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The State-of-the-Art of Electrification of Internet of Energy (IoE) for Electric Vehicles Considering Smart Grids

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أحدث التطورات في كهربة إنترنت الطاقة (*IoE*) للمركبات الكهربائية مع مراعاة الشبكات الذكية

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Abstract:
The electrification of the Internet of Energy (IoE) for Electric Vehicles (EVs), supported by smart grids, represents a transformative approach to addressing the challenges of integrating EVs into modern energy systems. As EV adoption accelerates globally, the strain on energy infrastructure and the need for sustainable energy solutions have become critical concerns. IoE, a digitalized and interconnected energy ecosystem, enables real-time communication, data exchange, and optimization of energy flows. When combined with smart grids, it facilitates advanced functionalities such as Vehicle-to-Grid (V2G) technology, dynamic pricing, and renewable energy integration. This integration not only enhances grid stability and efficiency but also transforms EVs into active participants in the energy network, capable of storing and supplying energy. Cutting-edge technologies like artificial intelligence, blockchain, and wireless charging are driving this evolution, offering benefits such as reduced carbon emissions, cost savings, and improved scalability. However, challenges such as infrastructure investment, interoperability, and data security must be addressed to fully realize the potential of this system. This article explores the state-of-the-art advancements, benefits, and future directions of IoE and smart grid integration for EVs, highlighting its pivotal role in shaping a sustainable and resilient energy future.

Keywords: The electrification, Internet of Energy, Electric Vehicles, Modern Energy Systems, Vehicle-to-Grid.

الملخص
تمثل كهرباء إنترنت الطاقة (IoE) للمركبات الكهربائية (EVs)، المدعومة بالشبكات الذكية، نهجًا تحويليًا لمعالجة التحديات المتعلقة بدمج المركبات الكهربائية في أنظمة الطاقة الحديثة. مع تسارع اعتماد المركبات الكهربائية عالميًا، أصبحت الضغوط على البنية التحتية للطاقة والحاجة إلى حلول طاقة مستدامة من القضايا الحرجة. يتيح إنترنت الطاقة، وهو نظام بيئي للطاقة رقمي ومترابط، الاتصال في الوقت الحقيقي، وتبادل البيانات، وتحسين تدفقات الطاقة. عند دمجه مع الشبكات الذكية، فإنه يسهل وظائف متقدمة مثل تقنية السيارة إلى الشبكة(V2G) ، والتسعير الديناميكي، ودمج الطاقة المتجددة. لا تعزز هذه التكاملات استقرار الشبكة وكفاءتها فحسب، بل تحول أيضًا المركبات الكهربائية إلى مشاركين نشطين في شبكة الطاقة، قادرين على تخزين الطاقة وتوفيرها. تدفع تقنيات متطورة مثل الذكاء الاصطناعي، والبلوكشين، والشحن اللاسلكي هذه التطورات، مما يوفر فوائد مثل تقليل انبعاثات الكربون، وتوفير التكاليف، وتحسين القابلية للتوسع. ومع ذلك، يجب معالجة تحديات مثل الاستثمار في البنية التحتية، والتوافق بين الأنظمة، وأمان البيانات لتحقيق الإمكانات الكاملة لهذا النظام. تستكشف هذه المقالة أحدث التطورات، والفوائد، والاتجاهات المستقبلية لدمج إنترنت الطاقة والشبكات الذكية للمركبات الكهربائية، مع تسليط الضوء على دورها المحوري في تشكيل مستقبل طاقة مستدام ومرن.

الكلمات المفتاحية: كهرباء، إنترنت الطاقة، المركبات الكهربائية، أنظمة الطاقة الحديثة، السيارة إلى الشبكة.

Introduction

The concept of the Internet of Energy (IoE) has emerged as a transformative solution, leveraging advanced technologies to create a seamless, intelligent, and interconnected energy ecosystem [1]. When combined with smart grids, the electrification of IoE for EVs represents a state-of-the-art approach to addressing these challenges [2], [3], [4], [5]. This article explores the latest advancements, benefits, and future directions of this integration. The rapid adoption of EVs is transforming the global transportation sector, driven by the need to reduce Greenhouse Gas (GHG) emissions and dependence on fossil fuels [6]. However, the widespread integration of EVs into existing energy systems poses significant challenges, particularly in terms of grid stability, energy management, and infrastructure scalability [7], [8]. The future smart grid is known as the Internet of Energy (IoE) due to its feasibility to plug and play the energy [9], [10]. The first scholar introduced the IoE is reported in [11], [12].

Additionally, the future smart grid is often referred to as the "Internet of Energy" It envisions a highly efficient and interconnected energy infrastructure that incorporates advanced technologies, such as sensors, communication networks, and data analytics, to optimize the generation, distribution, and consumption of electricity [13].

Similar to the Internet's ability to connect people and information globally, the Internet of Energy aims to connect various components of the energy system, including power plants, renewable energy sources, grid infrastructure, electric vehicles, and consumer devices [14]. This connectivity enables real-time data exchange, decentralized energy management, intelligent grid operations, and seamless integration of renewable energy resources.

By leveraging the Internet of Energy, the future smart grid can improve grid reliability, enhance energy efficiency, enable active participation of consumers, support greater adoption of renewable energy, and facilitate a more sustainable and resilient energy system. Some of the future prospects are listed in [15]. The main contribution of this article is providing a comprehensive review on internet of energy integration with renewables and electric vehicles as a smart grid used in order to transfer electrity to appliances through modern networks. The reming section of the article is structured as followes: Section 2 discussed the The Internet of Energy (IoE): A Paradigm Shift. Section 3 tabulated the Smart Grids: The Backbone of EV Electrification. Section 4 discussed the State-of-the-Art Technologies in EV Electrification. Section 5 show the Energy internet framework and standards communication, Section 6 summaried the details of Electric vehicle smart charging with RESs, additionally, Section 7 listed some of the Benefits of IoE and Smart Grid Integration for EVs. Section 8 tabulated the Challenges and Future Directions. Finally, the article closed by the summary of the Conclusion and list of cited recent literature from high ranked sources.

The Internet of Energy (IoE): A Paradigm Shift

The Internet of Energy (IoE) is an evolution of the traditional energy grid, where energy generation, distribution, and consumption are interconnected through digital technologies as illustrated in Figure 1 [16]. IoE enables real-time communication, data exchange, and automation across the energy network, creating a more efficient and resilient system. The main Key components of IoE are tabulated in Table 1.

Figure 1: Internet of Energy interconnected through digital technologies.

Table 1: Key components of IoE [17].

Key components of IoE	Explanation
Decentralized Energy Resources (DERs)	Solar panels, wind turbines, and energy storage systems that generate and store energy locally.
Advanced Metering Infrastructure (AMI)	Smart meters that provide real-time data on energy consumption and production.
IoT-enabled Devices	Sensors and actuators that monitor and control energy flows.
Artificial Intelligence (AI) and Machine Learning (ML)	Algorithms that optimize energy management and predict demand.

For EVs, IoE provides a framework for integrating vehicle-to-grid (V2G) technologies, enabling EVs to act as mobile energy storage units that can feed power back into the grid during peak demand as demonstrated in Figure 2.

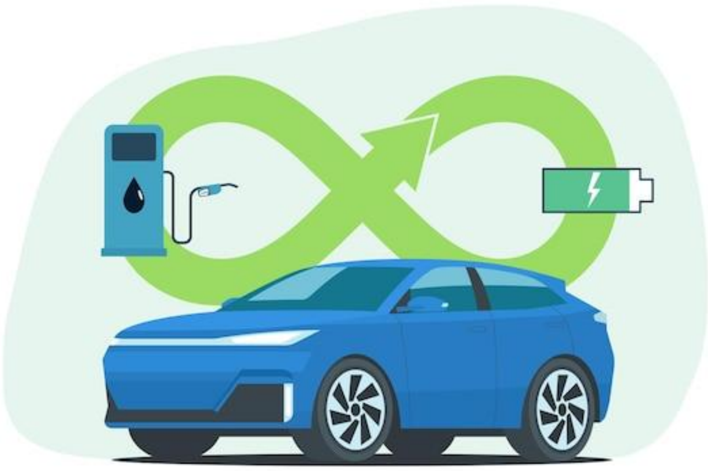

Figure 2: Vehicle-to-grid (V2G) technologies acting as mobility.

Smart Grids: The Backbone of EV Electrification

Smart grids are modernized electricity networks that use digital communication technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. For EV electrification, smart grids offer several critical functionalities as presented inTable 2. The integration of smart grids with IoE creates a synergistic relationship, where EVs are not just consumers of energy but active participants in the energy ecosystem.

Table 2: Modern smart grid networks with Internet of energy [18].

Smart grid networks	Explanations
Demand Response	Adjusting energy consumption in real-time based on grid conditions and EV charging needs.
Dynamic Pricing	Implementing time-of-use tariffs to incentivize off-peak charging.
Grid Balancing	Using EVs as distributed energy resources to stabilize the grid during fluctuations.
Renewable Energy Integration	Facilitating the use of solar and wind energy for EV charging, reducing reliance on fossil fuels.

State-of-the-Art Technologies in EV Electrification

Several cutting-edge technologies driving the electrification of IoE for EVs have been discussed in detailes as tabulated in Table 3.

Table 3: classifications of the electrification of IoE for EVs [19]

Classifications	Explanation
Vehicle-to-Grid (V2G) Technology	- V2G allows bidirectional energy flow between EVs and the grid, enabling EVs to store excess renewable energy and supply it back to the grid when needed. - This technology enhances grid stability and provides financial incentives to EV owners.
Blockchain for Energy Transactions	Blockchain technology ensures secure, transparent, and decentralized energy transactions between EVs, grid operators, and energy providers.
AI-driven Energy Management Systems	AI algorithms optimize charging schedules, predict energy demand, and balance grid loads, ensuring efficient use of resources.
Wireless Charging Infrastructure	Inductive and resonant wireless charging systems are being developed to enable seamless and convenient charging for EVs.
Edge Computing	By processing data locally at the edge of the network, edge computing reduces latency and enhances the real-time capabilities of IoE systems.

Energy internet framework and standards communication

The infrastructure of the energy internet is reported in [20] with five layers. The energy internet framework and standards communication refer to the set of protocols and guidelines that enable communication and data exchange within an energy internet system [21]. The energy internet is a concept that involves the integration of various energy sources, such as electricity, natural gas, and renewable energy, into a unified and interconnected network.

To ensure seamless communication between different components of an energy internet system, several frameworks and standards have been developed [22]. These frameworks define the structure and architecture of the system while the standards establish the rules and protocols for data exchange and interoperability. Some commonly used frameworks and standards in the energy internet domain includes the listed frameworks in Table 4.

Table 4: Frameworks and standards in the energy internet domain.

Frameworks	Remarks	Ref.
Internet of Things (IoT)	- IoT frameworks enable connectivity and data exchange between devices and sensors deployed in an energy internet system. - These frameworks help in collecting real-time data on energy generation, consumption, and distribution.	[23] [24]
OpenADR (Open Automated Demand Response)	- OpenADR is a standard that enables communication between electricity grid operators and energy consumers. - It allows consumers to adjust their energy usage in response to grid conditions, helping to optimize energy demand and supply.	[25]
IEC 61850	- This standard is used in the energy sector for the communication and integration of intelligent electronic devices (IEDs) within substations and power grids. - It facilitates real-time monitoring, control, and protection of power equipment	[22]
CIM (Common Information Model)	- CIM is an industry-standard that provides a common language and data model for exchanging information between different software systems in the energy sector. - It ensures interoperability between various energy management systems and devices.	[26]
IEEE 2030.5	- This standard focuses on the communication between distributed energy resources (DERs), such as solar panels or wind turbines, and the electric grid. - It enables seamless integration and control of DERs into the energy system.	[27]

These frameworks and standards play a crucial role in enabling efficient and secure communication within an energy internet system. They ensure compatibility and interoperability between different components, promote data exchange, and enable effective monitoring, control, and optimization of the energy network.

Electric vehicle smart charging with RESs

Electric vehicle (EV) smart charging integration with renewable energy sources refers to the process of optimizing charging times for EVs based on the availability of renewable energy [28]. This integration aims to minimize the carbon footprint of EV charging by ensuring that the vehicles are charged when renewable energy sources, such as solar or wind power, are generating electricity [29]. Some simplified explanations of the process as listed below.

1. **Monitoring renewable energy generation:** Power grids equipped with renewable energy sources are constantly monitored to determine the amount of clean energy being produced at any given time. This information can be obtained from smart meters or other monitoring systems.
2. **Matching EV charging with renewable energy generation:** EV charging systems are designed to communicate with the power grid and receive real-time updates on renewable energy availability. The charging system can then determine the optimal time to charge the EV, based on the amount of renewable energy being produced.
3. **Smart charging algorithms:** Advanced algorithms are used to schedule EV charging based on various factors, including the renewable energy generation, the desired charge level of the EV, and the availability of charging infrastructure. These algorithms aim to strike a balance between minimizing carbon emissions and meeting the changing needs of EV owners.
4. **Demand response programs:** In some cases, EV owners can participate in demand response programs, where they agree to adjust their charging patterns based on the needs of the power grid. This allows the grid operator to manage electricity demand more effectively, especially during peak usage periods.
5. **Energy storage integration:** To further optimize the integration of EV charging with renewable energy, energy storage systems, such as batteries, can be utilized. These systems store excess renewable energy during periods of high generation and release it during periods of low generation or high demand.

The integration of EV smart charging with renewable energy sources has several benefits [30], [31]. **Firstly,** it reduces the reliance on fossil fuel-generated electricity, contributing to a cleaner and more sustainable energy mix. **Secondly,** it can help reduce strain on the power grid during peak electricity demand, as EV charging can be shifted to off-peak hours when renewable energy is more abundant. This integration is a key step towards achieving a greener and more efficient transportation system, where EVs are charged using clean and renewable energy sources [32].

Benefits of IoE and Smart Grid Integration for EVs

The electrification of IoE for EVs, supported by smart grids, offers numerous benefits by redusing coats as shown in Table 5.

Table 5: Benefits of IoE and Smart Grid Integration for EVs [29].

Benefits of IoE	Features
Enhanced Grid Stability	EVs can act as distributed energy storage, absorbing excess energy during low demand and supplying it during peak periods.
Reduced Carbon Footprint	By integrating renewable energy sources and optimizing energy use, the system minimizes greenhouse gas emissions.
Cost Savings	Dynamic pricing and V2G incentives reduce energy costs for consumers and utilities.
Scalability	The modular nature of IoE and smart grids allows for seamless expansion as EV adoption grows.
Improved Reliability	Real-time monitoring and predictive maintenance enhance the resilience of the energy network.

Challenges and Future Directions

There are several challenges associated with the electrification of the internet of energy for electric vehicles (EVs) [33]. Some of the key challenges include:

Table 6: Challenges of internet of energy.

Challenges	Explanation
Infrastructure limitations	- One of the major challenges is the lack of adequate charging infrastructure. - Setting up widespread charging stations requires significant investment and coordination among various stakeholders. - Limited charging points can lead to longer waiting times and range anxiety for EV owners.
Grid capacity and stability	- The mass adoption of EVs can put strain on the power grid, especially if charging is not managed efficiently. - Peak charging times could create high demand periods, potentially leading to power outages or grid instability. - Ensuring that the grid can handle the increased load and implementing smart charging solutions are essential for the electrification of EVs.
Interoperability and standardization	- There are multiple charging standards and protocols available in the market, which can create compatibility issues. - Ensuring interoperability and standardization across different charging systems is crucial to enable seamless charging experiences and wide-scale adoption of EVs.
Energy management and optimization	- Integrating EV charging with renewable energy sources can pose challenges in terms of energy management and optimization. - Coordinating charging schedules with renewable energy generation peaks and valleys requires advanced energy management systems to ensure optimal utilization of clean energy
Data security and privacy	- The internet of energy for EVs involves the collection and exchange of data, including personal and vehicle information. - Ensuring robust cybersecurity measures to protect this data from unauthorized access and maintaining user privacy are significant challenges. - Protecting the energy network from cyber threats is a top priority
Affordability and accessibility	- EVs and the required charging infrastructure can be expensive, making them less accessible to individuals with limited financial resources. - Ensuring affordability and equitable access to electric mobility is essential for widespread adoption.
Policy and regulatory frameworks	- Developing and implementing supportive policies and regulations is crucial to accelerate the electrification of the internet of energy for EVs. - Clear guidelines regarding grid integration, charging standards, incentives, and subsidies can help overcome barriers and encourage investment and innovation. - Addressing these challenges requires collaborative efforts among governments, regulators, utilities, automakers, and technology providers. - Overcoming these obstacles is crucial to realize the full potential of EVs and their integration with the internet of energy.

Despite its potential, the electrification of IoE for EVs faces several challenges. There are several challenges and barriers to implementing electric vehicle (EV) smart charging integration with renewable energy sources as presented in Table 7.

Table 7: Challenges for EV with RESs [10], [34], [35], [36]

Challenges for EV with RESs	Features
Grid Integration	- Incorporating a large number of EVs into the grid can lead to increased demand and stress on the electrical infrastructure. - This requires careful planning and upgrading of the grid to handle the additional load.
Charging Infrastructure	- Expanding the charging infrastructure to meet the growing demand of EVs can be a challenge. - Setting up charging stations, especially in remote areas or densely populated urban areas, may require substantial investments and coordination with various stakeholders.
Variable Renewable Energy Generation	- Renewable energy sources like solar and wind are variable in nature, meaning they generate electricity intermittently.

	- Aligning EV charging with renewable energy availability can be challenging due to the unpredictable nature of these sources.
Energy Management and Load Balancing	- Integrating EV charging with renewable energy sources requires balancing the charging demand with the available renewable energy generation. - Intelligent energy management systems are needed to optimize charging patterns, prioritize charging when renewable energy generation is high, and adjust charging requirements based on the grid's needs.
Interoperability and Standardization	- Achieving interoperability and standardization between EVs, charging stations, and renewable energy systems is crucial for efficient integration. - This can be complicated due to different charging protocols, technologies, and EV models available in the market.
Policy and Regulatory Frameworks	- Policy and regulatory frameworks need to incentivize the deployment of renewable energy sources and EV charging infrastructure. - A supportive policy environment, including favorable regulations, financial incentives, and efficient permitting processes, can help overcome barriers to implementation.
Cost and Economic Viability	- Integrating EV smart charging with renewable energy sources may require significant initial investments. - The cost of installing renewable energy systems, upgrading the grid, and deploying charging infrastructure can be a barrier if not accompanied by cost-effective business models and financial mechanisms.
Consumer Awareness and Engagement	- Educating consumers about the benefits of EVs, renewable energy, and smart charging integration is essential for wider adoption. - Raising awareness, addressing concerns related to charging availability, and providing incentives can encourage consumers to actively participate in the integration of renewable energy and EV charging. - Overcoming these challenges and barriers requires a collaborative effort between government agencies, utility companies, EV manufacturers, technology providers, and consumers to create a sustainable and integrated system.
Infrastructure Investment	Significant capital is required to upgrade existing grids and deploy IoE technologies.
Interoperability	Ensuring compatibility between different devices, platforms, and standards is critical for seamless integration.
Regulatory Frameworks	Governments and policymakers must establish clear regulations to support the adoption of IoE and smart grid technologies.

The Internet of Energy (IoE) is a concept that integrates advanced digital technologies, renewable energy systems, and smart grids to optimize energy production, distribution, and consumption. It can be classified into several categories based on its components, applications, and functionalities. Here are the key classifications:

Table 8: Internet of Energy Integrate technologies [37], [38], [39], [40], [41].

Classifications	Types	Features
Based on Components	Energy Generation	- Renewable energy sources (solar, wind, hydro, geothermal). - Distributed energy resources (DERs) like rooftop solar panels and small-scale wind turbines. - Energy storage systems (batteries, pumped hydro, flywheels).
	Energy Distribution	- Smart grids with real-time monitoring and control. - Microgrids for localized energy distribution. - Advanced transmission systems (HVDC, FACTS).
	Energy Consumption	- Smart homes and buildings with IoT-enabled devices. - Industrial IoT (IIoT) for energy-efficient manufacturing. - Electric vehicles (EVs) and charging infrastructure.
	Digital Infrastructure	- IoT sensors and devices for data collection. - Cloud computing and edge computing for data processing. - AI and machine learning for predictive analytics and optimization.
Based on Applications	Smart Grids	- Real-time energy monitoring and management. - Demand response systems to balance supply and demand. - Self-healing grids to detect and resolve faults automatically.

	Energy Trading	- Peer-to-peer (P2P) energy trading platforms. - Blockchain-based energy transactions for transparency and security. - Virtual power plants (VPPs) aggregating distributed energy resources.
	Energy Efficiency	- Smart meters and energy management systems (EMS). - Predictive maintenance for energy infrastructure. - Optimization of energy usage in industrial and residential sectors.
	Sustainability	- Integration of renewable energy sources. - Carbon footprint tracking and reduction. - Circular energy systems for waste-to-energy conversion.
Based on Functionality	Monitoring and Control	- Real-time data collection from sensors and devices. - Remote control of energy systems for efficiency.
	Optimization	- AI-driven energy demand forecasting. - Load balancing and peak shaving.
	Automation	- Automated energy distribution and fault detection. - Autonomous energy trading and billing.
	Security	- Cybersecurity for protecting energy infrastructure. - Data privacy and secure communication protocols.
Based on Scale	Residential	- Smart homes with IoT-enabled appliances. - Home energy management systems (HEMS).
	Commercial	- Energy-efficient office buildings and retail spaces. - Smart lighting, HVAC, and energy monitoring.
	*Industrial	- Energy optimization in manufacturing processes. - Integration of renewable energy in industrial parks.
	Utility-Scale	- Large-scale renewable energy farms. - Grid-scale energy storage and distribution.
Based on Technology	IoT and Connectivity	- Sensors, actuators, and communication networks. - 5G and LPWAN for real-time data transmission.
	AI and Data Analytics	- Predictive maintenance and energy forecasting. - Machine learning for optimizing energy flows.
	Blockchain	- Decentralized energy trading platforms. - Transparent and secure energy transactions.
	Energy Storage	- Battery management systems (BMS). - Grid-scale storage solutions.

These classifications help in understanding the multifaceted nature of the Internet of Energy and its role in creating a sustainable, efficient, and interconnected energy ecosystem.

Conclusion

In conclusion, the electrification of the internet of energy for electric vehicles is an essential step towards a sustainable transportation future. It allows for efficient and seamless integration of electric vehicles into the grid, enabling benefits such as optimized charging, vehicle-to-grid capabilities, and smart energy management. This electrification will not only reduce dependency on fossil fuels but also pave the way for a reliable and resilient energy system. However, the successful implementation of the internet of energy requires collaboration among various stakeholders, including automakers, utilities, policymakers, and consumers, to ensure interoperability, scalability, and affordability. The electrification of the Internet of Energy for electric vehicles, supported by smart grids, represents a groundbreaking approach to addressing the challenges of EV integration into the energy system. By leveraging advanced technologies such as V2G, AI, and blockchain, this integration not only enhances grid stability and efficiency but also accelerates the transition to a sustainable energy future. As the world moves toward a decarbonized economy, the state-of-the-art solutions discussed in this article will play a pivotal role in shaping the future of transportation and energy.

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