

# Review on Electromagnetic Induction-Based Energy Harvesting Wheels

Shivaprasad D<sup>1</sup>, Ashish Ahammad K<sup>2</sup>, Tharun M<sup>3</sup>, Vinay N C<sup>4</sup>, Bommanna K<sup>5</sup>

<sup>1,5</sup>Assistant Professor, Department of Mechanical Engineering, AMC Engineering College, Bengaluru, Karnataka, India

<sup>2,3,4</sup>Research Scholar, Department of Mechanical Engineering, AMC Engineering College, Bengaluru, Karnataka, India

**Abstract:-** Recent studies on electromagnetic wheel-based energy harvesting show strong potential for powering onboard monitoring systems in high-speed and electric vehicles. Researchers developed vibration-driven harvesters for train wheel bearings using electromagnetic induction to convert low-frequency wheel vibrations into usable electrical energy. Mechanical and electromagnetic optimization improved relative motion between components, increasing output efficiency under real operating conditions. Advanced materials such as Invar 42 were selected to improve durability, fatigue resistance, and structural reliability for long-term service. Some studies also explain how wheel rotation and centrifugal effects support the principles of electromagnetic induction during motion. Magnetic energy harvesters have gained importance in wireless sensor networks by supplying power to sensors mounted on rotating vehicle wheels. Simulation tools such as Ansys Maxwell and MATLAB/Simulink were used to predict voltage, current, and power generation performance. Results consistently showed that higher wheel speed produces greater electrical output and improved harvesting capability. In electric and hybrid vehicles, this recovered energy can recharge batteries and extend driving range without external charging. Overall, electromagnetic wheel harvesters provide a compact, durable, and efficient solution for sustainable vehicle energy recovery.

**Keywords:** Electromagnetic induction, Energy harvesting, wheel induction.

## 1. Introduction

With the rapid growth of the Web of Things (WoT) Wireless Sensor Networks have become essential for real-time monitoring, control, and data-driven decision-making across applications such as healthcare, industry, and autonomous vehicles. A critical challenge in WSN deployment is the reliability of the energy supply system, especially in harsh or remote environments where conventional power sources are limited [1, 8-10]. To address this, energy harvesting techniques—particularly electromagnetic methods based on Electromagnetic Induction—have gained attention for converting ambient energies like vibration and magnetic fields into usable electrical power. Magnetic energy harvesters offer advantages such as high energy density, compact design, and compatibility with MEMS technologies, though challenges remain in impedance matching, voltage regulation, and system optimization [2, 11-13].

In parallel, the increasing dependence on automobiles and the environmental impact of fossil fuels have driven research toward sustainable mobility solutions. Recovering energy from vehicle motion presents a promising approach to reduce reliance on fuel and external charging, enabling improved battery performance and extended driving range in electric vehicles [3, 14-15].

Simultaneously, advancements in Magnetic Levitation technology have been a leading point in developing of high-speed maglev vehicles utilizing electrodynamic wheels (EDWs) for both levitation and propulsion. However, key design challenges—such as optimizing wheelbase dimensions and minimizing electromagnetic interference between multiple EDWs—remain unresolved [4]. Current research highlights the need for systematic analysis of electromagnetic interactions and experimental validation to enhance safety, efficiency,

and structural reliability. Overall, integrating energy harvesting with advanced electromagnetic transport systems presents a promising pathway toward efficient, sustainable, and self-powered mobility solutions.

## 2. Literature Review

**Hyunchul park et.al** [1] researched on electromagnetic induction energy harvesting for high-speed railroad applications presents the evolution of self-powered system designed to supply energy to communicational networks used in train monitoring, particularly for components like wheel bearings. It utilizes the principle of electromagnetic induction, where vibrations from the moving train create relative motion between permanent magnets and coils, generating electrical power. The organisation is optimized through combined mechanical, electromagnetic, and electrical modelling, and experimental results show that it can effectively produce usable power even from low-frequency vibrations. This makes it suitable for reducing dependence on conventional batteries and improving the reliability of real-time monitoring systems. However, the performance varies with vibration intensity and train speed, and efficiency decreases at lower speeds, with additional concerns about size and durability. Future improvements focus on enhancing power output, miniaturizing the device, integrating it with IoT-based systems, and exploring hybrid power bring in techniques for broader and more efficient applications.

**JavedEnayati et.al**[2] this comprehensive review and investigation of magnetic energy harvester (MEH) for powering wireless sensor networks, with a specific case study for vehicular applications. This author classifies (MEH) methods into independent and dependent types, discussing their working principles, advantages, and limitations. For the case study- feeding navigational sensors on a rotating vehicle wheel requiring approximately 40mW- they select the variable reluctance (VREH) method due to its suitable frequency range, simple structure, and adequate power capability. Using 2D finite element simulation sin ansys Maxwell, they demonstrate that with standard parameters, the (VREH) can harvest a mean power of 251 mW and maximum of 4.17 W. However, limitations include performance dependency on vehicle speed and air gap. Future work should focus on integrating an energy management system with storage to ensure continuous power delivery under varying operating conditions shown in figure1 and 2.

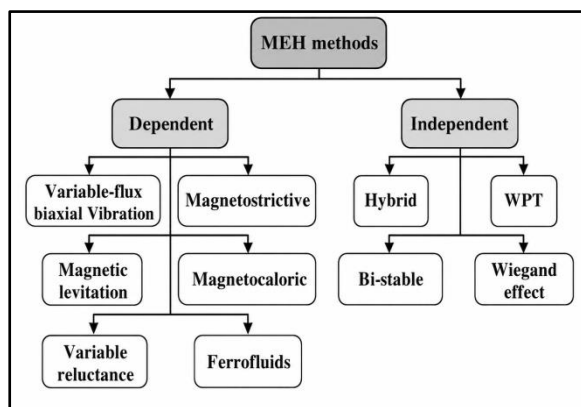


Figure 1: Classification of MEH methods

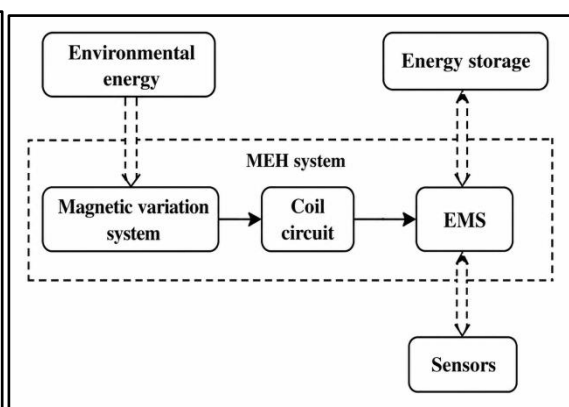


Figure 2: Flowchart of energy conversion process in a typical MEH system.

**Mbachu C.B. et.al** [3] focuses on enhancing the efficiency of electric and hybrid vehicles by converting wheel motion into electrical power using electromagnetic induction. By mounting D.C. machines on the rear wheels, the system acts as a generator during travel to charge the vehicle’s battery pack and extend its driving range. Simulation results using MATLAB and Simulink demonstrated that power generation increases with vehicle speed, reaching up to 181.5W at 140 RPM. However, the system faces limitations, such as a voltage regulator cap at 14.4V to prevent battery damage and sensitivity to environmental factors like tire friction and damping. The work successfully proves that energy typically lost during acceleration can be reclaimed to reduce dependence on external charging stations. Future scope includes optimizing the energy control unit for

consistent performance and integrating these systems into broader zero-emission transportation frameworks as shown in figure 3. This approach supports sustainable mobility by maximizing energy utilization and addressing the common challenge of limited battery life in modern electric vehicles.

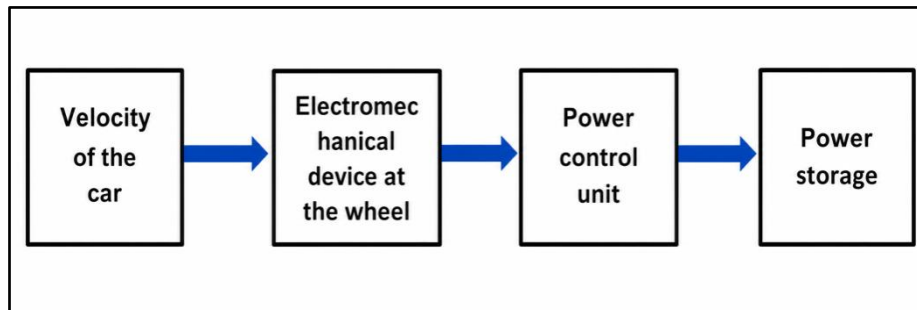


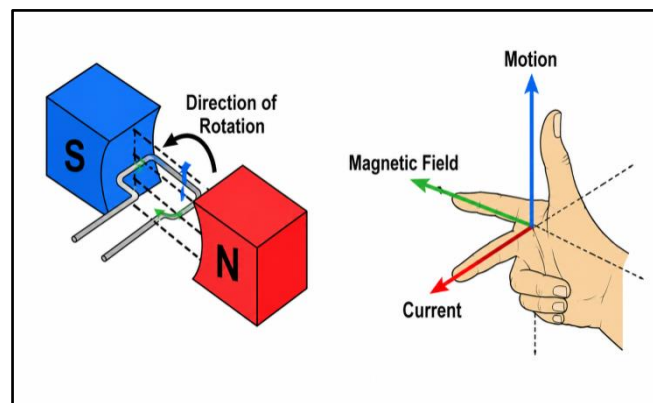
Figure 3: Block diagram of the System

**Yiyang Yang** et.al [4] explores the integration of suspension and propulsion systems for Maglev cars using double permanent magnet electrodynamic wheels (DPM-EDW). The study's primary purpose was to analyze the electromagnetic force characteristics of these wheels and determine an optimal wheelbase design to ensure vehicle stability on Maglev highways. By utilizing theoretical modelling and simulations, the authors successfully identified the mechanical relationships required for "suspension-drive" integration, outputting technical guidelines for wheelbase configurations that improve dynamic performance. However, the work is limited by its reliance on laboratory-scale research and idealized models, which may not fully account for the complex environmental variables of real-world infrastructure. The future scope of this work involves refining these electromagnetic designs for commercial high-speed ground transportation and exploring the scalability of DPM-EDW technology for mass-market Maglev transit systems. This research serves as a critical step toward developing more efficient, contactless vehicular technologies for future smart cities.

**Yongjun Moon** et.al [5] study on development of rotational type of wheel based electromagnetic induction. The primary purpose of the work is to develop a highly efficient electromagnetic induction energy harvester as an alternative to batteries for Tire Pressure Monitoring Systems (TPMS), adhering to the "install and forget" principle for the vehicle's lifetime. The study introduces an induction-type harvester that utilizes the relative motion between a rotating wheel and a fixed brake disc. A key output of the research is the identification of an optimal arrangement of coils and permanent magnets through the use of an orthogonal array, which significantly reduced experimental costs while verifying the module's validity through measurable storable energy. While the abstract highlights the successful verification of the module, current limitations involve the need for further testing to ensure performance matches the full mechanical lifespan of various vehicle types. The future scope of the work includes refining these energy harvesting modules for broader integration into Wireless Sensor Networks (WSN) and optimizing the design for mass-market automotive applications. This research provides a foundational step toward self-powered vehicular safety systems that eliminate the maintenance burden of traditional battery replacements.

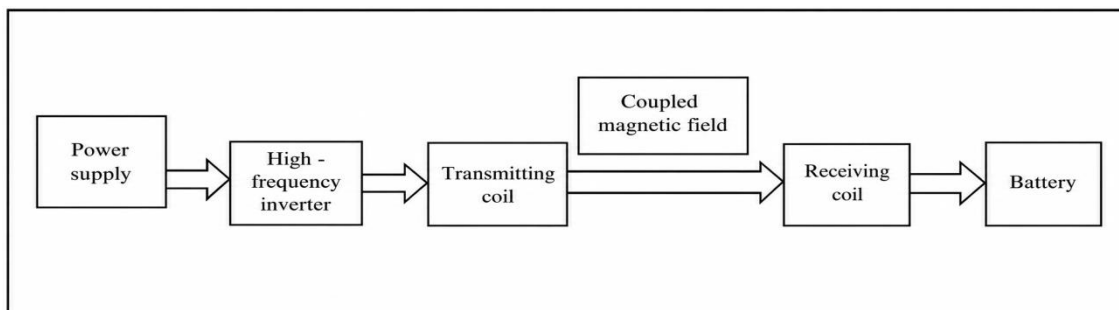
**ArchisBasangaret.al** [6] investigates on system for driving spherical wheels using induction mechanism. The primary purpose of the work is to address the technological demand for highly manoeuvrable mobility by exploring the use of spherical wheels driven by the law of electromagnetic induction. A significant output of the research is the conceptualization and analysis of a system where alternating current creates an induction mechanism to generate the necessary torque for rotation. While the abstract points to "large number of potential applications" in robotics and advanced transportation, it implies limitations common to such induction-based systems, such as the complexity of maintaining precise control and power efficiency over a full 360-degree range of motion. The future scope of the work highlights its potential as a "technological breakthrough" for robotics and autonomous vehicles requiring omnidirectional movement without the mechanical friction of traditional axles. Overall, the study provides a theoretical foundation for next-generation vehicle propulsion that prioritizes extreme agility through electromagnetic induction.

**Frederick David Tombe** et.al [7] inspects on Electromagnetic and rolling wheel. The primary purpose of this work is to provide a closer examination of the mechanical and electromagnetic forces involved in a rolling wheel, specifically investigating how it is driven forward by the linear momentum in its upper half shown in figure 4. As a significant output, the paper establishes a theoretical framework that connects classical mechanics with electromagnetic principles to explain the dynamics of rolling motion. While the provided abstract focuses on these fundamental physics concepts, a limitation of the work is its highly theoretical nature, which may require further empirical validation in complex real-world engineering scenarios. The future scope of the research suggests that these foundational principles could be applied to better understand advanced propulsion systems and energy-efficient vehicular technologies. Overall, the study serves as a critical bridge between two core areas of physics to clarify the underpinnings of rotational and translational motion.



**Figure 4: Schematic Representation of Electromagnetic Induction and Fleming's Right-Hand Rule**

### 3. Flow Chart



**Figure 5: Block diagram of the System**

In figure 5, Wireless power transfer (WPT), commonly used in charging devices and electric vehicles without cables. This explains the Power conversion, Magnetic induction, Energy capture, storage in simple manner.

### 4. Results

Energy harvesting- the study confirms that converting mechanical motion into electrical energy is possible real life and efficient solution for day to day life transportation systems, such as rolling wheels. If the power generated is small, it is perfect for low power applications, including sensors and monitoring devices. The transition from theoretical physics to practical application has confirmed that converting mechanical motion into electrical energy is a viable solution for modern transportation. By utilizing the constant kinetic energy generated by rolling wheels, systems can capture energy that would otherwise be dissipated as heat or friction. This process typically leverages technologies like electromagnetic induction or piezoelectric materials, which generate a voltage when subjected to mechanical stress or movement.

In the context of day-to-day transportation, this means that every rotation of a tire or vibration of a chassis represents a consistent, untapped power source capable of contributing to a vehicle's overall energy efficiency. While these harvesting systems may not yet replace primary fuel sources or large EV batteries, the "small-scale" power they generate is exceptionally well-suited for low-power applications. Modern vehicles and transit infrastructures are increasingly reliant on a dense network of sensors and micro-controllers. Energy harvesting provides a path toward "set-and-forget" technology, where components like Tire Pressure Monitoring Systems (TPMS), structural integrity sensors, and GPS trackers can operate indefinitely without the need for complex wiring or battery replacements. This creates a self-sustaining ecosystem where the motion of the transport system itself provides the lifeblood for its digital monitoring tools.

Electromagnetic induction- core of the system depends on the relative motion between magnetic fields and conductive elements to produce a electrical output. Performance is directly proportional to physical variables, especially with induced voltage and power output increase when: 1) Higher rotational speeds. 2) greater magnetic fields strength. 3) optimized coil designs. The principle of electromagnetic induction serves as the operational backbone for kinetic energy harvesting in transportation. At its simplest level, this process occurs when a conductor, such as a copper coil, is exposed to a changing magnetic field—a phenomenon defined by Faraday's Law of Induction.

In the context of a rolling wheel, magnets and coils are strategically positioned so that the wheel's rotation creates a continuous change in magnetic flux. This relative motion forces the flow of electrons within the conductive elements, effectively translating the mechanical "work" of the vehicle into a usable electrical current. The efficiency of this energy conversion is highly sensitive to the physical variables of the system, most notably the rotational speed. Because the induced voltage is determined by the rate at which the magnetic field lines are "cut" by the coil, higher speeds lead to a more rapid change in flux, which exponentially boosts the electrical output. This makes the system particularly effective for highway travel or high-speed rail, where the velocity is consistent and high. As the wheel spins faster, the frequency of the electromagnetic interactions increases, ensuring a steady stream of power for onboard electronics. Beyond speed, the system's performance is governed by the quality of its components, specifically the magnetic field strength and coil architecture. Utilizing high-grade neodymium magnets creates a denser magnetic field, which ensures that even slight movements result in significant energy generation. Similarly, optimizing the coil design—by increasing the number of wire turns or using high-conductivity materials—allows the system to capture that flux more effectively. When these three variables (speed, field strength, and design) are synchronized, the harvester transforms from a simple experimental tool into a high-performance power plant capable of supporting complex vehicle monitoring systems.

Energy capture- the systems requires the integration of recifiers and storage elements. These components allow the energy to be collected. Hence, the efficiency of this capture is sensitive to external factors, it means the mechanical alignment and speed fluctuations must be carefully managed to maintain optimal output. The process of energy capture, particularly in kinetic or renewable systems, relies on a seamless conversion chain that begins with the integration of rectifiers and storage elements. Rectifiers serve as the critical bridge between raw generation and usable power, converting variable Alternating Current (AC) produced by mechanical movement into stable Direct Current (DC). This conversion is essential because most modern storage solutions, such as batteries or supercapacitors, require a steady DC input to chemically or electrostatically hold a charge. Without this precise electronic handshake, the energy harvested would be erratic, potentially damaging the hardware or dissipating as waste heat before it can be effectively "collected."

The efficiency of this capture process is inherently sensitive to the mechanical alignment of the generator. In systems like wind turbines or vibration-based harvesters, even a minor deviation in the physical axis can lead to significant friction losses or a reduction in electromagnetic induction. If the mechanical components are not perfectly synchronized with the magnetic fields intended to capture the energy, the system operates under "off-design" conditions. This misalignment creates parasitic loads that force the system to work harder for less output, effectively lowering the overall performance coefficient of the entire energy-gathering apparatus.

## 5. Conclusion

Following conclusion were taken from the available literature papers

- ✓ Sustainable power alternative- electromagnetic induction is taken as alternative to traditional power sources, significantly reduces the dependency on battery and maintenance in transportation and industrial sectors.
- ✓ Real life integration- system is feasible for day to day life applications, especially for self-powered systems like remote monitoring and sensors networks.
- ✓ Operational limitations- present challenges include decreased efficiency at low speeds and sensitivity to environment conditions.
- ✓ Optimization goals- future success depends on enhancing conversion efficiency, refining system geometry, and downsizing the hardware for easier integration into compact spaces.
- ✓ Hybrid Potential- Combining electromagnetic methods with other harvesting techniques (such as piezoelectric or thermal) is highlighted as a primary strategy to boost overall power output and system reliability.

## References

- [1] Hyunchul park, Jaehoon Kim “Electromagnetic induction energy harvester for high-speed railroad applications”, International journal of precision engineering and manufacturing- green technology, Volume-3, pp 41-48, (2016).
- [2] JavedEnayati, PedramAsef, “Review and analysis of Magnetic Energy harvesters: A Case study for Vehicular Applications” , IEEE Access journal, (2017).
- [3] Mbachu C.B, Uju I.U, Ezirim U.I “Electromagnetic Induction Technique for Generation of Electric Power from Electric car wheels for the charging of its stacked Batteries”, International journal of Engineering Inventions, Volume-12, Issue 4, pp 216- 225, (April, 2023)
- [4] Yiyang yang, Zhihaoke, Jingguo Bi, Zhengyan Li, Jun Zheng, Jun Zheng, Zigang Deng “Analysis of Electromagnetic force characteristics and wheelbase design of Maglev car based on double permanent magnet electrodynamic wheels”, Journal Applications of physics, (2024)
- [5] Hyunchul park, Yongjun Moon, Sejin Kwon “Development of rotational type of wheel-based electromagnetic induction energy harvester by using orthogonal array” Transactions of the Korean society of Mechanical engineers,B, Volume 37, Issue 2, pp 125-130 (Feb 2013)
- [6] Archisbasangar “System for driving spherical wheels using induction mechanism”, SSRN Electronic journal (March 20,2019)
- [7] Frederick David Tombe “Electromagnetism and the rolling wheel” (December 30,2019)
- [8] Keiji, T., “Summary and Recent Trend of the Energy Harvesting Technologies,” Automation Control and Instrumentation, Vol. 24, No. 9, pp. 46-51, 2011.
- [9] Cepnik, C. and Wallrabe, U., “Practical and Theoretical Limits of the Output Power of Electromagnetic Energy Harvesters at Miniaturization”, Proc. of the PowerMEMS, pp. 69-72, 2010.
- [10] Priya, S. and Inman, D. J., “Energy Harvesting Technologies,” Springer, 1st Ed., 2009
- [11] Behera, M. M. “Piezoelectric Energy Harvesting from Vehicle Wheels”, International Journal of Engineering Research & Technology (IJERT), 4(05) (2015).

- [12] Naik, N., Suresh, P., Yadav, S., Nisha, M. P., Arias-González, J. L., Cotrina-Aliaga, J. C., Bhat, R., Jalageri, M. D., Kaushik, Y., &Kunjibettu, A. B. “A Review on Composite Materials for Energy Harvesting in Electric Vehicles” *Energies*, 16(8), 3348 (2023).
- [13] Kobbi, M. D., Alombah, H., &Ngwa, M. M. “Energy Harvesting Technologies in Electric Vehicles and Applications in Sustainable Agricultural Transportation: A Review”, *REM (Renewable Energy and Mechanics)*, Vol. 7 No. 02 (2024).
- [14] X. Ma, A. J. Peyton, and M. Soleimani. Imaging Internal Structure with Electromagnetic Induction Tomography, Instrumentation and Measurement Technology Conference, Proceedings of the IEEE, 299-303, 2006.
- [15] H, L. Xiong, L. A. Xu. Electromagnetic tomography (EMT): Theoretical analysis of the forward problem, *Applied Mathematics and Mechanics*, Vol. 21, No. 9, 1034-1044, 2000.