eliminate the constraint of magnetic saturation and improve the energy harvesting level, multiple desaturation methods are presented with parameter influence assessment and validated via experiments.