# CONCEPTS, TECHNOLOGIES, AND FUTURE PROSPECTS FOR THE ENERGY INTERNET

**Abstract**

Significant difficulties have resulted from the climate change crisis, which is being compounded by the world's reliance on fossil fuels. Extensive electrification based on renewable energy sources is seen as one of the most potential growth options to tackle these issues in the medium to long term. In any case, this is real if and only if the power grid can handle increased use of renewable energy sources and distributed energy resources like batteries and heat pumps. A novel idea is needed to achieve the electricity generation goals based on renewable energy. In light of current developments in information and telecommunication network technology, the concept of the Energy Internet (EI) has been proposed. Many steps have been done recently to put the EI into practise. These EI models have a lot in common, and yet no one has settled on a single, definitive definition of the EI. Some studies have even offered protocols and designs, but there hasn't been any comprehensive look at the technology involved thus far. If we want to work towards a standardised version of the EI that will make it easier to deploy it around the world, we need to have a firm grasp on the technologies that underpin and encompass the existing and future EI. The paper begins by reviewing and critiquing the most common EI definitions seen in academic journals. The scientific literature is then divided into four categories, each of which represents a different perspective on the EI as shown through its definitions, assumptions, scope, and application domains. Then, we propose a new universal definition of the EI by bringing together the various existing definitions and concepts in light of the upcoming smart grid. We also pinpoint the fundamental technologies responsible for

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coordinating and controlling the many parts of a system, whether they are locally located or geographically dispersed. The study wraps up by outlining the most pressing problems that will need to be solved in order to implement an EI-based energy system in the future, as well as outlining the essential conditions that such a system must meet in order to achieve its goals.

**Keywords:** Smart grid, energy management, internet of things, communication, smart metering

## I. INTRODUCTION

As traditional fossil fuels become more difficult to get and as worries about the environmental effects of fossil fuel consumption grow, there has been a significant shift in recent years towards studying and developing alternative energy sources [1].

Historically, fossil fuels have been used extensively in the generation of electricity, leading to higher levels of carbon dioxide (CO2) in the atmosphere and other environmental problems.

Insufficient consumer participation, weak market mechanisms, and additional sustainability and economic difficulties are just some of the ways in which the conventional power grid slows down the transition to a more sustainable energy system [2].

In response to the growing popularity of "smart grids" and in light of the significant technological advances made by the "data" internet, the idea of a "energy internet" (EI) has been proposed.

The EI's conceptual beginnings were covered in the 2004 issue of the prominent publication The Economist. For instance, the "EI" intelligent grid takes advantage of internet-based technologies like real-time data, enhanced power line quality, and numerous sensors and micro-power sources to foresee bidirectional ow of (various forms of) energy and information. In the late 00's, researchers first began systematically using the EI as their primary variable. Tsoukalas and Gao, for instance, laid out the foundational principles, architectural specifications, and prototype implementation for what they called a "energy network" in the vein of the internet [3]. The main assumptions of an EI are summed up in, and they include things like smart metering infrastructure, load and price predictions, and virtual storage. Parallels between the internet and power grids were also studied in this paper. However, the authors did not conduct any assessments of the technology's major components or the necessary hardware, such as energy routers with plug-and-play capabilities [4-5].

The German Federal Ministry of Economics and Technology also launched E-Energy (Internet of Energy) about the same time. From generation to transmission to distribution and consumption, the E-Energy paradigm emphasises digitally integrated, sustainable energy systems enabled by information and communication technologies (ICTs) [6].

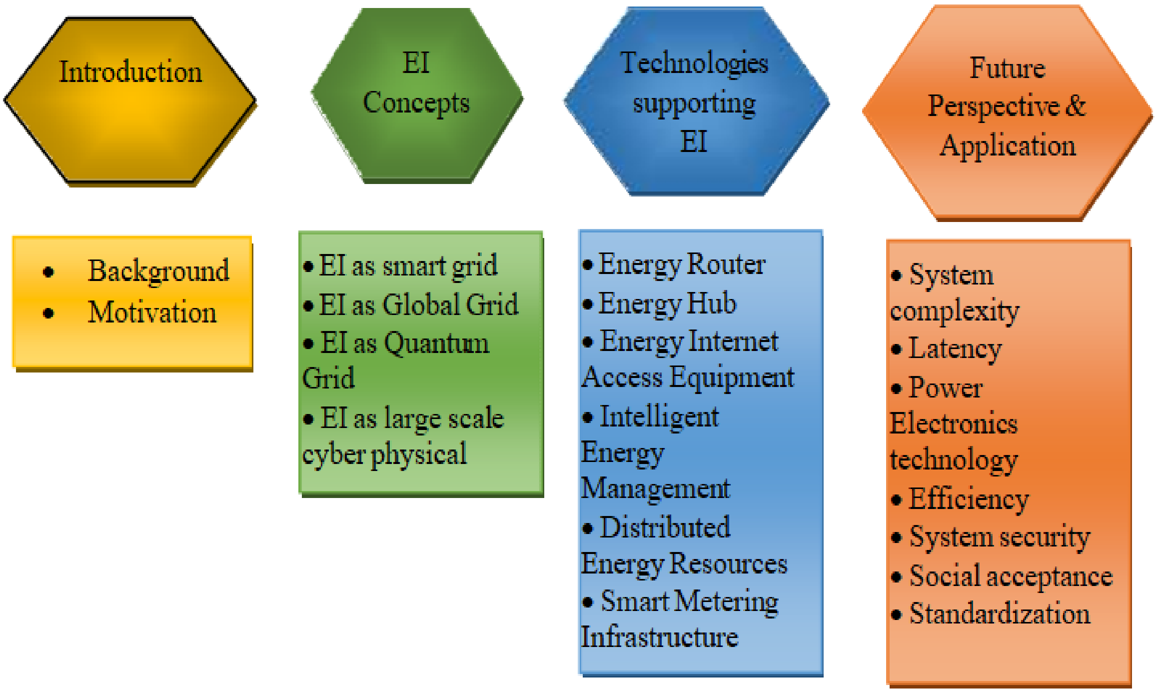


**Figure 1:** Brief summary of the review papers' organisation and the technical issues covered

The published papers' organisation has been addressed in figure 1. While early researchers like Cowan and Daim looked at EI through the lens of a smart grid, while earlier studies treated EI as part of the smart grid's enabling paradigm, more recent studies have begun to treat EI as a distinct paradigm. Examples of such literature include articles that highlight how smart grid technology differs significantly from EI [7].

The Energy Internet is a proposed framework for maximising the efficient collection, distribution, and management of energy sources using networked computing and communication systems. By connecting the smart grid to the web, the system's dependability is enhanced, and energy is used more efficiently. For the energy Internet to function and be managed effectively, a dependable and scalable information and communication infrastructure is essential. An energy router (ER) is a device similar to a communication router used to manage and direct electrical energy rather than data packets. This article provides a comprehensive overview of the development of the energy Internet, including its architecture, several kinds of ERs, and the advantages and disadvantages of implementing it. This study also provides a comprehensive overview of the various ER kinds' designs and architectures. The advantages of the energy Internet are highlighted, as well as the difficulties associated with implementing it on a large-scale distributed architecture that makes use of renewable energy sources. Future reliability and security assurances provided by the energy Internet are also discussed.

1. **The Development, Current State, and Global Context of the Energy Internet:** A day-ahead energy market was suggested as part of Energy Internet's operational plan to improve energy cell interaction [14,15]. To further optimise energy flow amongst energy prosumers, Si et al. [25] have developed an Energy Internet model. Gas and electricity were also possibilities. Energy market coupling model that includes both household and business prosumers. Hong et al. [19] have done similar work in China, investigating the

viability of multi-energy micro-grid models. The model has been used to show how the energy market may generate far more money than the conventional power company model. Next, Hua et al. [26] offer a deep reinforcement learning method for solving the optimum control issue, demonstrating how cutting-edge computer methods may be put to use in the Energy Internet.

Energy Internet was conceived by scientists in response to the rapid development of technologies like smart grids, home batteries, and vehicle-to-grid (V2G). Micro-grid architecture in the Energy Internet has been studied to determine the best way to make use of electric cars and their associated storage facility [19]. In addition, there has been a lot of research in the recent literature [27,28] on the evolution of blockchain technology and its potential to integrate with contemporary energy systems. This research dives at how Energy Internet, powered by blockchain technology, may put into action a power grid where batteries from EVs would be used to store energy. There are currently no operational versions of Energy Internet anywhere in the world, since the idea is still in its infancy. Smart grid infrastructure, a forerunner to Energy Internet, has been crucial in the electricity system transformations seen in many nations. Researchers all across the world are trying to come up with a unique Energy Internet for each country's power grid. While the term "Energy Internet" is most often used in the United States and China, it has been recognised by scholars all across the globe under several titles despite sharing many features. The names these nations have given to their envisioned concepts for the Energy Internet are shown in Figure 2.

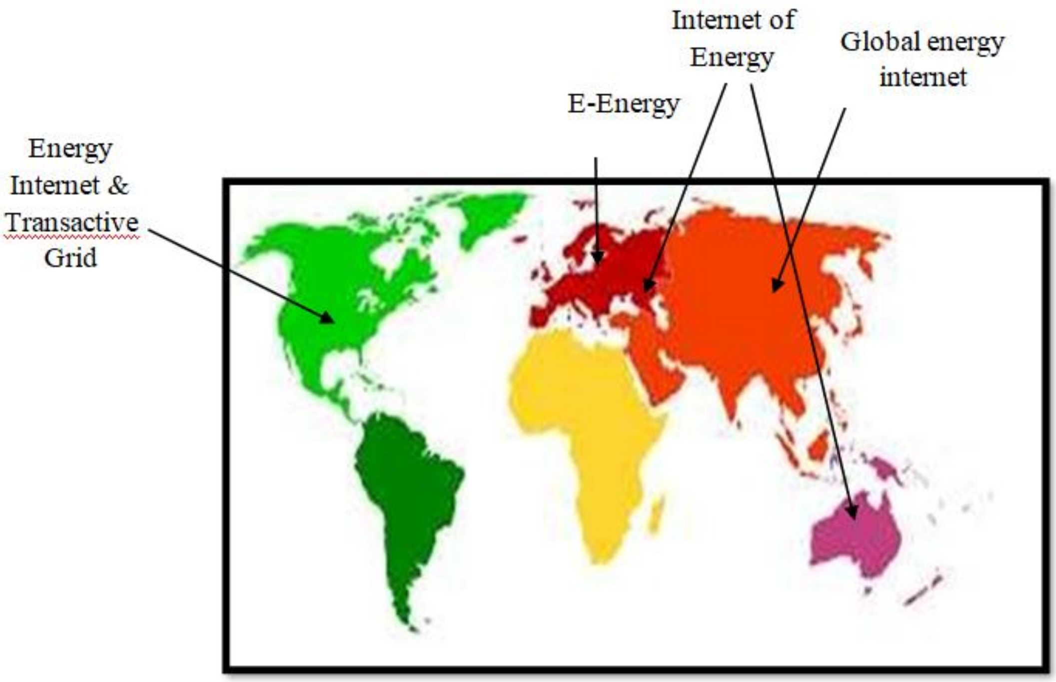


**Figure 2:** Energy Internet across the globe. Sources [19-24]

In the present energy consumption scenario, relying too heavily on fossil fuels like coal, natural gas, and oil to meet energy demands is a serious problem that has the potential to exacerbate both the depletion of traditional energy sources and the warming of the planet as a result of the greenhouse gases they produce.

Solving these problems requires creating an efficient and trustworthy energy utilisation regime and tapping into renewable energy sources including solar, wind, biomass, the ocean, and geothermal. Energy utilisation from DERs (distributed energy resources) is necessary since these unconventional energy sources are often dispersed over large regions.

2. **Energy Internet: Some Fundamental Ideas:** This section provides a high-level overview of many fundamental topics in the field of Energy Internet. Knowing these interconnected ideas is crucial for appreciating the commercial benefits and dissecting the technological advancements of the Energy Internet ecosystem.

- **Prosumer:** In 1980, Alvin Toffler coined the word "prosumer." It was first used to describe someone who straddles the line between being a consumer and a producer. The term "prosumer" has since acquired several ancillary meanings and applications.

  As can be seen in figure 3, fast advancements and widespread applications of distributed power generation and storage in the energy industry have enabled formerly passive energy users to become active participants in the energy value chain. Users of energy are no longer isolated, uninvolved bystanders in the Energy Internet ecosystem. Because of this, people will be both producers and consumers (thus the term "prosumer").

  In various countries, including Germany and China, a new Energy Internet business model based on leasing and crowd-financing for distributed wind power and solar power generation has evolved. There is a growing trend of consumer participation in the energy industry.

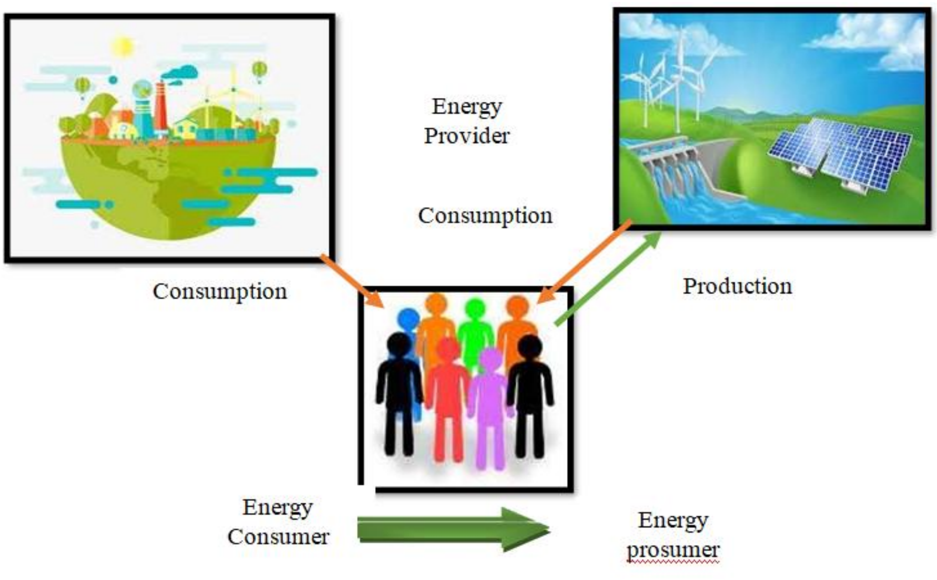


**Figure 3:** Energy Prosumer

- **Microgrid:** To provide electricity to consumers, a microgrid integrates many distributed energy resources (DERs). DERs can be anything from decentralised power plants to battery arrays. In a smart grid environment, it is an excellent backup power source for the primary power grid. Microgrids often combine traditional power plants with renewable energy sources like wind and solar, as well as distributed generators and storage devices including diesel generators, micro turbines, and fuel cells.

Microgrids often place low-voltage generators in close proximity to the loads they serve. Therefore, microgrid offers numerous benefits over the conventional huge main power system. several options exist for power generation, the system is reliable, several sources of power supply are available, and emissions are kept to a minimum.

- **Virtual Power Plant (VPP):** VPP is a novel energy system operation concept. This refers to the use of cutting-edge control, metering, communication, and other technologies to bring together a wide variety of decentralised energy resources (DERs), such as power plants, batteries, variable loads, electric cars, and more.

When applied to the coordination of many DERs, a more advanced degree of software architecture is more conducive to the most efficient setup and use of available resources. Instability flaws in various DERs may be remedied with the help of VPP engineering. As such, the VPPs may be compared to conventional power plants. It is predicted that by 2020, the total capacity of worldwide VPP would reach 28 GW, with residential photovoltaic systems and offshore wind farms contributing the vast majority. The pictorial presentation of VPP is given in figure 4.

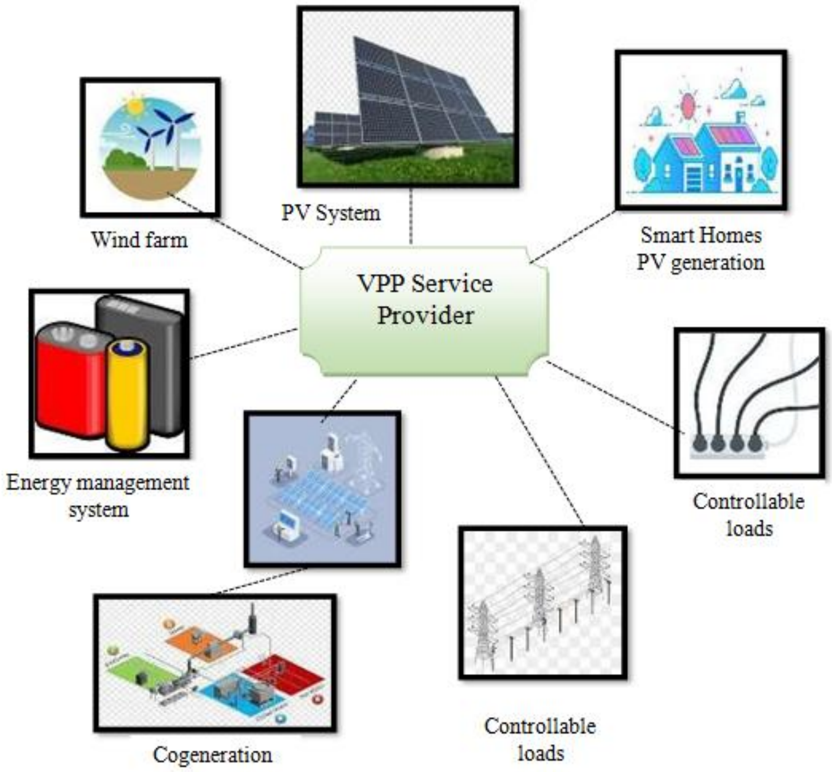


**Figure 4:** Structure of VPP

3. **EI Concepts:** There is no agreed-upon definition of what defines an EI, and scholars have approached the concept of EI from a wide variety of angles.

- **Smart Grid EI:** Over the past decade, most analyses have explained the EI by referring to the concept of a "smart grid." Some research classifies the EI as a web-based smart grid, while other research classifies it as a smart grid feature. Tsoukalas and Gao described EI as "an implementation of smart grids" in which "electricity flows from suppliers to clients like data packets do on the Internet." They examine the EI's assumptions, the needs for reorganising energy supply, and the basics of an energy network in the form of the internet [8-9].

  By drawing connections between the internet and energy networks, the EI is also viewed as an advanced form of smart grid, the pictorial view in presented in figure 5.

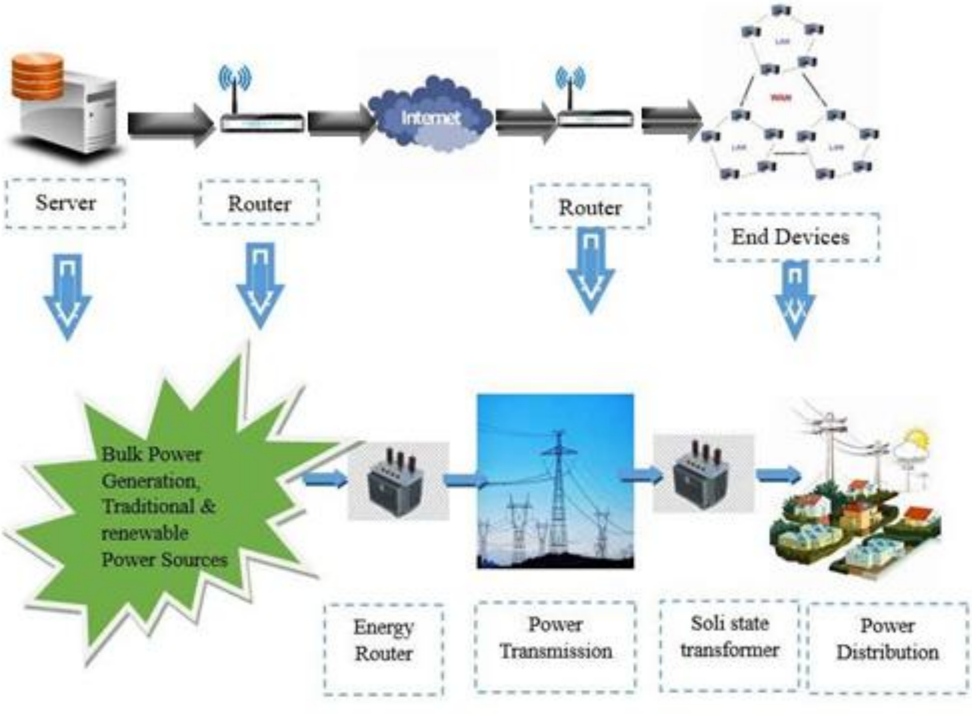


**Figure 5:** Analogy between electricity transmission through the internet and the electrical grid [10]

- **EI as a global EI:** In [13], Liu et al. investigate the EI as a global energy internet (GEI) and a "strong" smart grid on a much greater scale, both of which are attractive ideas. The GEI's goal is to link RERs all around the world [11].

  Solar, wind, hydro, and geothermal, guarantee the best possible administration and coordination of these assets, and guarantee a safe, sustainable, and environmentally friendly global energy infrastructure. The authors propose three areas for more study: the system dynamics model, simulation approaches, and multi-agent game theory. However, building a GEI is no small task and necessitates research into a wide range of topics, such as investment planning, investment decision making, international cooperation, and technical issues [11- 12].

- **EI as a Quantum Grid:** In [14], the EI is described in a novel way by placing it within the framework of a quantum grid (QR).

  The so-called quantum grid is analogous to the electrical power grid and incorporates internet-revolutionized communication. Like computers and other internet-connected equipment, power lines and nodes are also assigned unique IDs known as IP addresses [13]. Power nodes, also known as quantum grid routers (QGR), are vital for optimising and regulating the energy generating resources, such as distributed energy resources, bulk power generation, and consumption. The power plan, routing and control plan, and business strategy are the three pillars upon which the QR network rests. ICT links all of these methods together, letting QGR share data at different levels of abstraction via energy packets [14].

- **Conceptualising EI as a Global Cyber-Physical System:** When the various meanings of the EI are taken into account, it becomes evident that the EI is a broad concept that brings together numerous networks based on various forms of energy (heat, gas, electricity, etc.) onto a common ground for more efficient resource sharing and coordination. This has resulted in the EI architecture's development becoming increasingly complex and multidisciplinary [15]. We analyse the EI framework and its supporting technologies from the perspective of electrical network energy distribution and transactions.

- **E-router Types and Their Potential Uses:** Power grid intelligence is shown in the seamless connection between energy and data flows. To this end, smart grids [16] make use of state-of-the-art information, communication, and control technologies; the E-router is a prototypical piece of equipment that combines these technologies for use in the emerging energy internet. There are three distinct varieties of E- router, each catering to a particular set of technological requirements.

  The SST-based E-router in Figure 6 is used in the distribution network or the micro grid to convert between different energy types and voltage levels.

  In figure 7, the MPC-based E-router and the SST-based E-router have a similar implementation idea, although the latter is more often used in high-voltage distribution systems, such as those used in large commercial and industrial facilities.

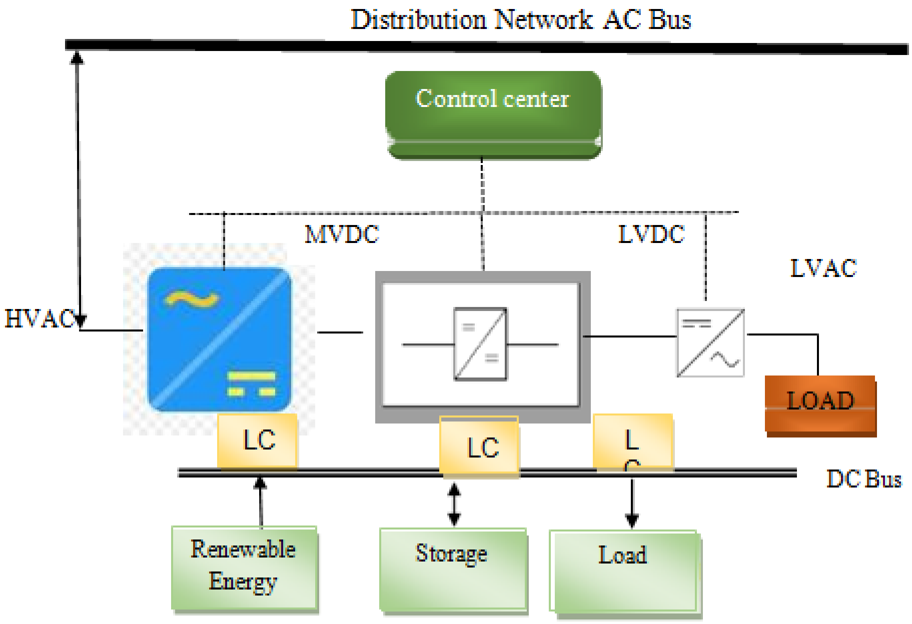


**Figure 6:** SST based E-router Micro Grid AC Bus

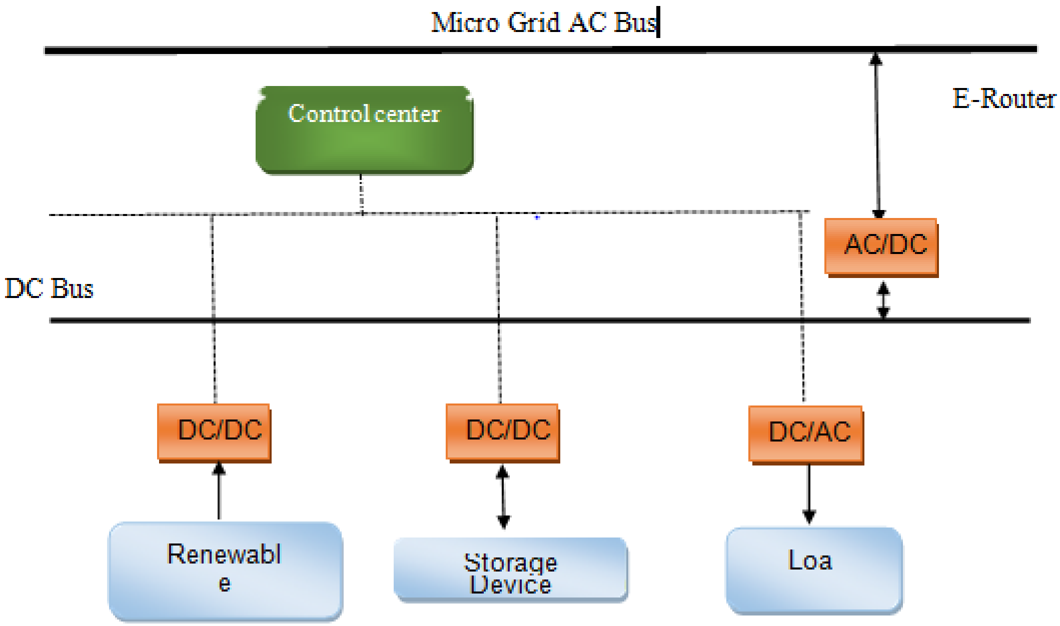


**Figure 7:** MPC Based E-Router

Energy Internet has a promising future due of the rising emphasis on distributed renewable energy systems, the integrability of developing technologies, and its applicability in energy sharing networks. This article introduces the Energy Internet as a potential evolution of a hybrid power grid by discussing its conceptual model, model structure through the introduction of a new concept called the Energy Intranet, and its processes in detail. Given the size of the potential payoff, we expect policymakers to make the necessary adjustments to the rules that will allow the Energy Internet to replace the current centralised electrical grid. Regulatory support for electric transportation, energy storage, electronic payments, and emerging technologies like blockchains and vehicle-to-grid is possible as a result of current efforts [17- 18].

## II. CONCLUSION

In this chapter, we have examined the existing scientific definitions and conceptual foundations for EI, classified them into broad categories, and proposed a new universal definition that does a better job of capturing the essence of the concept and its range of applications. Additionally, we have examined the technologies that support the EI paradigm and its applications. The steps that must be taken to realise our envisioned EI in its totality and as defined by us have been laid down. In conclusion, we have laid out the obstacles that must be removed in order for EI to become a mainstream technology.

The Energy Internet is envisioned as a network for the equitable distribution of energy in the near future. Advantages and new approaches to electricity generation and consumption may result from its qualities like plug-and-play simplicity and real-time bidirectional flow of energy, information, and money. Supported by cutting-edge innovations like the Internet of Things, vehicle-to-grid, and blockchain, Energy Internet connects diverse energy resources including solar panels, wind turbines, batteries, and electric cars to facilitate efficient power trading. Research in this area is vital, innovative, and relevant since there is currently no scaled-up functioning model of Energy Internet and literature is scant. In light of this, the following is an effort to define the basic components of an Energy Internet, describe its organisational structure, and explain how it would function.

Increased interest in decentralised renewable energy systems, the potential for Energy Internet to incorporate emerging technology, and its potential use in energy sharing networks all bode well for its long-term viability. This article introduces the Energy Internet as a potential advancement of a transitional electrical system through in-depth discussions on conceptual model, model structure by introduction of new concept called Energy Intranet, and mechanisms of Energy Internet. To replace the present centralised electricity system with the Energy Internet, we anticipate that legislators will make the required revisions to the rules. Regulatory support for electric transportation, energy storage, electronic payments, and emerging technologies like blockchains and vehicle-to-grid is possible as a result of current efforts.

There has been constant development in energy infrastructure throughout the past few centuries. Since the advent of electricity during the second industrial revolution, the energy systems have primarily. There are four phases: the primitive, the conventional, the dispersed, and the smart and linked. Energy Internet is a cutting-edge, fourth-generation energy system. To encourage further improvements in the energy system's business model and service model, this research has provided a fresh angle from which to view the economic benefits of the Energy Internet. But Energy Internet is in its infantile stage right now.

While the Energy Internet's precise road map remains hazy, the market potential and societal advantages of the concept are becoming increasingly evident.

At first, the concept of Energy Internet and its suitability as the next generation of electrical infrastructure are introduced. Second, Energy Internet's foundational ideas, frameworks, and capabilities are explained. Third, the term "Energy Intranet" is used to describe a more compact version of the Energy Internet that includes energy prosumers and regional energy markets. Finally, the Energy Internet's network architecture, the importance of new technologies, and the effectiveness of novel operational procedures are discussed.

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