Energy Reports 10 (2023) 3970–3992

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Review article

Recent advancement of energy internet for emerging energy management technologies: Key features, potential applications, methods and open issues

M.A. Hannan [a,b,h,*], Pin Jern Ker [b,**], M. Mansor [c], MS Hossain Lipu [d], Ali Q. Al-Shetwi [e], Sultan M. Alghamdi [f], R.A. Begum [g], S.K. Tiong [b]

[a] School of Engineering and Technology, Sunway University, Bandar Sunway, Petaling Jaya 47500, Malaysia
[b] Institute of Sustainable Energy, Universiti Tenaga Nasional, Kajang 43000, Malaysia
[c] Department of Electrical and Electronic Engineering, Universiti Tenaga Nasional, Kajang 43000, Malaysia
[d] Department of Electrical and Electronic Engineering, Green University of Bangladesh,1207 Dhaka, Bangladesh
[e] Electrical Engineering Department, Fahad Bin Sultan University, Tabuk 71454, Saudi Arabia
[f] Department of Electrical and Computer Engineering, King Abdulaziz University, Jeddah 22254, Saudi Arabia
[g] Department of Finance, UTS Business School, University of Technology Sydney, Ultimo, NSW 2007, Australia
[h] School of Electrical Engineering, Korea University, Seongbuk-Gu, Seoul 136-701, Korea

ARTICLE INFO

Keywords:
Energy distribution
Energy internet
Energy management
Energy storage
Electric vehicle
Renewable energy

ABSTRACT

This article deals with a thorough investigation of the energy internet towards future emerging technologies for energy distribution and management to solve existing limitations and enhance the performance of future sustainable energy. In consequence, a comprehensive review of energy internet features, applications, methods and existing issues and challenges are explained by developing arguments for future prospects. Key features of the energy internet such as energy sources, communication technologies, data computation, energy management systems and financial analysis are highlighted to enhance the energy efficiency, reliability, and security of the power network. Different energy internet application architectures and models are demonstrated for regulatory bodies under different dimensional concepts, networks, and layers. This article also explains the energy internet methods related to different programming approaches, artificial intelligence, and optimization algorithms for achieving granted reliability and enabling a decentralized energy market with a two-way energy flow. Furthermore, the present review focuses on the various issues and challenges of existing energy internet platforms related to safety, security, standards, protocols, costing and complexity as well as provides recommendations for future energy internet toward efficient energy distribution and management. Moreover, the study analyzes the impact of the energy internet on the conventional power grid and provides a global landscape of energy internet projects to make it more effective, dependable, and sustainable. All the highlighted insights of this review collectively inspire advancements in the energy internet platform for future energy data dissemination and management.

1. Introduction

The energy demand is increasing day by day which raises the consumption of fossil fuels significantly causing global warming and depletion in air quality problems (Bistline and Blanford, 2021;Bastida et al., 2019). To address these issues, many research works have been conducted to search for clean and alternative sources of energy (Reza et al., 2023). Hence, the demand for distributed renewable energy sources (RES) specifically solar and wind energy and related energy storage systems (ESSs) has received extensive consideration in recent years (Abu et al., 2023). However, the RES and ESS integration into the grid results in voltage, frequency fluctuation, grid synchronizations and power quality problems (Al-Shetwi et al., 2020; Hannan et al., 2020a). In recent times, the smart grid offers two-way flows of electricity and information in distributed energy sources through smart meters and sensors in real-time (He et al., 2017; Uludag et al., 2016). The execution of the smart grid is promising; nevertheless, it lacks in delivering an efficient form of energy when the power system has a high volume of

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* Corresponding author at: School of Engineering and Technology, Sunway University, Bandar Sunway, Petaling Jaya 47500, Malaysia.
** Corresponding author.
E-mail address: hannan@sunway.edu.my (M.A. Hannan).

https://doi.org/10.1016/j.egyr.2023.10.051
Received 5 August 2023; Received in revised form 1 October 2023; Accepted 14 October 2023

Table 1
The overview of the recently published survey articles.

Ref.	Year	Research focus	Research gap
(Mahmud et al., 2018)	2018	- The role of EVs in future smart grids is discussed - Challenges of integrating EVs into the grid - Reviews on EV technologies - Review on EV energy management schemes	The role and impact of EVs with the grid integration are discussed only.
(Wu et al., 2021b)	2021	- EI approach in achieving sustainability, efficiency, and digitization. - A three-layered framework encompassing energy networks, communication networks, and service management is introduced - A multidisciplinary perspective on EI's architecture, technologies, standards, services, and platforms is analyzed	While the abstract outlines a comprehensive study of the EI, a few key factors such as data security and socio-economic impacts of EI are not included.
(Ahmad and Zhang, 2021)	2021	- IoT in smart energy systems and networks. - Applications of IoT in the energy sector, including transmission and distribution, RE integration, and load demand management. - The benefits of incorporating Ei into EMS strategies for businesses, including potential challenges and drawbacks.	The detailed IoT framework is provided, however, the detailed description of EI methods and key features is missing
(Zhang, 2021)	2021	- The challenges and solutions for ensuring information security in the development of EI - The distributed energy station architecture under the EI environment is introduced - The implementation of information security protection for distributed energy stations, safety mechanisms and gateway security policies are discussed	A detailed description regarding information security is provided, however, the application of AI and discussion on the overall key feature of the entire EI framework is not included.
(De Oliveira Cavalcanti and Pimenta, 2023)	2023	- A systematic literature review is conducted on IoT applications in electricity management in buildings. - The factors influencing electricity consumption and management, presenting a conceptual framework that consolidates various aspects of energy use and real-time IoT-based monitoring are provided	The systematic review lacks a detailed comprehensive study on the features, methods and application of EI in the energy sector

loads leading to complexity and variability issues. In addition, the smart grid has limited flexibility concerning two-way electricity flows, scheduling, routing and resource utilization (Das et al., 2020; Reka and Dragicevic, 2018). Moreover, the traditional smart grid has also faced several challenges and issues such as; interoperability among various grid components, data handling and management across a wide geographic area with different environmental conditions (Hui et al., 2020). To overcome these limitations, the concept of energy internet (EI) is introduced which integrates the smart grid with new communication technologies (Shahzad et al., 2020; Wu et al., 2021a; Hemanand et al., 2021; Nižetić et al., 2020; Joseph and Balachandra, 2020a).

The EI is a basic platform that provides access, control and transmission of big data applications including different kinds of distributed renewable energy (RE), energy storage (ES) equipment and loads using the internet on a largescale level in a smart electricity grid (Yang et al., 2020). The EI has been a growing and emerging technology in recent years predominantly applied in electrical power industries for efficient consumption and conservation of various energy sources (Cheng et al., 2019). The EI is an intelligent system that integrates, manages and controls the distributed and scalable RES, electrical vehicles (EVs) and RES with a smart electricity grid through information and communication technologies (ICT) and energy routers (Wang et al., 2018). The EI aims to develop a secure, interconnected, efficient, and sustainable energy ecosystem by allowing for the seamless integration, monitoring, and management of multiple energy sources (Wu et al., 2021b). The EI is the solution to the energy crisis and environmental condition so it adopts RE, increases consumption and solves the incontinency between the supply of current energy and the demand of energy from generation to consumption (Lin et al., 2020a). The EI responds to the energy crisis by optimizing resource utilization, efficiently integrating RES, and adopting decentralized energy generation, thereby improving reliability and sustainability while lowering reliance on fossil fuels. EI develops a more robust and responsive energy infrastructure through real-time data analysis and smart grid management while minimizing the impact of energy shortages and emergencies. After RES, ESS is another important part of the EI (Du et al., 2018). The energy is stored in ESS through various devices such as a battery, flywheel, hydrogen, supercapacitors etc. If the consumers do not want to use this energy or any surplus amount of energy exists, then it could be sent back to the grid through EI. Afterwards, EI transmits the energy from ESS to consumers through energy routers (Golp?ra and Bahramara, 2020; Samanta et al., 2020). EVs and their charging stations are one of the types of ESS as they store the energy from RES and then transmit and distribute the stored energy to the places that need energy. EVs can also feed their energy back to the grid through the vehicle-to-grid (V2G) concept (Wang et al., 2020).

The concept of EI has progressively developed to achieve wide attention and become increasingly popular with noteworthy real-world advantages (Ahmad and Zhang, 2021). EI has tremendous potential that has led the paradigm to move from the conventional centralized energy system to a distributed energy system through the appropriate management and control strategies using various communication technologies (Zhang, 2021; xia Sang et al., 2021). The deployment of the EI is expected to provide huge opportunities towards the use of green and clean energy resources integrating with artificial intelligence (AI) methods, power electronics technologies and advanced ICT systems (Lin and Zhou, 2021; Jin and Zhao, 2021). Certainly, the EI platform with new features, emerging technologies, robust methods and energy management has provided great potential to convert the traditional electricity grid into an intelligent grid (Menck et al., 2014; Ren et al., 2021). A few significant survey articles have been published recently on EI and its application in the energy sector (Wu et al., 2021b; Ahmad and Zhang, 2021; Zhang, 2021; Mahmud et al., 2018; De Oliveira Cavalcanti and Pimenta, 2023). In Table 1, an overview of the recently published articles is provided.

However, the execution of EI still exists in the initial phase and there are numerous shortcomings such as security, stability reliability, scalability, congestion and pricing that make EI integrated system complex and vulnerable (Khatua et al., 2020; Miglani et al., 2020). Therefore, advanced research works are progressing on EI emphasizing the model development, planning methods, architecture, security, communication standards and protocols. There are potential opportunities and scope to improve EI infrastructure and communication technologies further. This review paper presents a comprehensive framework of EI for future electricity distribution and management systems in the smart grid. This research aims to comprehensively investigate the EI, its features, applications, and methods, with a focus on addressing existing limitations and improving the performance of future sustainable energy distribution and management. The key contributions of this review are summarized below:

- A comprehensive overview of the EI, including its features, applications, methods, and challenges are provided
- A detailed explanation of various key features of EI highlighting target, operation and benefits are presented.
- The potential applications of EI in various fields including microgrids, RE, ES, EV and buildings are provided.
- A detailed discussion regarding the methods, programming approaches, AI, and optimization algorithms, which are crucial for achieving reliability and enabling a decentralized energy market.
- The key issues and limitations are identified regarding cost, complexity, safety, security and reliability.
- A global perspective on the impact of the EI on the conventional power grid is presented by providing the landscape of EI projects worldwide.
- The future prospects and recommendations for the deployment and improvement of EI in various applications toward sustainable energy distribution and management systems are delivered.

The remainder of the paper is arranged into seven sections. Section 2 narrates the process of surveying methods. The key features of EI are outlined in Section 3. The various potential applications of EI are presented in Section 4. The EI methods and models are covered in Section 5. The key issues and challenges are explored in Section 6. The global landscape of the existing EI projects is outlined in Section 7. The future perspectives and concluding remarks are highlighted in Section 8 and Section 9 respectively.

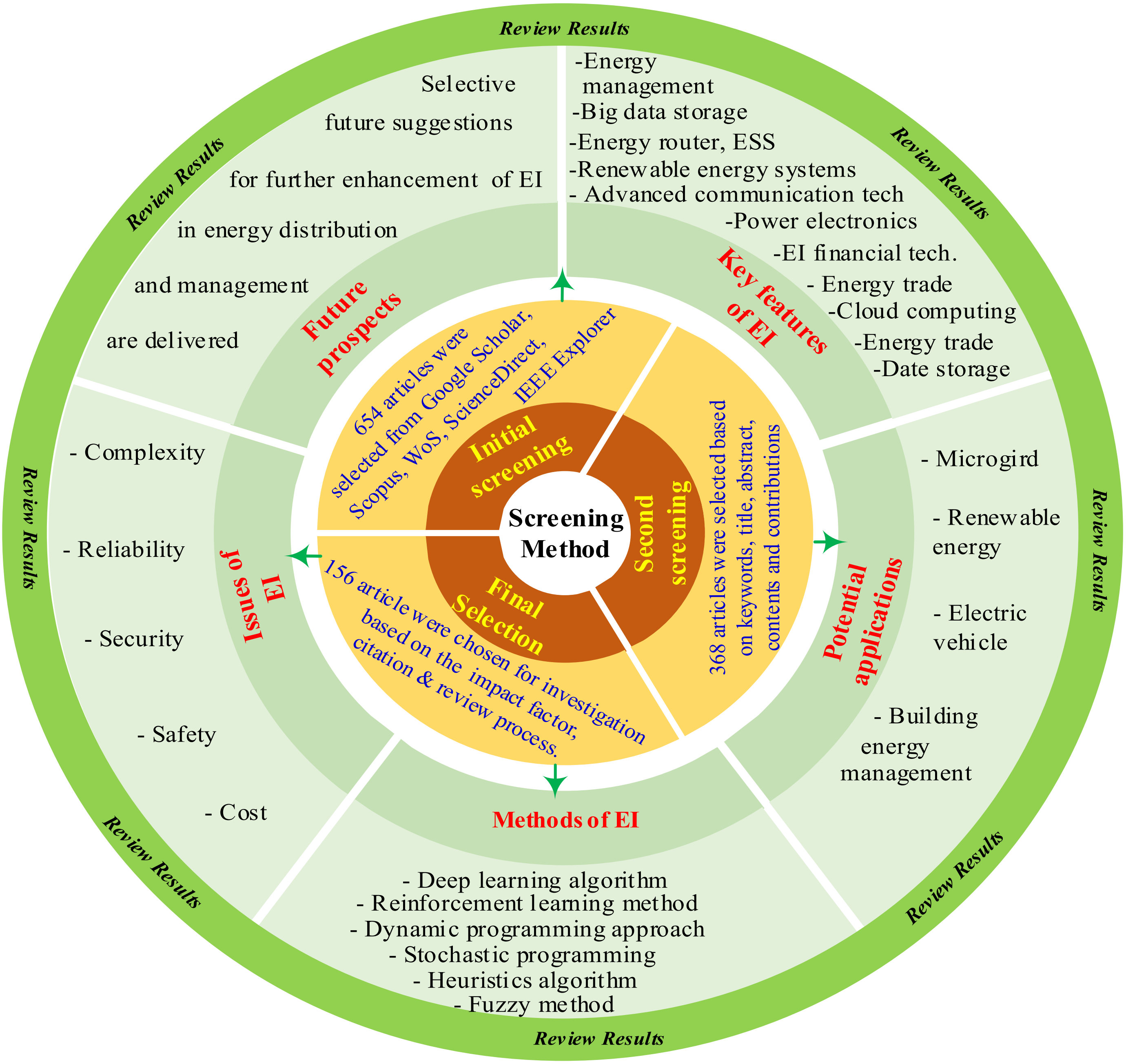


Fig. 1. Schematic illustration of the reviewing methodology.

2. Article selection methodology

The literature survey was conducted using different platforms including Google Scholar, Web of Science, Scopus, IEEE Explore and ScienceDirect. This survey adopts content analysis to extract the key information and conduct the analysis. Three screening and assessment phases were employed to select the relevant literature. Subsequently, a total of 654 articles were identified after the first screening as shown in Fig. 1. The article selection through the second screening phase was performed using the essential keywords including energy internet, energy router, renewable energy, energy storage, energy management, energy distribution, and electric vehicle. A total of 368 articles are found after the second screening in which the paper title, abstract, subjects, and contributions are evaluated to explore the relevant articles for this stage.

The final selection of the article is carried out using the impact factor, citations and review process. In sum, the review, analysis and critical discussion relating to EI-based energy management, distributions, and methods in different applications along with issues and challenges are conducted using the final filtered 156 articles. Several key findings were achieved through the three screening phases which can be divided into five groups including (*a*) the key features of EI were reviewed; (*b*) various potential applications of EI were highlighted; (*c*) different methods employed in EI were explored; (*d*) numerous open issues of EI were identified; and (*e*) the review has offered effective proposals for future advances of EI towards energy distribution and management.

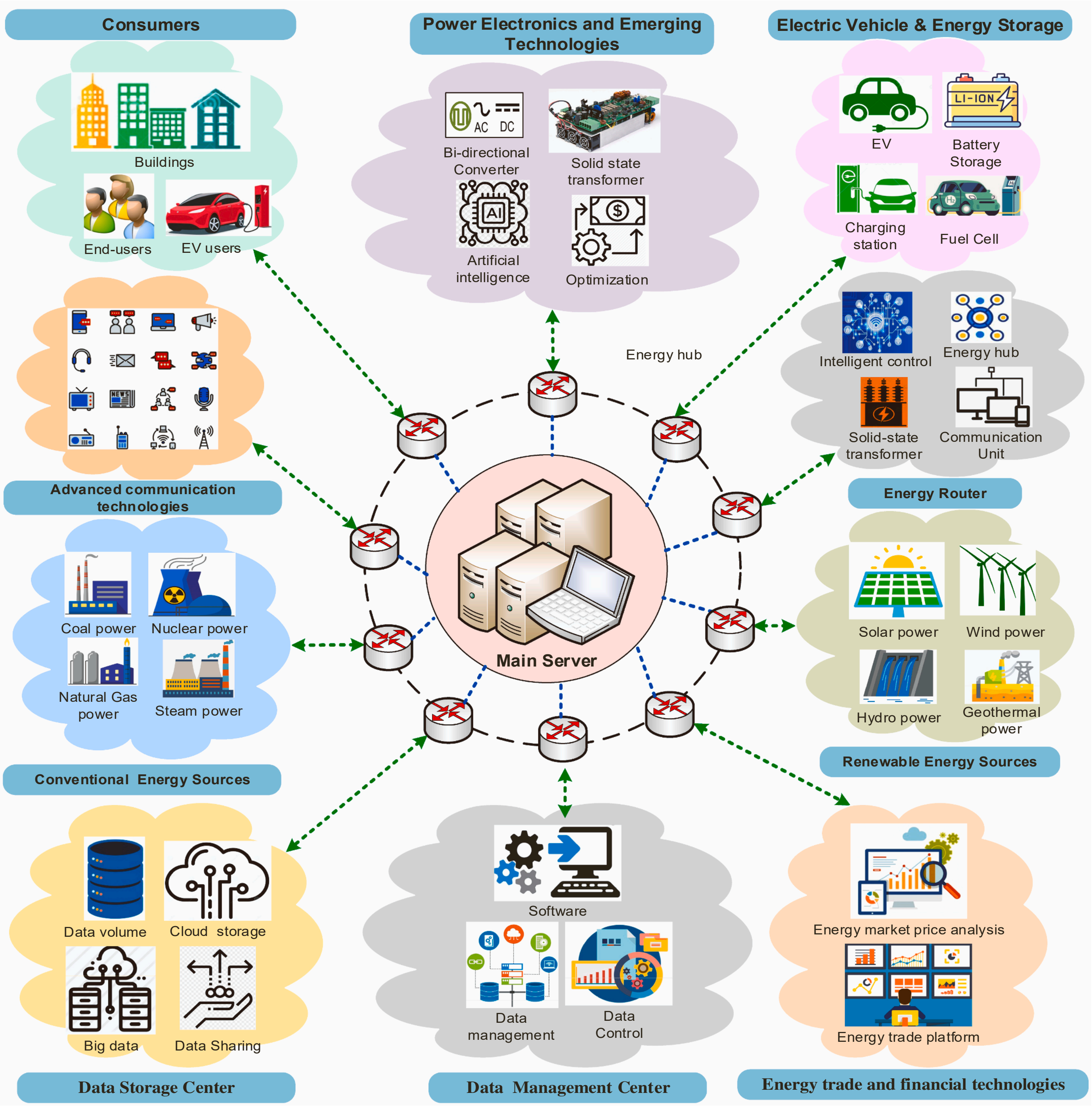


Fig. 2. EI framework with RES, EV, ESS, EMS, control, energy trade and emerging technologies towards a smart electricity grid.

Fig. 1 depicts the schematic presentation of the reviewing methodology.

3. key features of the energy internet framework

EI strives to increase energy efficiency and user satisfaction by optimizing the energy structure, adapting to a variety of new energy access, maximizing the benefits of various energy sources, and utilizing sophisticated technology to promote energy efficiency (Yang et al., 2020). The main features of the EI framework include the energy router, EV and ESS, RES, power electronics and emerging technologies, advanced communication technologies, EMS, data storage centre, energy trade, and financial technologies. These components collectively form the framework of the EI, resulting in an interconnected and dynamic energy ecosystem implied to improve energy sustainability, reliability, and efficiency. The EI is a fundamental platform for accessing, controlling, and transmitting big data applications, such as distributed renewable energy, energy storage devices, and loads, over the internet at a wide scale in a smart electrical grid, as shown in Fig. 2.

3.1. Energy router

The conventional power structure cannot handle the complexity of the energy system integrated with diverse loads, renewable energy, electric vehicles, and different participants in the network. Hence, the development of a "hub" component is necessary that can control and manage the energy flow and support the energy trading or exchange between the peers within the network. The energy router is considered the hub device of the modern power system which provides access for generation, transmission and consumption of energy (Guo et al., 2018). Generally, the energy router comprises a communication unit, an intelligent control system and a solid-state transformer (Guo et al., 2019a). Energy router connects, supervises, dispatches, communicates and maintains different energy units including microgrid, distributed energy generation and energy storage, as shown in Fig. 3 (Zeng et al., 2022). Also, the energy router coordinates the physical layer, information layer and operational layer as well as exchanges information among infrastructures (Gao et al., 2018). The router can enhance the system efficiency, reliability, and security of the power network through the optimization of energy usage by balancing supply and demand (Chen et al., 2019).

3.2. EV energy storage

Usually, energy storage is used to capture the energy generated at a particular period and then utilise the energy later, hence ensuring the smooth supply of electricity. There are different types of energy storage technologies being employed such as electrochemical, electromagnetic, thermal and mechanical (Khan et al., 2022). The conventional grid has a unidirectional energy exchange between generation and consumption (C-c et al., 2017). Nevertheless, the stored energy can be transformed into different forms as well as sent back into the system when needed and thus provide a two-way energy balance leading to more stability, reliability and flexibility of the power system (Lin et al., 2017). Energy storage devices can perform several versatile services in a grid system including enabling grid electricity in a well-coordinated manner with thermal, gas, cold, and transportation networks (Chen et al., 2019; Zhou et al., 2017). Besides, energy storage can support the EI in terms of reducing the intermittency problems of RES as well as obtaining peak load shaving, power quality management and frequency regulation (Zhou et al., 2017). The EV energy storage can serve a dual role in the Energy Internet (EI). When associated with the EI framework, EV energy storage can respond to real-time grid conditions, charging during low-demand periods and feeding surplus energy back to the grid during peak times (Mahmud et al., 2018; Sui et al., 2019). This bi-directional capability, known as V2G, enhances grid stability, supports RE integration, and enables demand response (Wang et al., 2022). Moreover, EVs can serve as distributed energy resources, contributing to a more resilient and sustainable energy ecosystem. To obtain the maximum

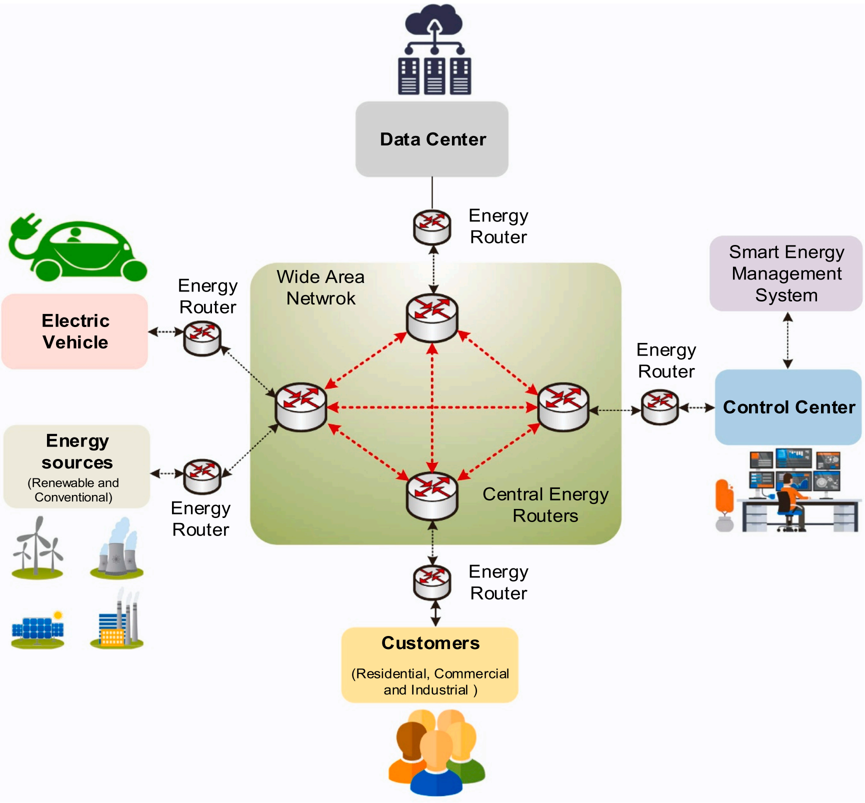


Fig. 3. The function of the energy router in the EI network (Kabalci and Kabalci, 2019).

benefits of EV integration in future smart grids with local renewable power, EI can play a critical role (Hannan et al., 2017).

3.3. Renewable energy sources

The EI is integrated with various renewable sources to achieve a stable and green environment (Wang et al., 2018). Renewable energy sources can be used for wide-scale power generation, production of heat and other applications. In recent decades, the deployment of RES has increased significantly due to the public interest, cost competitiveness, improved research and investment. RES exhibits several benefits such as high diversity, clean energy production and low or zero carbon emission (Bjørn et al., 2022). The successful implementation of EI needs a high percentage share of renewable energy in the energy mix (Li et al., 2020). Although solar photovoltaic and wind have become dominant in renewable power generation, they have shortcomings concerning intermittency, power quality and low intensity (Moness and Moustafa AM, 2015). Thus, more research works are required to promote RES technologies, power electronics technologies, and energy storage and control strategies.

3.4. Power electronics and emerging technologies

The EI needs proper interfacing and functionality of power electronic technologies interconnected with various RES and energy storage devices. Power converters, switching techniques and control schemes are important to achieve a secured and reliable power transfer from RES, and ESSs to the electrical load (Baharani et al., 2019). Nonetheless, power electronic technologies have limitations in terms of high switching loss, high components, slow dynamic response, high current stress, and computational complexity (Hannan et al., 2019). With the recent advancement in fabrication and design, silicon-based electronic devices such as SiC and GaN have resulted in a larger bandgap and enhanced switching properties in MOSFET, IECT, IGBT, IGCT, etc. The silicon-based devices offer attractive features including lower switch loss, higher operating current and voltage, higher frequency and lower volumes (Hamada et al., 2015). Besides, solid-state transformers and DC circuit breakers are the key power electronic technologies that can act as the energy coordinator of the DC power system through the appropriate coordination of the energy flow (Dong et al., 2019).

3.5. Solid-state transformer

Solid-state transformer (SST) is an emerging technology in EI that can convert low-frequency power to high-frequency power with suitable electronics converters and control circuitries (Hannan et al., 2020b). SST has many advantageous features including power flow control, voltage regulation, reactive power compensation, harmonic block, fault current limiting, galvanic isolation, and bi-directional power flow (Zhang et al., 2019). Because of reduced size and weight reduction, portability, and low installation cost, SST can be installed in certain inconvenient areas as well as applied for widespread distribution systems (Liserre et al., 2016). EI framework with SST can ensure a stable system operation by integrating distributed energy resources with ESS, increasing the power quality and efficiency (Costa et al., 2017).

3.6. Advanced communication technologies

The two-way exchange of communication in EI contains a huge workload and a large amount of information that needs to be transmitted at high speed (Geng et al., 2021). Thus, the EI needs advanced communication technologies to receive the information at a high quality and simultaneously send the information at a high speed while ensuring high efficiency and information safety (Wang et al., 2017a). There are various data processing modules and transmission protocols being employed in the EI platform (Motlagh et al., 2020). Arduino has easy implementation but suffers from powerful module capabilities and limited bit resolution. Raspberry Pi is an effective module but it lacks in having a real-time clock with a battery backup (Pawar et al., 2020). The programmable logic controller obtains satisfactory outcomes in controlling data; however, it has a limitation in handling large amounts of data. The microcontroller is energy efficient and reusable; nevertheless, it has programming complexity (Zeadally et al., 2020). Concerning transmission protocol, ZigBee is cost-effective and has low power consumption. Nevertheless, it has a signal interference issue (Varghese et al., 2019). Although Wi-Fi can transfer data at high speed, it has a limited coverage area (Khairy et al., 2019). Bluetooth has low power consumption and easily upgradable characteristics. Nonetheless, it undergoes authorization, authentication and encryption problems. GSM has a wide area coverage network with a low error rate. However, it has a weakness concerning data interruption and data connection (Prabhu Deva Kumar and Akashe, 2017). LoRa has been demonstrated as a powerful module due to its long-range data transmission but it has operational constraints in terms of network size which is limited by the duty cycle (Petrariu et al., 2021).

3.7. Energy management system

The execution of RES and various non-linear loads result in intermittency and uncertainty in the electricity grid (Chen et al., 2018). Hence, EI needs an energy management system to coordinate the various energy sources in achieving efficient operation and control of the energy generation, consumption and optimization (Golp?ra and Bahramara, 2020). Moreover, an effective energy management system enhances economic value and efficiency through the appropriate interaction or communication between different prosumers, consumers and producers. The operation of an energy management system could be either centralized or distributed subject to the producers/consumers of the system, supply/demand, and market strategies (Peng et al., 2022).

3.8. Data storage center

In a conventional energy system, most often the energy information and resources remain unused, thus resulting in poor efficiency in the grid electricity network (Zhou et al., 2016a). The deployment of EI with the efficient utilization and fusion of energy information helps in improving the development, and operation as well as optimizing the energy dispatch (Wang et al., 2017b). Big data platform under the EI environment not only keeps information related to various energy sources such as grid, RES, ESS, and EV but also social and economic related energy information concerning population, geography, and meteorology (Kaur et al., 2020). In line with that, it also provides details on data compilation, data preparation, investigation, and applications. Moreover, big data has a vast source of information that can help to build various business models by providing detailed reports about the various operating conditions of a power system and the specific requirements of every participant. The cloud computing concept in EI is essential not only to utilize big data but also to achieve value excavation that can turn information into wealth (Ismail and Materwala, 2018). Also, cloud computing technology assists any participant in sharing the computing power urgently (Yadav et al., 2018). Moreover, cloud computing has data processing capability using computing resources that can help to diversify the interaction between energy production and exchange (Guo et al., 2019b). Thus, cloud computing advocates the integration of all available computing resources to the cloud in an optimized way.

3.9. Energy trade and financial technologies

The successful implementation of EI depends on the formation of an efficient market strategy that can support several energy transactions and businesses (Motlagh et al., 2020). The energy trade platform aims to introduce different market structures into the energy system so that energy generation, transmission and distribution are coordinated based on real-time demand and requirement, thus improving energy utilization, accessibility and opportuneness (Sadeeq and Zeebaree, 2021). An energy trade platform technology can promote various energy market mechanisms by selling their properties and commodities (Rath and Tomar, 2020). Also, an energy trade program can help to transform the conventional power grid into energy service providers. Besides, a suitable energy trade policy can open up opportunities for various energy service providers to be presented and traded (Chen et al., 2022). Hence, the operation of EI needs real-time energy trade and clearance that can support and execute business activities efficiently.

Table 2
Summary of key features used in the EI platform.

Key features	Purpose	Operation	Benefits	Ref.
Energy router	-Control and manage the energy flow and support the energy trading -Energy exchange between the peers within the network.	-Connect, supervise, dispatch, communicate and maintain different energy units including microgrid, distributed energy generation and energy storage. -Coordinates the physical, information and operational layers and exchanges information among infrastructures	-Improve the system efficiency, reliability, and security of the power network	(Guo et al., 2018, 2019a; Zeng et al., 2022; Gao et al., 2018; Chen et al., 2019)
Energy storage	-Capture the energy generated at a particular period and then utilise the energy at a later time.	- Bidirectional energy balance leading to more stability, reliability and flexibility of the power	-Ensure the smooth supply of electricity. -Reduce the intermittency problems of RES. -Obtain peak load shaving, PQ, and frequency regulation	(Khan et al., 2022; C-c et al., 2017; Lin et al., 2017; Zhou et al., 2017)
Renewable energy	-Wide-scale power generation. -Reduce CO_2 emissions and mitigate climate change. -Improve energy security and economic development.	-Can be operated as stand-alone and grid-connected mode. -Achieve stable grid operation with suitable power electronics technologies, energy storage and control strategies.	- High diversity - Clean energy production - Cost competitiveness - Low or zero carbon emission	(Wang et al., 2018; Bjørn et al., 2022; Li et al., 2020; Moness and Moustafa AM, 2015)
Power electronics devices	-Achieve a secured and reliable power transfer from RES, and ESSs to the electrical load.	-Power conversion (AC to DC/ DC to AC/ DC to DC/AC to AC) and control through diodes, thyristors, MOSFET and IGBT.	-Lower switch loss. -Higher operating current and voltage. -Higher frequency -Low volumes.	(Hannan et al., 2019; Hamada et al., 2015; Dong et al., 2019)
Solid-state transformer	electricity grid into an intelligent grid	-Integrated with distributed energy resources with ESS, increasing power quality and efficiency. -Convert low-frequency power to high-frequency power with suitable electronics converters and control circuitries.	-Reduce harmonic -Limit fault current -Low volume -Low weight -Low installation cost	(Hannan et al., 2019; Hamada et al., 2015; Dong et al., 2019; Hannan et al., 2020b; Zhang et al., 2019; Liserre et al., 2016; Costa et al., 2017)
Advanced communication technologies	-Transmit a large amount of information at a high speed. -Ensure high efficiency and information safety.	-The data is monitored and analyzed through various data processing modules and transmission protocols such as Arduino, Raspberry Pi, microcontroller, ZigBee, Wi-Fi, Bluetooth, GSM etc.	-Cost-effective -Low power consumption -Transfer data at high speed -Wide area coverage network -Long-range data transmission	(Geng et al., 2021; Wang et al., 2017a; Motlagh et al., 2020; Pawar et al., 2020; Zeadally et al., 2020; Varghese et al., 2019; Khairy et al., 2019; Prabhu Deva Kumar and Akashe, 2017; Petrariu et al., 2021)
Energy management system	-Coordinate the various energy sources in achieving efficient operation. -Control and optimization of energy generation, and consumption.	-Can be operated in either centralized or distributed subject to the producers/ consumers of the system, supply/demand, and market strategies.	-Improve the economic value and efficiency through the appropriate communication between different prosumers, consumers and producers	(Golp?ra and Bahramara, 2020; Chen et al., 2018; Peng et al., 2022)
Big data	-Keeps information on RES, ESS, and EV. - Provides compilation, preparation, investigation of data, and application.	-Provide detailed reports about the various operating conditions of a power system.	-Improve the development, and operation as well as optimize the energy dispatch.	(Zhou et al., 2016a; Wang et al., 2017b; Kaur et al., 2020)
Cloud computing	-Utilize the big data and computing resources to diversify the interaction of energy production and exchange.	-Advocate the integration of all available computing resources to the cloud in an optimized way	-Support any participant in sharing the computing power urgently	(Ismail and Materwala, 2018; Yadav et al., 2018; Guo et al., 2019b)
Energy trade platform	-Promote the various energy market mechanisms by selling their properties and commodities.	-Use different market structures in the energy system to coordinate the energy generation, transmission and distribution.	-Support several energy transactions and business -Improves energy utilization, accessibility, and opportuneness	(Motlagh et al., 2020; Sadeeq and Zeebaree, 2021; Rath and Tomar, 2020; Chen et al., 2022)
Energy internet financial technologies	-Create a huge opening for the financial industries to come forward and explore their chances through different energy markets	-Develop a pathway for the establishment of various financial industries to collaborate and operate among themselves.	-Create vast opportunities for investment -Achieve high possibilities of profit and payback	(Palattella et al., 2016; Plazas et al., 2020; Zhou et al., 2016b)
Virtual power plant	-Incorporate the scattered capabilities of all the distributed energy sources to fulfil certain requirements in EI.	-Integrate different distributed energy sources such as RES, EV or large-scale energy systems through data processing, smart metering and communication.	-Improve the consumption of distributed energy resources. -Enhances the efficiency and cost-effectiveness of the system.	(Mahmud et al., 2020; Lin et al., 2020b; Fang et al., 2020; Thomas et al., 2019)

The implementation of Internet technologies has led to a revolution in the economic industry and financial technology (Palattella et al., 2016). The development of EI needs a large amount of expenditure which is a huge opening for financial services. Moreover, EI needs different energy market strategies in which financial industries can come forward and explore their chances. Besides, the progress of EI has created a pathway for the establishment of various financial industries to collaborate and operate among themselves (Plazas et al., 2020). In summary, the EI platform can attract numerous financial industries by creating vast opportunities for investment and achieving high possibilities of profit and payback (Zhou et al., 2016b).

3.10. Virtual power plant

Virtual power plant (VPP) technology incorporates the scattered capabilities of all the distributed energy sources to fulfil certain requirements in EI (Mahmud et al., 2020). VPP framework exhibits the key features and technologies including data processing, smart metering and communication, and thus could be utilized for integrating different distributed energy sources such as RES, EV or large-scale energy systems (Lin et al., 2020b). Also, VPP has significant impacts on energy markets concerning carbon trade, ancillary services, and so on. Moreover, VPP improves the consumption of distributed energy resources, hence helping the whole system to work efficiently and cost-effectively (Lin et al., 2020b; Fang et al., 2020; Thomas et al., 2019). The target, executions and advantages of various key features of EI are shown in Table 2.

The EI consists of an integrated set of components that collaborate harmoniously. The energy router optimizes distribution from RES and ESS. Power electronics and emerging technologies improve efficiency, while modern communication technologies facilitate real-time data transfer. The EMS manage the resources and controls the energy flow while integrating with financial technologies to ensure secure transactions. The data storage center aids data management and analysis whereas the EVs are becoming important contributors to grid stability. The energy trade mechanisms facilitate peer-to-peer trading. These integrated features constitute a responsive, efficient EI that will modernize energy management, sustainability, and consumption.

4. Energy internet applications

The EI is an energy management system that includes both traditional power grids and DG sources. The EI is created by combining information and communication technology with energy systems. It is made up of major components: energy systems, network systems, and communication technologies systems, all of which are linked via energy routers (Khan et al., 2022).

4.1. Energy internet in microgrid

The microgrid has an elementary feature in EI that operates both in islanded and grid-connected modes (Nasr et al., 2020). A microgrid energy management system (MEMS) is an essential tool for the microgrid, which takes the responsibility of cell units of energy internet

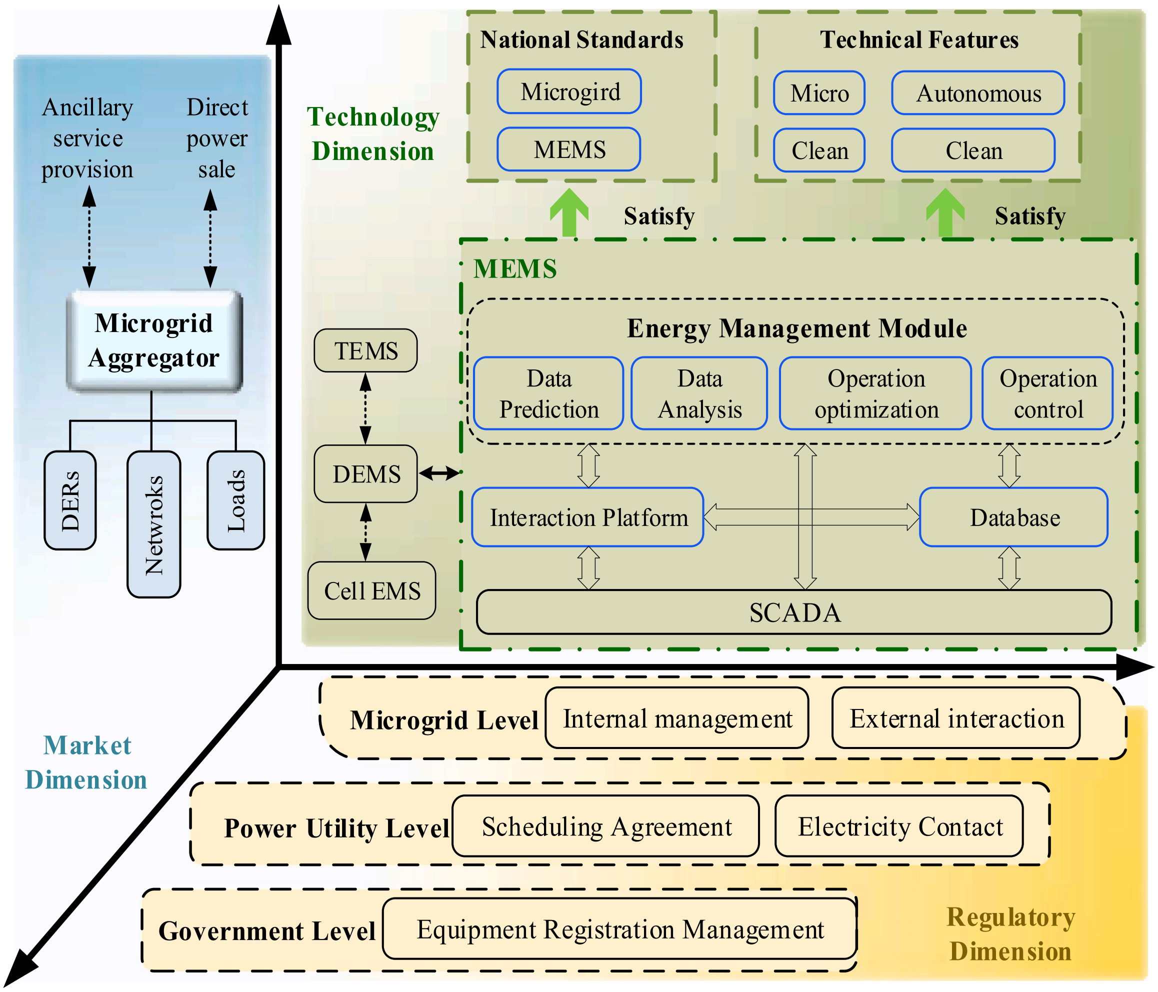


Fig. 4. The architecture of the microgrid energy management system in the EI platform (Hong et al., 2018).

(Leonori et al., 2020). The microgrid MEMS is the core element that monitors, makes schedules and controls all distributed energy resources (DERs) and electric vehicles (EVs) and other additional devices (e.g. protection devices) providing a secure and stable performance (Zia et al., 2018). The main objective of MEMs is to provide an economic operation of the microgrid by reducing its operating cost (Ahmadi et al., 2020). The architecture of MEMS in the context of EI is shown in Fig. 4. MEMS is classified into three dimensions such as technology layer, market layer, and regulatory dimension. In the technology dimension, the energy management module is responsible for data analysis, operation optimization, control, interaction, and SCADA that interconnects with the hardware equipment. The market dimension provides market-related functions such as direct power sales with nearby customers providing business promotion as well as creating opportunities to reform the power market and ancillary service providers. The regulatory dimension carries out various functions for regulatory bodies such as power utilities and governments in the aspects of scheduling agreements, electricity contracts and equipment registration management (Ahmadi et al., 2020).

4.2. *Energy internet in electric vehicles*

As the amount of CO_2 emission is increasing day by day, the world moves toward the deployment of renewable energy sources and wider adaptation of EVs (Hannan et al., 2019; Fan et al., 2017). In (Chen and Leung, 2020; Lam et al., 2017; Muratori, 2018), the V2G system is proposed in which the smart grid uses the energy storage of EVs and allows EVs to feed their batteries stored energy back to the grid as needed. In (Liu et al., 2019a), an EI-based method for optimal management and allocation of logistics resources for dynamic optimization of vehicles and tasks is proposed. The author in (Yi et al., 2016) proposed a novel model of EV internet energy that uses EVs and charging stations to transmit, distribute, and store energy from renewable energy sources to places that need the energy. The concept of EV energy internet is based on the EVs that act as a transmitter to adopt energy from renewable energy sources (wind or solar) and then transfer to such areas that need energy e.g. charging stations and houses. The schematic diagram of an EV energy internet is divided into two layers as shown in Fig. 5.

The lower layer is known as a physical EV transportation network that consists of three parts energy generation, energy transmission, and energy consumption. The energy generation has renewable generation units. Energy transmission has EVs and charging stations for EVs. The users that need energy are in energy consumption. The upper layer in Fig. 5 is an EV energy internet that shows the logical view of the physical EV transportation network in which the charging stations acts as energy router while the EVs work as an energy or data packet that transmits from the energy router and receives by the user that needs energy.

4.3. *Energy internet in renewable energy*

The EI combines the new energy technology and information that fulfils the efficient utilization and intelligent management of large-scale RES (Wang et al., 2018; Hussain et al., 2019). EI efficiently manages the

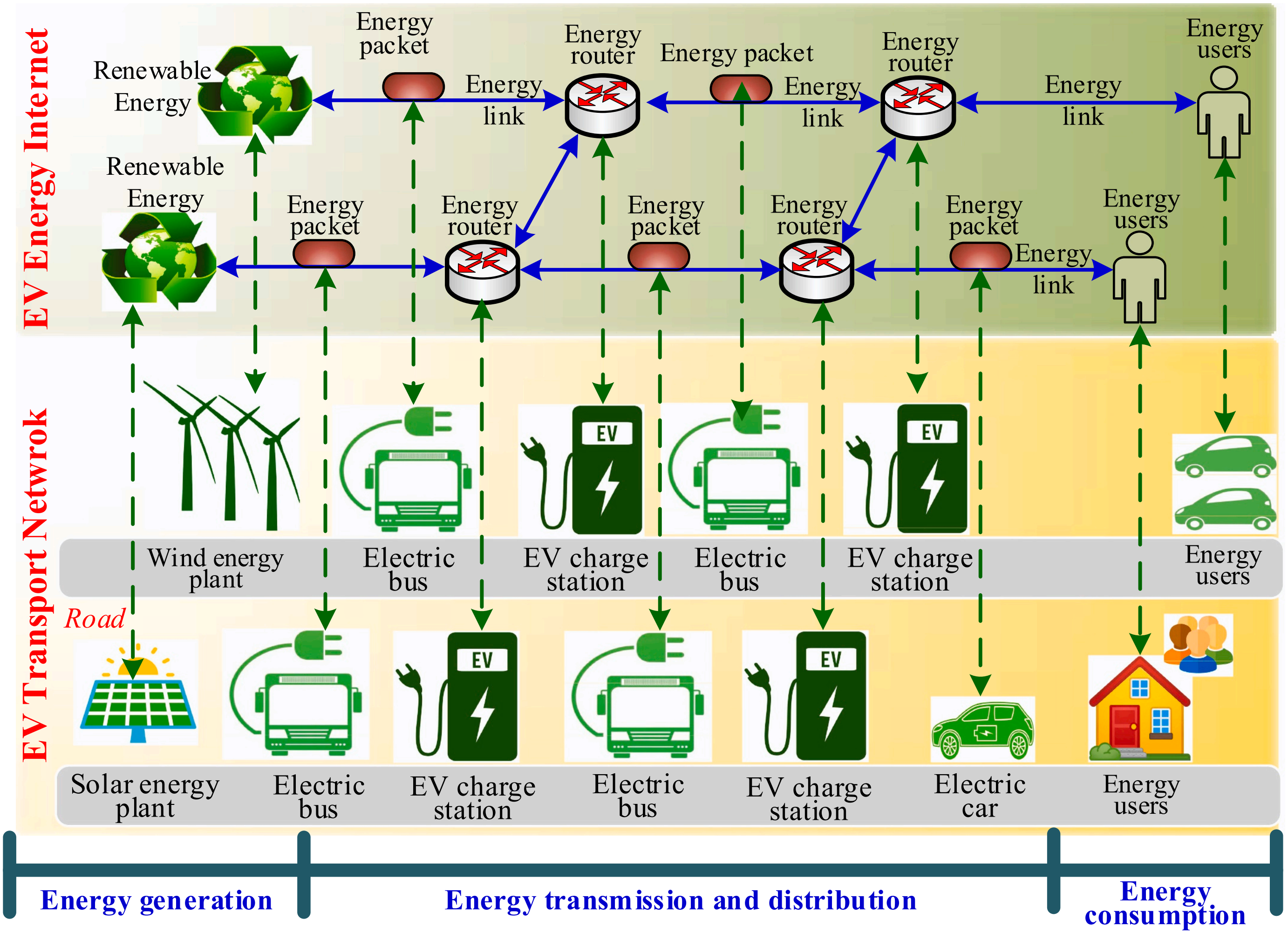


Fig. 5. Electric vehicle in IOE architecture (Yi et al., 2016).

dual flow energy information when it controls the various energy flows including electrical energy, electromagnetic energy and thermal chemical energy (Cao et al., 2018). Furthermore, it shares the energy peer-to-peer between the grid and energy management system for monitoring and controlling power generation units (Kusakana, 2020). Although the main energy source of EI is the RES, it faces two potential problems. Firstly, the unified energy management system is not suited for large-scale grid-integrated RES under different geographical locations due to the intermittent and uncontrolled nature of the RES output (Saba et al., 2021). Secondly, the centralized information management system has the main issues related to data acquisition, data storage and data transmission because of the numerous intelligent devices and high growth of energy data in EI (Strielkowski et al., 2019). The main problem in EI architecture is related to the method in which the RES can be safely and steadily connected to the EI for real-time energy sharing and efficient management. In (Du et al., 2018) proposed the hierarchical integration of RES architecture with the EI, as shown in Fig. 6.

In (Du et al., 2018), the architecture is divided into three layers; the E-edge layer, regional E-fog layer and cloud layer. The e-edge layer is the most basic energy unit which is the part of the demand side and the supply side of energy in the EI. In the E-edge layer, the E-microgrid is a dual flow management centre that is responsible for managing each E-edge unit's external energy demand and supply. It can work in the grid-connected mode and simultaneously store information connected with the E-edge units. In the E-fog layer, the independent power generation system (IPGS) may comprise a considerably large power generation unit or power plant that is connected to E-fog to ensure stable and safe operation. The E-fog layer is defined as a regional control center with a dual flow of information and it is tasked to provide geographically proximal E-microgrids. Similar to the E-microgrid of the E-edge layer, it is connected with a more demanding and resourceful control centre and data storage infrastructure or facility. It supplies power and energy to territorial demand sides which are of larger scale such as factories, EV charging stations, skyscrapers, etc. Lastly, the cloud centre controls the scheduling of power and interconnection of power and energy between E-fogs. In the cloud control centre layer, it only processes the information and interacts with information with others. Cloud centre ensures the balance between supply and demand, provides the monitoring of the power grid, and the maintenance and the security and protection of the network. The responsibility of territorial energy distribution and coordination is also ensured by the cloud centre. EI architecture solves the problems due to the large-scale connection of the RES grid and also resolves the dynamic usage and real-time issues related to the distributed RES. This architecture is established on the concept of peer-to-peer and open information and energy or power integration.

4.4. Energy internet in building energy management

EI-oriented building energy management (BEMS) is significant in minimizing energy consumption and CO_2 emissions. The target of energy conservation is achieved by exchanging information on energy supply and demand (Luo et al., 2020). Several researchers have proposed zero energy building (ZEB) to optimize the cost, economy, and energy consumption of renewable sources (Wu et al., 2018). The result illustrates that ZEBs are the solution to fulfil the objectives related to efficient energy management, control and energy cost reduction (Bourrelle, 2014). The feasibility of net-zero energy building (nZEB) is investigated from the technical, economic, environmental, and social perspectives. The study demonstrated the benefits of nZEB over conventional buildings with regard to carbon emissions and cost savings (Cano et al., 2014).

In Europe, several EI-based BEMS have been introduced employing various modelling, energy consumption and management techniques as well as smart energy-efficient middleware for public spaces (SEEMPubS) projects. The SEEMPubS is applied to historical buildings using computer-based energy management and control systems (Salerno et al., 2021). The BMES integrated with the EI platform is shown in Fig. 7

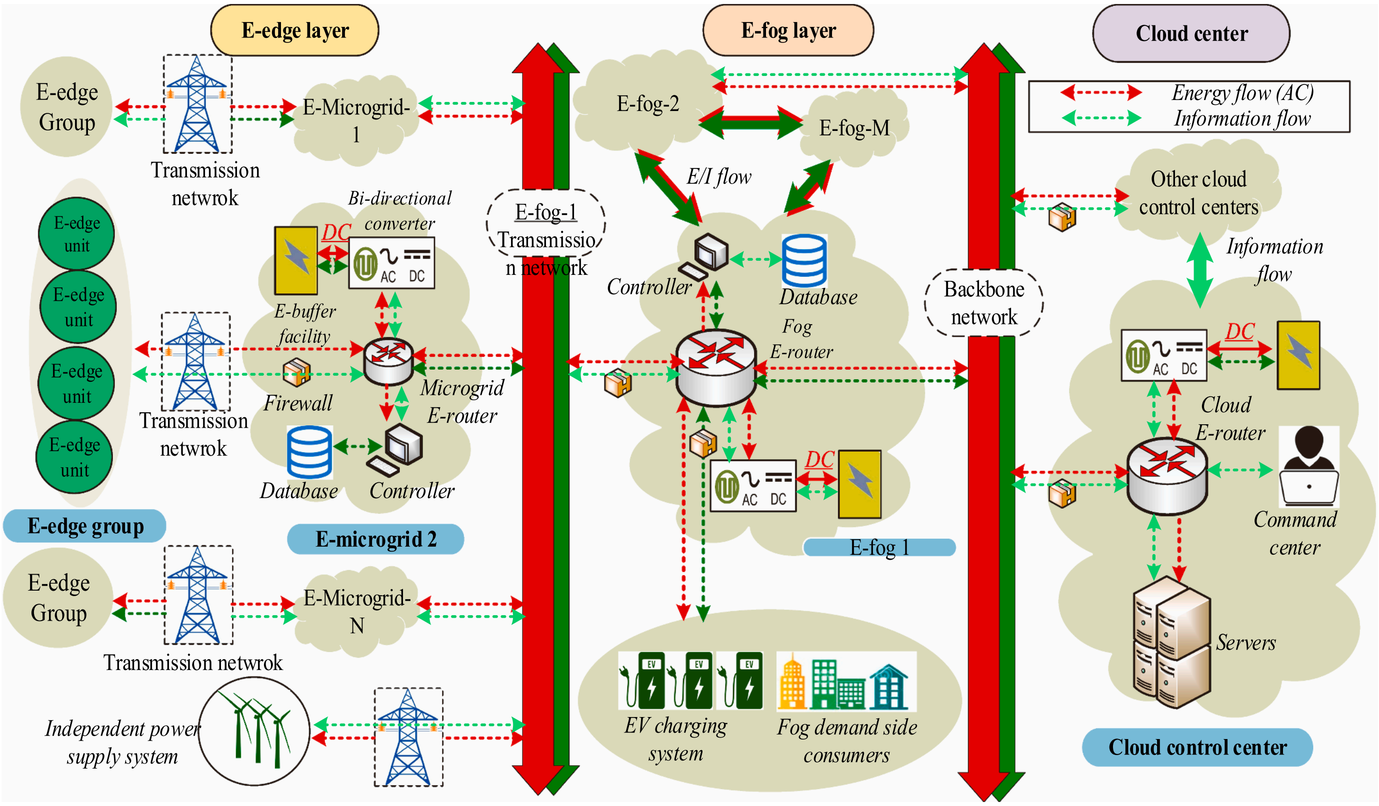


Fig. 6. Renewable energy integration in IOE architecture (Du et al., 2018).

where EV, solar energy, wind energy, hydroelectric energy and natural gas power plants are connected to the main grid. The appropriate power exchange, balance and control are carried out using a grid management system and accordingly, the information is transferred and stored in the cloud storage and internet centre for future analysis.

5. Energy internet methods

Recent methods have been developed for the advancement of EI applications for electricity distribution and management systems and efficiency improvement. These methods include the thermo-electric decoupling method to manage the distributed energy systems (DES) with wind power and solar power; DES with wind power and fuel cell power; and DES with wind power, solar power, and fuel cell. The method of battery charging and discharging model for peak load shifting based on IE has also been developed to address the peak load shifting problem. Recent approaches such as the neural network approach for energy management issues, reinforcement learning method, deep learning algorithm, heuristics algorithm, and others have been developed and consequently described in detail in the following subsections.

5.1. Thermo-electric decoupling method

Distributed energy systems (DES) have many types such as DES with wind power and solar, DES with wind power and fuel cell, and DES with wind power, solar, and fuel cell (Hou et al., 2021). Since DES becomes an issue of energy, the existing system evaluation methods are mainly created for a single energy system. The flow and topology of energy in a single graph are difficult because the composition and structure of EI-oriented DES are complicated. In (Perera et al., 2021), the single-layer bus structure could easily balance energy equations and equipment constraints for different power supplies, such as electricity, heat, energy storage and cooling-heat-power conversion devices. However, the grid is simplified into a single layer, the electric and heat bus have different transmission characteristics and their network losses are not well analyzed, thus it cannot meet the requirement of the precision of the model. Therefore, the two-layer bus structure is developed based on the thermo-electric decoupling method, which separates the electric and heat systems as shown in Fig. 8. According to (Perera et al., 2021) the balance equations and constraints of the external electric bus and the internal bus model are expressed as below,

$$P_{grid} + P_{PV} + P_{WT} + P_{pgu} + L_E + P_{ES} + P_{EC} + P_{loss} = 0 \tag{1}$$

$$Q_{PGU\eta WH} + Q_{boiler} + L_{heat} + Q_{ES,heat} + Q_{loss,heat} = 0 \tag{2}$$

$$f(X, \mu, P) = 0 \tag{3}$$

$$h_{\min} \le H(X, \mu, P) \le h_{\max} \tag{4}$$

where $P_{grid}$is grid exchange power, $P_{PV}$is the PV output power, $P_{WT}$is the wind turbine output power, $P_{pgu}$is the output power from combined heat and power (CHP) unit, $L_E$is electrical load, $P_{ES}$is the exchange power from energy storage, $P_{EC}$is the electric chiller consumption power, $P_{loss}$is the network loss, $Q_{PGU\eta WH}$is the heat production from CHP unit, $Q_{boiler}$is the heat from the boiler, $L_{heat}$is the heat demand, $Q_{ES,heat}$is heat consumption from the energy storage, $X, \mu$and Pdenote the state variable, dispatch optimization variable and power injection value, respectively.

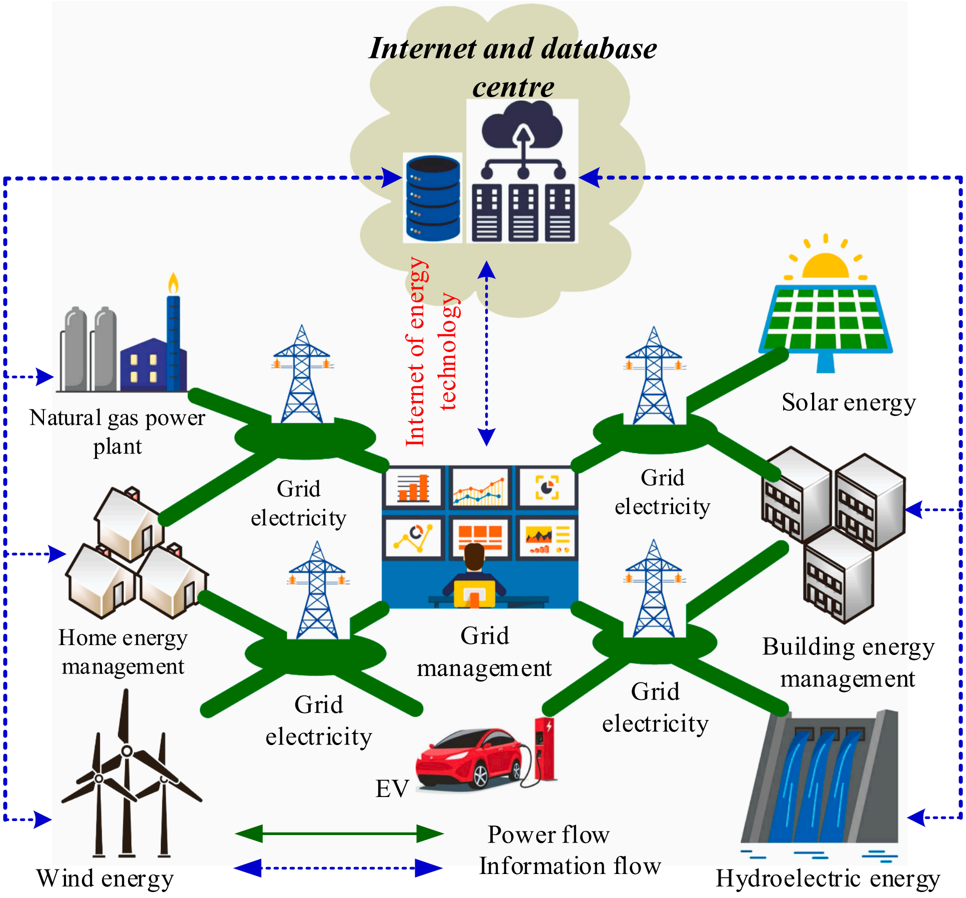


Fig. 7. The operation of BEMS integrated with the EI environment.

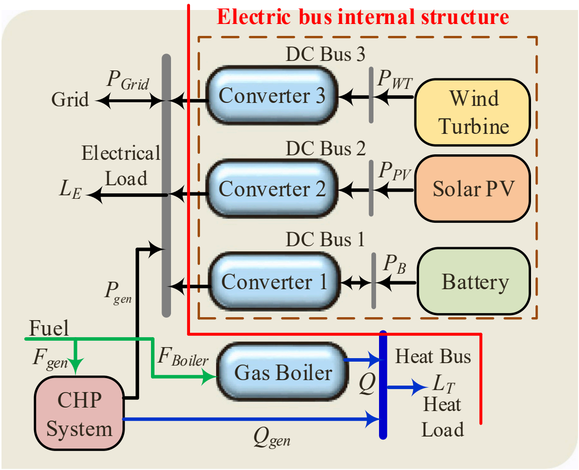


Fig. 8. Two-layer bus structure of EI-oriented DES optimization.

5.2. Neural network approach for energy management issue

With the help of the EI concept, multiple MGs are connected and send electric power from one MG to others via an energy router. An energy management issue occurs due to an MG connected with energy routers. For each MG in EI, the local battery energy storage (BES) devices and controllable microturbines are assumed to regulate the power deviation on the power bus. If the MG does not achieve the power balance, then the energy router implements the wide-area energy routing strategy such that the local MG can transmit into/out the external power. In (Hua et al., 2019), a novel hybrid approach with recurrent neural networks (RNNs) is proposed to achieve an accurate prediction model for both photovoltaic panels (PVs) and loads. A dynamic programming approach is introduced and a stochastic optimal control problem is formulated to address the energy management issue. The mathematical hybrid modelling for PV and loads are expressed in (Hua et al., 2019), using the following equations:

$$P_{PV}(t) = P^D_{PV}(t) + P_{solar}(t)P^S_{PV}(t) \tag{5}$$

$$dP^S_{PV}(t) = k_{PV}\left(\mu_{PV} - P^S_{PV}(t)\right)dt + \sigma_{PV}d\omega_{PV}(t) \tag{6}$$

$$P_L(t) = P^D_L(t) + P^S_L(t) \tag{7}$$

$$dP^S_L(t) = k_L\left(u_L - P^S_L(t)\right)dt + \sigma_L d\omega_L(t) \tag{8}$$

$$dP_{MT}(t) = -\frac{1}{T_{MT}}\left(P_{MT}(t) - K_{MT}u_{MT}(t)\right)dt \tag{9}$$

$$dSOC(t) = \frac{\eta(P_{BES}(t))P_{BES}(t)}{Q_s}dt \tag{10}$$

$$P_{ER}(t) = K_{ER}u_{ER}(t) \tag{11}$$

where $P_{PV}$is solar PV power, $P_{solar}$is the solar radiation,$P_L$is the load power,$P^D_{PV}$and P^S_{PV}denote the deterministic and stochastic part of P_{PV}, respectively, $P^D_L$and $P^S_L$are the deterministic part and stochastic part of P_L, respectively. $P_{BES}$is the BES power, $Q_s$is BES capacity, $P_{MT}$is the output power of micro-turbine, $K_{MT}$and u_{MT} are the control signal gain and control input gain, respectively,$k, \mu, \sigma$are the constant parameters, $\omega(t)$is the Weiner process,$K_{ER}$is the pre-set value for the power transmitted through the energy router.

The deep learning algorithm can handle the big volume and high dimensional nonlinear data (How et al., 2020). The sophisticated deep-learning algorithm fulfilled the short-term and long-term forecasting of wind power. In (Zhou et al., 2017), the authors presented a deep learning-based short-term wind power forecasting model that combined the stacked autoencoders (SAE), the genetic algorithm, and the backpropagation algorithm. An energy management problem is formulated as a three-stage Stackelberg game, aiming to minimize the individual payoff while ensuring system reliability and satisfying consumer energy demands. A three-stage optimization problem is addressed by using demand strategies and optimal prices. After, the theoretical framework of the energy management algorithm is analyzed including Nash equilibrium and Stackelberg equilibrium. The simulation results demonstrate that the proposed model has a low prediction error in the optimal payoff of the microgrid. The objective function of the utility company $U_g(L_{m,g}p_g)$is developed considering electricity generation cost and the pollutant emission cost while the line loss and power loss inefficiencies are taken into consideration to formulate the objective function of the storage company, $U_s(L_{m,s}p_s)$. The necessary mathematical expressions that are used in (Zhou et al., 2017) are shown as in the following equations:

$$U_g\left(L_{m,g}p_g\right) = R_g\left(L_{m,g}p_g\right) - C_g\left(\varepsilon_g L_{m,g}\right) - I_g\left(\varepsilon_g L_{m,g}\right) \tag{19}$$

$$R_g\left(L_{m,g}p_g\right) = L_{m,g}p_g \tag{20}$$

$$C_g\left(\varepsilon_g L_{m,g}\right) = a_g\left(\varepsilon_g L_{m,g}\right)^2 + b_g\left(\varepsilon_g L_{m,g}\right) + c_g \tag{21}$$

$$I_g\left(\varepsilon_g L_{m,g}\right) = \alpha_g\left(\varepsilon_g L_{m,g}\right)^2 + \beta_g\left(\varepsilon_g L_{m,g}\right) \tag{22}$$

$$U_s\left(L_{m,s}p_s\right) = R_s\left(L_{m,s}p_s\right) - C_s\left(\varepsilon_s L_{m,s}\right) \tag{23}$$

$$R_s\left(L_{m,s}p_s\right) = L_{m,s}p_s \tag{24}$$

$$C_s\left(\varepsilon_s L_{m,s}\right) = \frac{c_s\varepsilon_s L_{m,s}}{\eta_c\eta_d} \tag{25}$$

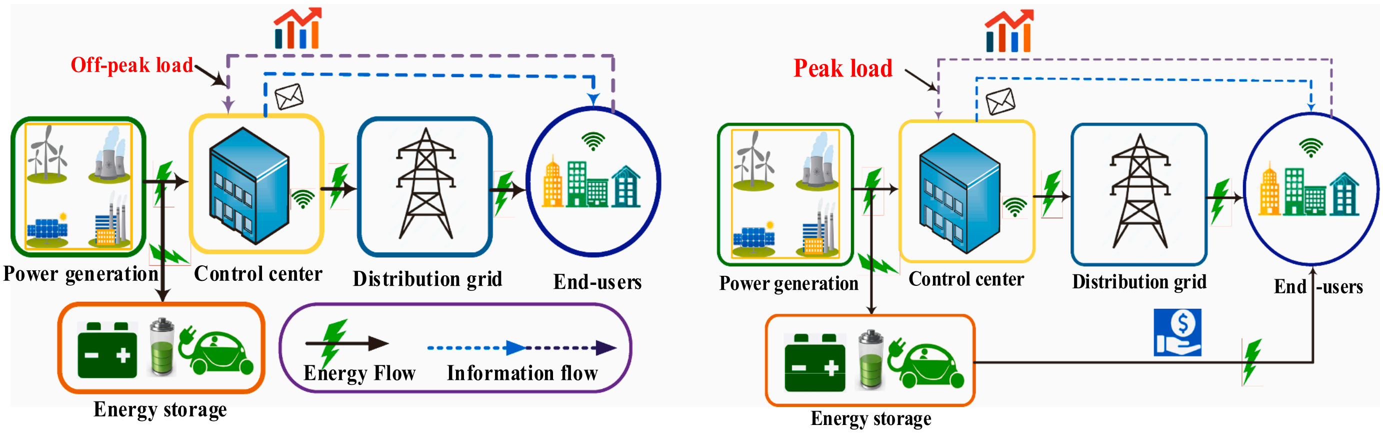
where $R_g(L_{m,g}p_g)$and $R_s(L_{m,s}p_s)$ represent the electricity revenue related to the utility company and storage company, respectively. The objective functions of the power generation and the pollutant emission are denoted as $C_g(\varepsilon_g L_{m,g})$and $I_g(\varepsilon_g L_{m,g})$, respectively. $L_{m,g}$and $L_{m,s}$ denote the amount of electricity bought from utility companies and storage companies, respectively. $p_g$and$p_s$are the unit cost of electricity of the utility company and storage company, respectively. a_g, b_g, c_g, $\alpha_g$are the cost parameters of $C_g(\varepsilon_g L_{m,g})$.$\varepsilon_g L_{m,g}$and $\varepsilon_s L_{m,s}$ are the electricity generated by the utility company and storage company, respectively to satisfy the MG demand. $C_s(\varepsilon_s L_{m,s})$is the objective function of energy storage. $\eta_c$and $\eta_d$are battery charging and discharging efficiencies, c_s which is the operation and maintenance cost.

5.3. Battery charging and discharging model for peak load shifting

Nowadays, the consumption of energy increases which causes a shortage of energy during peak loads. In general, the additional energy stored during the off-peak load period can be utilized during the peak load period by adopting a peak load shifting method with low energy demand. The EI framework addresses the peak load shifting problem. In (Lin et al., 2017), The authors employed the EI platform to explore the peak load shifting problem in which end-users have the opportunity to charge and discharge the energy storage facilities to reduce the total operational expenses, as depicted in Fig. 9(b and c).

In this framework, each end-user in the energy market can act as both supplier and demander. The energy is stored from both renewable energy sources and a conventional grid. A mathematical programming model-based battery charging-discharging and scheduling approach is established to minimize the energy cost and energy waste of grids. The objective function and constraints are formulated to reduce the energy consumption of the end-users which is written in (Lin et al., 2017) as follows:

$$Minimize C_{grid} + C_m + C_{res} - B_{store} \tag{12}$$



(a)

(b)

Fig. 9. Peak load shifting in EI framework (a) battery charging during off-peak load duration, (b) battery discharging during peak load duration.

$$C_{grid} = \sum_{t=1}^{24} RTP_i(t).E_L^i(t) + \sum_{t=1}^{24} RTP_i(t).E_{ES,t}^i.\delta_{grid,t} \tag{13}$$

$$C_m = P_{PCS}^u.P + P_{store}^u.E_{store} + P_{BOP}^u.P \tag{14}$$

$$C_{res} = C_{PV} + C_{wind} \tag{15}$$

where $C_{grid}$is the grid energy usage cost. $C_m$is the energy-storage facilities maintenance cost. C_{res} is the end-users renewable energy cost. B_{store} is the income generated through selling energy of own energy-storage facilities.$RTP_i(t)$is the real-time price at the t-th hour on day i. $E_L^i$is grid energy consumed by the end-users at the t-th hour on day i. $E_{ES,t}^i$is the grid energy used by the end-users to charge electricity at the t-th hour on day i. δ_{grid}denotes the decision variables to decide whether the end-users are charged to use grid electricity. P is the amount of energy, P_{PCS}^u, $P_{store}^u$and P_{BOP}^u are the unit cost of power-conversion-system, energy storage and balance-of-plants, respectively. C_{PV} and C_{wind} are the cost of producing solar PV and wind energy, respectively. In (Rahimi et al., 2013), BES is adapted to shift the peak load of grids in which the remaining unused amount of energy can be stored during off-peak load so that it can be supplied later during the storage or peak load period. An optimal charge/discharge interval is developed to reshape the aggregated load profile.

5.4. Reinforcement learning method

Energy systems adopt reinforcement learning in various fields such as optimal control for the multi-agent system (Li et al., 2020), optimization control of reactive power (Zhang et al., 2014) and design controller for fault diagnosis (Wang et al., 2016) etc. Besides, reinforcement learning is used in energy management systems such as to obtain the optimal control of the dynamic energy management system (Rahbar et al., 2014) and the minimization of the economic cost of the energy management systems. A work by (Lee and Choi, 2019) presented a reinforcement learning-based energy scheduling approach to minimize the consumer electricity bill in a smart home with a rooftop solar PV system. A home energy management systems (HEMSs) optimization problem and constraints are formulated aiming to reduce the total electricity cost and user discomfort cost, as expressed in (Lee and Choi, 2019), in the following equations:

$$\underset{E_t^{net},T_t^{in}}{Min} \underbrace{\sum_{t\in\tau} \pi_t E_t^{net}}_{J_1\left(E_t^{net}\right)} + \varepsilon \underbrace{\sum_{t\in\tau} \left|T_t^{in} - T^{set}\right|}_{J_2\left(T_t^{in}\right)} \tag{16}$$

$$E_t^{net} = \sum_{a\in A} E_{a,t} - \widehat{E}_t^{PV} \tag{17}$$

$$\sum_{a\in A} E_{a,t} = \sum_{a\in A_r^c} E_{a,t} + \sum_{a\in A_s^{c,NI}} E_{a,t} + \sum_{a\in A_s^{c,I}} \left(E_{a,t}^{ch} - E_{a,t}^{dch}\right) + \sum_{a\in A^{uc}} E_{a,t} \tag{18}$$

where$J_1(E_t^{net})$and $J_2(T_t^{in})$ represent the total electricity cost and penalty cost involving consumer discomfort cost, respectively. $\pi_t$is the time of use (TOU) electricity price. $E_t^{net}$is the total energy consumption under PV generation output. $\varepsilon$is the penalty factor for user discomfort cost.$T_t^{in}$and $T^{set}$are the indoor temperature and consumer temperature, respectively. $\sum_{a\in A} E_{a,t}$is the total energy consumption of all appliances. $\widehat{E}_t^{PV}$ is the output of PV generation. $a \in A_r^c$, $a \in A_s^{c,NI}$, $a \in A_s^{c,I}$ and $a \in A^{uc}$denote the reducible, shiftable non-interruptible load, shiftable interruptible load and uncontrollable appliances, respectively.

5.5. Peer-to-peer energy trading framework

The concept of EI is to share and coordinate the energy from one MG to another, However, EI shares the energy from energy storage if the MG cannot fulfil the demand. To distribute the energy from the MG efficiently, a peer-to-peer (P2P) energy-sharing mechanism is adopted that is a suitable model for energy trading in future microgrid distribution systems (Saba et al., 2021). The real-time price (RTP) and time storage dynamics, $g_i^t$are electrical loads and d_i^t is the demand of energy consumption.

5.6. Heuristics algorithm for cooperative energy transportation and storage

In EI, the help of bi-directional energy transportation adopts P2P energy sharing between the power distribution network (PDNs). PDNs are connected with the energy router that provides energy conversion between the microgrid and renewable energy access. However, in EI, cooperative energy transportation and storage are not resolved properly. In (Huang et al., 2019), a three-layer architecture is designed to develop an efficient schedulable distributed renewable energy source in a PDN using an EI platform. The power line communication (PLC) based power router not only supports the power flow transmission in the multipath but also utilizes the energy storage capacity (Takahashi et al., 2015). The stability of energy transfer of the power router is classified by the smart control method proposed by (Sun et al., 2017) that also detects the fault domain. A multi-agent-based consensus algorithm was presented to keep the voltage angle and amplitude of all PDNs stable (Sun et al., 2015). In (Hou et al., 2017), a novel heuristics algorithm is designed combined with two strategies; one with the least distant energy storage and the other is the highest-utilized energy storage. A complementary platform is built using Software-Defined Networking (SDN) to make an effective decision for cooperative energy transportation and storage. The objective function problem and related constraints are formulated in (Hou et al., 2017) to minimize the total electricity price, as shown in the following equations:

$$MinimzeP_h.\sum_{t\in[t_1,t_2]}[Be(v_1,t)]+P_m.\sum_{t\in[t_1,t_T]}\sum_{v'\in[v_2,v|V]}[Be('v,t)]+P_l.\sum_{t\in[t_1,t_T]}\sum_{v'\in[v_2,v|V]}[De('v,t)] \tag{26}$$

$$\forall t : TC(t)=c.\sum_{v_i\in V}\sum_{v_j\in V,v_j\neq V_i}\left[E_{vi.vj}(t).D\left(v_{i,}v_j\right)\right] \tag{27}$$

$$\forall e\in E,t : \sum_{v_i\in V}\sum_{v_j\in V,v_j\neq V_i}\left[E_{vi.vj}(t).\phi_{e,t}^{v_i.v_j}\right]\leq C_t \tag{28}$$

$$\forall v_1,t : \left[RE_{v1}(t)+\sum_{k\in[v_2,v|V]}RE_{k,v_1}(t)\right]\leq C_s \tag{29}$$

$$\forall j,t : \left[RE_j^s(t)+\sum_{k\in[v_2,v|V]}RE_{k,j}(t)\right]\leq C_{ps} \tag{30}$$

where the term $P_h.\sum_{t\in[t_1,t_2]}[Be(v_1,t)]$ $P_m.\sum_{t\in[t_1,t_T]}\sum_{v'\in[v_2,v|V]}[Be('v,t)]$ denotes the energy price that borrows from the main grid and PDN, respectively. The term $P_l.\sum_{t\in[t_1,t_T]}\sum_{v'\in[v_2,v|V]}[De('v,t)]$ represents the energy cost of buying local energy. C is the transportation cost (per unit energy/distance), $E_{vi.vj}(t)$ is the energy transported from the power router, $D(v_{i,}v_j)$ and is the route length from i to j. $\phi_{e,t}^{v_i,v_j}$ is the boolean variable. RE_{v1} and RE_j^s are the redundant energy of the main grid and PDN, respectively. The terms $\sum_{k\in[v_2,v|V]}RE_{k,v_1}$ and $\sum_{k\in[v_2,v|V]}RE_{k,j}(t)$ are the total redundant energy transported from PDN to the main grid and from without energy storage PDN to energy storage PDN, respectively.

5.7. Greedy heuristic approach in EVs

The applications of EI in EVs enable EVs and charging stations of EVs to transmit, distribute and store renewable energies. The V2G concept in EI allows the EV batteries to charge first and then feed their energy to the grid as needed (Sufyan et al., 2020), (Shi et al., 2020). However, the exploration of the suitable location of charging stations for EVs in the EI platform is a challenging task (Peng et al., 2017). In (Tang et al., 2019), a bipartite graph model is used to discover the energy routers from energy sources to charging stations in traffic jams. In (Rigas et al., 2018), a greedy algorithm is adopted to schedule and assign energy in the EV energy internet. In (Zhao and Lu, 2019), a greedy heuristic algorithm based on adaptive large neighbourhood search (ALNS) is proposed to solve the problems of energy routers applied in real-world EVs in the EI platform. The generalized cost function and optimal feasible routes of ALNS are expressed using the following equations:

$$f_{gen}(s)=f_{obj}(s)+\alpha f_{tw}(s)+\beta f_{cap}(s)+\gamma f_{batt}(s) \tag{31}$$

$$Min\sum_{r\in R_{\text{model}}}c_r.x_r \tag{32}$$

$$s.t.\sum_{r\in R_{\text{model}}}\alpha_{ri}.x_r=\forall i\in N \tag{33}$$

$$x_r=\{0,1\}\forall r\in R_{\text{model}} \tag{35}$$

where $f_{obj}$is objective value. α, β and γ are weight penalties. f_{tw}, $f_{cap}$and f_{batt}denote the penalty terms related to window violations, capacity violations and battery capacity violations, respectively. The local optimum feasible routes during the iterations of the ALNS are denoted as R_{model}. The route cost of router r is recorded by $c_r.x_r$is the decision variable which is 1 if route r is chosen in the optimal solution and otherwise 0. $\alpha_{ri}$is 1 if customer i is visited by route r and otherwise 0.

5.8. Fuzzy controller for efficient data transfer

The fuzzy logic is used in the EI platform in various ways. A work in (Shah, 2018) proposed a fuzzy logic model to optimize the network performance through fuzzy inference rules and energy-efficient possibilistic routing by regulating the transmission of the routing request packets aiming to decrease the packet loss and increase the network lifetime. In (Nur Altun et al., 2018), The Internet of Things (IoT) enabled fuzzy logic is employed to optimize the energy efficiency of RESs by considering various factors including battery occupancy ratio, environmental conditions and light intensity. In (Collotta and Pau, 2015), a fuzzy logic-based home automation environment utilizing Bluetooth Low Energy (BLE) mechanism is suggested to improve power management in smart homes. In (Sankar and Srinivasan, 2018), a fuzzy logic-based energy-aware routing protocol (FLEA-RPL) is presented to explore the best path for data transfer of the network efficiently using residual energy, routing metrics load and expected transmission count (ETX). In (Kumar Kashyap et al., 2019), an adaptive neuro-fuzzy clustering algorithm (ANFCA) is developed using fuzzy rules, sets, and membership functions to choose the suitable number of cluster heads and distribution of loads among the sensors. The expression for cluster head's energy consumption that was expressed in (Kumar Kashyap et al., 2019) is written as follows:

$$E_{dst}^c(h)=\begin{cases}(x_n-1)mE_{elect}+x_nmE_{da}+mE_{elect}+m\varepsilon_{mpf}l_{\text{htoBS}}^4, h\in CH\\ mE_{elect}+m\varepsilon_{fsp}l_{\text{htoBS}}^2, h\in non-CH\end{cases} \tag{36}$$

where x_n, e, m, h, BS and CH stand for the total number of sensor nodes connected to cluster head nodes, m-bit data, nodes, base station, and linguistic variable chance, respectively.$E_{elect}$is the energy dissipation in the electronic circuit. The energy consumption factor in the free space path and multipath fading are denoted as$\varepsilon_{mpf}$and ε_{fsp}, respectively.

5.9. Deterministic method

Mixed-integer linear programming (MILP) is a deterministic method that is flexible and powerful and is employed for analysis and optimization in high-dimensional and nonlinear systems. In (Al-Azez et al., 2019), an energy-efficient cloud computing platform-based MILP is designed to optimize the location and the placement of Virtual Machines (VMs) to minimize the power consumption caused by traffic aggregation. In (Dhungana and Bulut, 2020), a MILP-based wireless charging method is designed to determine the charging relation optimally between IoT devices and smartphones. In (Yan et al., 2018), a MILP is applied on a combined power and natural gas network in the EI platform to optimize the cost of lost load through the development of a risk evaluation model including transmission line contingencies, load fluctuation and natural gas pipeline contingencies. The objective function is formulated using the value of lost load (VOLL) of natural gas and the quantity of lost electricity load. The constraints include natural gas source output, node pressure, gas flow and gas compressor. The target of the objective function used in (Yan et al., 2018) is to minimize the economic loss as shown in the following equation:

$$Minimize \sum_{r\in SWL} Cg_r \times wlc_r + \sum_{r\in SD} Ce_k \times pdc_k \tag{37}$$

$$s.t\begin{cases} WS_h^{\min} \le WS_h \le WS_h^{\max} \forall h \in SWS \\ \pi_i^{\min} \le \pi_i \le \pi_i^{\max} \\ -F_p^{\max} \le fp_p \le F_p^{\max},\ p \in SP \\ \pi_j \le \Upsilon_c \pi_i, 0 \le fc_c \le F_c^{\max}, c \in SC \\ PG_i^{\min} \le pg_i \le PG_i^{\max}, \forall i \in SEG \\ -F_l^{\max} \le fl_i \le F_l^{\max},\ \forall l \in SEL \end{cases} \tag{38}$$

where *SWL* and *SD* denote the set of natural gas load nodes and electricity load nodes, respectively. $Cg_r$and Ce_k are the VOLL of the *r*-th node and *k*-th node, respectively. The quantity of lost gas load in the *r*-th node and quantity of lost electricity load in the *k*-th node are represented by$wlc_r$and pdc_k, respectively. The natural gas output constraints are denoted as $WS_h^{\min}$and $WS_h^{\max}$that is limited by the device capacity and gas pressure. The lower and upper limit of gas pressure of the i-th node are characterized as $\pi_i^{\min}$and $\pi_i^{\max}$, respectively. The upper limit of natural gas flow in *p*-th pipeline and power flow in *l*-th transmission are recorded as$F_p^{\max}$and$F_l^{\max}$, respectively. Υ_c,fcandflstand for compressor factor, compressor gas flow and transmission power flow, respectively. The minimum and maximum electricity generation output are denoted as $PG_i^{\min}$and $PG_i^{\max}$, respectively.

5.10. Stochastic programming method

Stochastic programming provides a framework that can solve optimization problems under various uncertainties. Another work in (Reddy et al., 2017) assessed the stochastic programming method in a smart grid aiming to optimize the objective function of energy generation cost, power transmission planning, power loss, fuel cost, economic dispatch, voltage control, load allocation, voltage stability enhancement, reactive loss minimization and emission. The authors in (Zhang and Cao, 2019) applied the stochastic programming methodology to investigate the safety requirements and constraints for mobile edge computing on the internet of vehicle applications under the uncertainties including connectivity between server and vehicle users, vehicle random movement and varying traffic load. The proposed approach considers energy consumption to minimize the total cost-effectively through the offloading decision-making process. From (Zhang and Cao, 2019), the mathematical expressions for the total energy consumption for the *i-th* user are presented in the following equations:

$$E_{i,j}\left(k, T_{i,j}^{ct}\right) = E_{i,j}^{tran}\left(k, T_{i,j}^{ct}\right) + E_{i,j}^{local}\left(k, T_{i,j}^{ct}\right) \tag{39}$$

$$E_{i,j}^{tran}\left(k, T_{i,j}^{ct}\right) = P_i t_{i,j}^{send}\left(k, T_{i,j}^{ct}\right) \tag{40}$$

$$E_{i,j}^{local}\left(k, T_{i,j}^{ct}\right) = \xi\left(f_i^l\right)^3\left(t_i^{local}(k) + t_{i,j}^{unsent}\left(k, T_{i,j}^{ct}\right)\right) \tag{41}$$

$$t_{i,j}^{send}\left(k, T_{i,j}^{ct}\right) = \begin{cases} T_{i,j}^{ct}\text{if}T_{i,j}^{ct} \le T_{i,j}^{send}(k) \\ T_{i,j}^{send}(k)\text{otherwise} \end{cases} \tag{42}$$

$$t_{i,j}^{unsent}\left(k, T_{i,j}^{ct}\right) = \begin{cases} \dfrac{D_{i,j}^{unsent} C_i}{f_i^l}, \text{if}T_{i,j}^{ct} \le T_{i,j}^{send}(k) \\ 0 Otherwise \end{cases} \tag{43}$$

where energy consumption for workload transmission and the energy consumption for local computing for the *i*-th user are denoted by $E_{i,j}^{tran}$and $E_{i,j}^{local}$, respectively. $T_{i,j}^{ct}$ is the actual time consumption of the *i*-th user related to mobile edge computing server $j.P_i$is the transmitted power.$\xi$is the chip architecture coefficient. The time consumption for sending workload and unsent workload are represented by $t_{i,j}^{send}$and $t_{i,j}^{unsent}$, respectively. $D_{i,j}^{unsent}$is the quantity of unsent workload. $C_i$and f_i^lstand for workload capacity and computing capacity, respectively. The summary of different methods in the EI platform focusing on objectives, parameters, constraints and achievements is presented in Table 3.

6. Open issues of energy internet

As described above, The EI has many advantages for reliable operation and control in power systems by managing the information provided via its components. This will result in significant financial savings as well as a large reduction in energy waste. However, for efficient operation of an EI system, there are some challenges to achieving optimal EI operation in terms of energy distribution and management. These challenges are highlighted in this section for future energy data dissemination and management.

6.1. Energy internet reliability and safety issues

EI aims to integrate internet information technology with energy technology providing a secured and reliable power transfer between distributed ESS and various types of loads (Ren et al., 2021). However misleading information and incorrect decisions in EI-based ESS may damage power systems and unbalanced grid operation (Liu et al., 2020). Moreover, the voltages vary depending on the battery condition and SOC (Hannan et al., 2020c). Moreover, the unreliability in the existing power network system occurs due to a lack of fault diagnosis, efficient monitoring and maintenance of the systems (Ahmadi et al., 2020). An efficient ESS plays a key role in stabilizing the power quality and can ensure an uninterrupted power supply to the load by balancing the power with the grid (Wang et al., 2019). The robustness of the energy grid increases if the energy is stored in the grid at a sufficient amount and delivered cheaply and efficiently (Liu et al., 2019a). Hence, smart power infrastructure along with the monitoring and control system is required to develop reliable EI-based ESSs.

6.2. Strategic issue of energy internet standards and protocols

Energy systems are rapidly upgrading with time. The future energy system and the future grid are the energy internet. Also, EI is involved in many industries 4.0 and different sectors. However, the concept and execution of EI vary from country to country due to their different standards and models of EI (Rana, 2017). Therefore, the strategic issues of EI including various standards and protocols need to be studied. Since there are some standards related to the power grid, smart power distribution and communication protocols, e.g. IEC standards, NIST standards, CGCC standards and Ethernet, GPRS, LTE, Wi-Fi and Zigbee have been embraced. In addition, the plug-and-play concept is proposed in which it cannot detect any devices or equipment type based on the load characteristics without a standard protocol and interface (Joseph and Balachandra, 2020b). Thus, an open-source, systematic, professional

Table 3
Analysis of various methods used in the EI environment.

Ref.	Method	Objective	Parameters/Constraints	Contributions
(Perera et al., 2021)	Thermo-Electric decoupling method	-To determine the energy flow and equipment power balance equations.	-Grid exchange power. -Electrical load and network loss. -PV and wind turbine output power. -Electric chiller consumption power -Heat production from CHP -Heat consumption from storage	-Reduce dimension and the complexity of the system -Enhance flexibility, accuracy and optimal planning model.
(Hua et al., 2019)	Neural network approach	-To obtain an accurate prediction model for PV and loads.	-PV power and solar radiation. -Load power, BES power and capacity. -Control signal gain and control input gain.	- Neural network-based stochastic optimal control in the EI platform is proven effective. - Controls the power deviations through the utilization of BES, micro-turbines and energy routers.
(Zhou et al., 2017)	Deep learning algorithm	-To develop the big data-based wind power forecasting technique. -To improve the EMS by considering utility companies, ES companies, the microgrid, and electricity users.	-Electricity revenue related to utility company and storage company. -Amount of electricity bought from utility company and storage company. -The unit cost of electricity. -Battery charging and discharging efficiencies. -Operation and maintenance costs.	- The optimal payoff of the microgrid is reduced ensuring reliable operation of the system while satisfying the electricity demands of the users.
(Lin et al., 2017)	Battery charging and discharging model for peak load shifting	-To reduce the total operational expenses through charge/ discharge energy storage facilities	-Grid energy usage cost, energy-storage facilities cost and end-users renewable energy cost. -Solar PV and wind energy generation cost. -Grid energy consumed by the end-users -Unit cost of power-conversion-system, energy storage and balance-of-plants	-Achieve peak load shifting and reduce energy loss using renewable energy and energy storage facilities. -Provide efficient energy trading in the EI framework between grid energy and renewable energies.
(Li et al., 2020)	Reinforcement learning method	-To achieve the trade-off among power transmission cost, DG cost, BES charging and discharging power cost	-Power flow of photovoltaic, wind turbine and load -Power generation by microturbine, DG, fuel cell and BES -BES charge/discharge power and state of charge (SOC) -Co-efficient microturbine, DG, fuel cell and battery charge/ discharge efficiency.	-The proposed deep reinforcement learning achieves better performance than the optimal power flow solution. -Restrict the power exchange between the EI network and the external grid. -The proposed method utilizes the BESs more rationally.
(Saba et al., 2021)	P2P energy trading framework	-To obtain higher renewable energy penetration and cost-saving using EI-based P2P energy transactions and coordination integrated with the ADMM algorithm.	-Transactions within the neighbourhood level. -Transaction between customer and utility company -EES operational cost. -Battery charging and discharging rate.	-Provide an efficient and flexible distributed energy management and control operation. -Lower economic cost is saved following real-world renewable energy datasets and real-time electricity prices.
(Hou et al., 2017)	Heuristics algorithm	-The heuristics algorithm is combined with the SDN platform to provide decisions for cooperative energy transportation and storage. -To minimize the total electricity price.	-Cost of borrowing electricity from the main grid -Energy cost of buying local energy. -Redundant energy of the main grid and PDN -Energy transported cost.	-Reduce the electricity cost by 58% compared to the benchmark case. -Achieve the energy transportation cost savings by 89%.
(Zhao and Lu, 2019)	Greedy heuristic approach	-To find the optimal feasible routes in real-world EVs under the EI platform using a greedy heuristic ALNS.	-Penalty to window violations, capacity violations and battery capacity violations. -Route cost of the router. -Local optimum feasible routes	-Obtain operational cost savings by 7.52%
(Kumar Kashyap et al., 2019)	Fuzzy method	- To select the suitable number of cluster heads and distribution of loads among the sensors using ANFCA	-Total number of sensor nodes connected to cluster head nodes -Energy dissipation in the electronic circuit -Energy consumption factor	-The proposed method is superior to other methods concerning network lifetime, cluster formation, energy expenditure and standard deviation of residual energy.
(Yan et al., 2018)	Deterministic method	-To optimize the cost of lost load using MILP integrated with a combined power and natural gas network in the EI platform.	-VOLL of natural gas and quantity of lost electricity load. -Natural gas source output, node pressure, gas flow and gas compressor.	-Achieve minimum economic loss through the cost of losing load minimization model and the adjustment of the combined gas and electricity system

(continued on next page)

Table 3 (*continued*)

Ref.	Method	Objective	Parameters/Constraints	Contributions
			-Electricity generation output, electricity load nodes.	-Evaluates the risk level of the gas and electricity system accurately.
(Zhang and Cao, 2019)	Stochastic programming methods	-To investigate the safety requirements and constraints for mobile edge computing in the internet of vehicle applications	-Connectivity between server and vehicle users. -Vehicle random movement. -Varying traffic load. -Actual time consumption for sending workload and unsent workload	-Minimize the total cost-effectively through the offloading decision-making process.

and coordinated standard and protocol should be formed.

6.3. Energy internet security

In recent times, many issues have been raised about energy information transmission, cybersecurity challenges of the communication systems, cloud energy storage privacy protection, false data injection, eavesdropping etc (Rath and Tomar, 2020; Eissa and MH, 2019). The electric power systems integrated with the EI operating system could have been hacked if security in not been tightened up strongly (Zeng et al., 2020). In EI, the privacy protection issue is very critical because of the vast amount of information on energy, the grid and users. Therefore, fog cloud computing can be utilized to ensure that data is protected and encrypted in the cloud (Yaghmaee Moghaddam and Leon-Garcia, 2018). The high authorities such as the government, organizations and educational institutes should take the great initiative to come up with security privacy protection for EI.

6.4. Energy internet cost

Cost is another main issue of EI-based ESS. EI is the combination of renewable energy and battery energy storage systems so it includes ESS material cost, energy cost, operating and monitoring cost, infrastructure cost, energy routers cost etc. The integration costs of renewable sources such as solar energy vary gradually (Notton et al., 2018) whereas the initial investment cost of wind energy and geothermal energy is high (Hrnčić et al., 2021). Many researchers are working on the cost estimation model of EI. Therefore, the development of a cost-effective and feasible EI-based ESS system is a challenge for the future development of EI.

6.5. Energy internet complexity

The power system has a complex structure and physical properties containing generation, transmission, and distribution under high-dimension, nonlinear, time-invariance conditions. Moreover, the communication network consists of vast amounts of data, information, analysis and optimization which are tough issues to be explored (Zhou et al., 2016a). In line with that, designing, modelling and analyzing the communication infrastructure of EI are challenging. Furthermore, the safety and reliability of the power system interconnecting with the various communication networks have become a concerned topic (Wang et al., 2017a). In addition, the energy router is a crucial and core component in the EI platform that can dispatch, manage and exchange energy flows and information to fulfil the demand of the system (Guo et al., 2019a). The effectiveness of EI depends on proper routing mechanisms so that the quality of energy flow is maintained and energy is routed to the appreciated load accurately. Thus, the energy router in EI requires a reliable communication structure that can make automatic adjustments and stimulatingly assess the energy information in real time. Thus, an advanced communication infrastructure needs to be designed that improves the energy efficiency of the system as well as provides real-time management of energy supply and demand. The detailed issues and challenges of EI, their causes, impacts and remedies is presented in Fig. 10.

7. Global landscape of energy internet projects

EI has been an emerging research subject in many developed countries around the world. While considering the smart city development, the innovative use of widespread IoT-enabling technology, including 5 G, AI, sensors and green energy utilization is considered (Lai et al., 2020). The integration of the EI concept is critical in the establishment of smart cities (Savithramma et al., 2022). Smart cities may optimize energy usage, reduce carbon footprints, and improve sustainability by using advanced technologies such as IoT, AI, and real-time data analytics, resulting in more efficient and eco-friendly environments for both residents and industries worldwide (Razmjoo et al., 2022). There were several ongoing and emerging real-time implementations of EI projects around the world. In Germany, the E-Energy concept is adopted which transforms the whole transmission grid in the energy internet through information and communication technology (E-Energy, 2020). In the US, the future renewable electric energy delivery and management proposes the concept of energy routers and accordingly builds a plug-and-play of high-efficiency distributed renewable energy and storage devices (Wu et al., 2021b). In Switzerland, the vision of a future energy network is introduced which consists of two concepts such as a hybrid energy hub and an energy interconnector (Maroufmashat et al., 2019). In Japan, the digital grid power router is described (Japan Industry news, 2023). In China, the net energy concept is presented, which integrates the energy network with cloud computing (Liu et al., 2019b). In Australia, Siemens and Swinburne University of Technology have collaboratively established the Siemens Swinburne Energy Transition Hub in Melbourne, with a substantial $5.2 million investment. This innovative hub aims to create Australia's most advanced future energy grid laboratory, facilitating research and industry collaboration to develop greener and more efficient energy systems (Australian Trade and Comisssion, 2023). Moreover, EI optimizes EV charging networks using advanced connectivity and data analysis, assuring effective energy use, decreased carbon emissions, and increased urban mobility, harmonizing with the sustainability objectives of smart city applications (Haidar et al., 2015). The global panorama of EI projects demonstrates the innovative potential of the new technologies in transforming the energy sector. These initiatives, which span countries and applications, represent a concerted drive towards a more sustainable energy future.

8. Future prospects of energy internet

It is becoming more and more obvious when we consider the potential of EI as it can significantly impact the generation, distribution and management process of the energy sector. The EI has the potential to transform the global energy landscape through innovations which are expected to improve efficiency, sustainability, and resilience as it continues to develop at a rapid rate. The study aims to provide a comprehensive overview of the field of EI considering the features, applications, methods and issues. Considering the previously discussed issues and challenges, the following recommendations are proposed for the future:

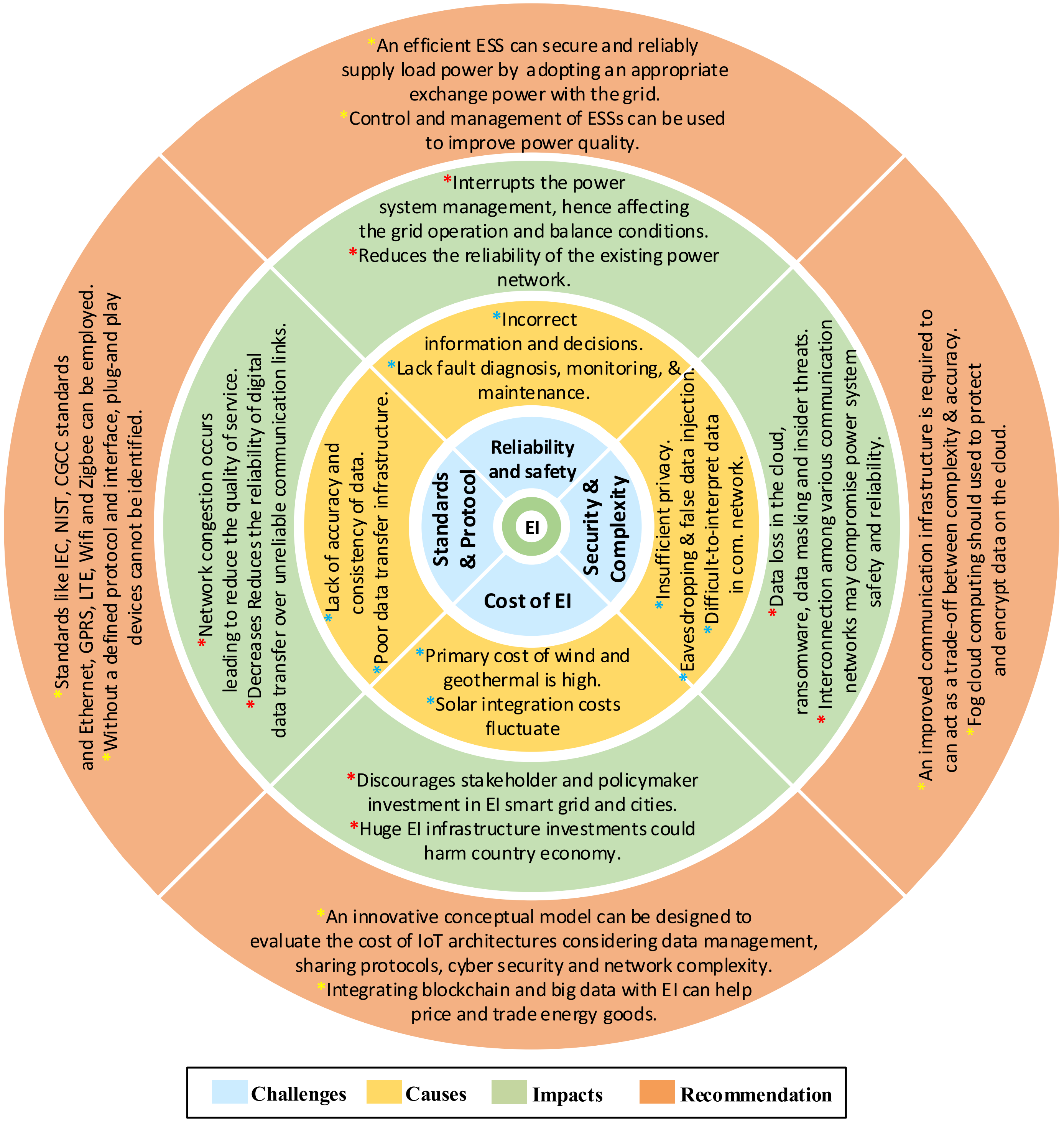


Fig. 10. summarizing the challenges, causes, impacts and remedies of different issues of EI.

- A new grid interface is required which has access to the plug-and-play option so that energy can be supplied anywhere and anytime. A distributed grid intelligence software can be introduced that can ensure supply and demand through real-time EMS and control strategies. Moreover, real-time information and communication system is essential to identify the various power failures in EI.
- An effective EI communication infrastructure with efficient bidirectional communication among ESS, distributed RES, and different energy loads while having optimal resource allocation is needed. For this, an efficient data handling capability, quick responses and strong computation intelligence to compute static and interaction data toward accurate energy analysis, evaluation and efficiency improvement are compulsory to develop. Moreover, a flexible cross-layer optimization methodology is required to reduce energy consumption by taking into account energy scheduling. In line with that, a decision support tool is needed to perform the optimal scheduling of distributed energy resources as well as the optimization of the energy service to increase the net profits.
- EI has a data transmission congestion issue resulting in a sharp drop in energy flow and a decrease in transmission efficiency. To balance

energy loads and reduce energy transmission congestion, the development of an ideal routing model of EI is necessary to address the complexity of routing and data transmission problems. In addition, an enhanced cooperative structure and multiagent framework are needed to perform device monitoring, failure detection, control process execution and switching actions for the restoration of abnormal loads.

- EVs should merge with new communication technologies using various external sensors, built-in sensors and communication nodes. Real-time interaction between the external hardware and the vehicle from different sensors is required to assess the different state estimation of the battery, temperature control, fault diagnosis and battery charge equalization (Tang et al., 2019). Hence, a suitable model needs to be designed to build an autonomous electric vehicle toward enhanced control operation and reduced computational burden under various dynamic features and driving constraints.
- Various RESs are integrated with the EI platform including solar PV, wind power, solar thermal power, solar thermal storage systems, hydroelectric power, biomass power and tidal power generation. However, there are various technical challenges and issues of RESs which need to be explored in detail. For instance, the operation of wind energy is influenced by design structure, control strategy, site selection, aerodynamics performance and capital cost (Hannan et al., 2021; Wali et al., 2021). In contrast, solar PV has many technical challenges concerning design, sizing, cost, power quality and energy loss (Powell et al., 2017). Moreover, solar PV has potential issues relating to types of solar cells, materials, environmental settings and energy efficiency. In addition, solar thermal storage can store excess thermal energy, which can be used for heating, cooling, or power generation during peak demand (Li, 2015). Moreover, a flexible cross-layer optimization methodology is required to reduce energy consumption by taking into account energy scheduling. Thus, further studies are required on the issue of challenges of RESs toward quality and reliable power generation.
- The security of EI could be vulnerable due to inaccurate monitoring processes, tampering, communication outages and computer viruses leading to instability in the EI communication system. Moreover, the operating system in EI communication could have issues like programming errors, false logic design and system vulnerabilities allowing the illegal attackers to enter and implant viruses. As a result, key energy data, information and control operation of EI may be stolen. Moreover, malicious attacks can be launched by hackers through various information carriers such as mobile hard disks and USB disks. Hence, a robust security system is necessary to confirm the safety and reliability of the EI system. Moreover, a smart and autonomous system with self-healing control technology is necessary to restore the system to the steady-state condition under power failures.
- The different types of consumers and widespread opportunities for applications put the EI system in a high-risk stage. Illegal users, side-channel attacks, malicious users and eavesdropping may enter the EI system leading to serious issues such as customer privacy leakage, chaos, information blockage or termination and network collapse (Zeng et al., 2020). Thus, a comprehensive investigation is required to address the security issues in EI. Further studies can be carried out on different network security standards such as 802.11i, 802.16e, 3GPP LTE and ISO/IEC18883.
- EI data management has limitations concerning standardized access permission causing the issue of private information leakage. Besides, EI lacks in providing strong data backup measures and data storage centres which could hamper the data recovery process (Uludag et al., 2016). Moreover, the EI access channel has security risks due to the unauthorized large number of accesses and external connections leading to data or illegal tampering problems. Thus, further attention is required on data security issues in EI communication systems.
- Advanced computing technology is essential in achieving the full potential of the EI, optimizing resource allocation, and enabling seamless integration into the energy infrastructure.
- The monitoring sensors are considered one of the key components of the EI system to monitor environmental conditions, grid performance, EV battery health, and battery SOC status (Javaid et al., 2021). Advanced monitoring and EMS are needed to improve power network performance and reliability.
- Advanced AI-powered EMS can adapt to grid complications, optimize resource allocation, and enable effective integration of RES. Moreover, an extensive data analysis process through machine learning algorithms is needed to introduce to improve grid forecasting and demand response, optimize energy distribution, overall improve grid reliability, lower costs, and ensure regulatory compliance.
- The development of a unified platform and suitable model in EI is challenging since EI is linked with a large number of connected devices. The security of EI with numerous heterogeneous communication standards and technologies to satisfy the specific requirements is considered emerging research. Moreover, multiple heterogeneous systems result in complex network configurations and may have vulnerable operations between the protocols in the EI system. Therefore, future investigation should be carried out on the selection of appropriate information, and communication strategy, interfacing, and protocols to improve the EI security system.

9. Conclusion

In this era of industrialization due to the rapid technological advancements and a growing emphasis on sustainability, the EI is emerging as an evolutionary force, promising to transform the production, distribution and usage of energy. This review article comprehensively analyses the concept, applications, methods and issues of EI. Initially, after an extensive selection process from various publically available article databases, 156 articles were chosen for the reviewing process. A detailed discussion regarding the concept of EI by highlighting various key features is presented followed by the numerous potential applications used in EI together with framework and execution. Based on the review process few key issues and challenges concerning various limitations and drawbacks of EI are explored. Moreover, a global landscape of the existing EI-based projects is discussed. Finally, several selective and effective recommendations for future research works and opportunities to strengthen the technological advancements of EI-integrated energy distribution and management systems. The main highlights of the research are stated below:

- A comprehensive research of the EI, covering its various aspects, from features and applications to methods and challenges is provided.
- The key application of the EI includes RES and ESS integrated microgrid, building power management and control system, EV application and smart grid application.
- The main limitations regarding the development of efficient EI for the energy sector are system cost, data security and EMS optimization.
- Advanced computing and AI-power EMS are the key factors for effective EI implementation.
- The communication infrastructure of EI must support efficient bidirectional communication between energy storage, renewable sources, and loads. Therefore, efficient data handling capability, quick responses and strong computation intelligence to compute static and interaction data toward accurate energy analysis, evaluation and efficiency improvement.
- An efficient EI communication network with optimal resource allocation is a key content to be investigated.

The EI presents numerous possibilities to overcome existing limitations and shape a more sustainable energy ecosystem. By providing a comprehensive understanding of features, applications, methods and challenges of EI, the article hopefully helps the engineers and researchers with the knowledge to develop strategies and implement solutions that improve energy efficiency, reliability, and security, which lead towards the development of advanced EI methods and communication technologies for the future sustainable electricity grid.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M A Hannan reports was provided by Sunway University.

Data Availability

No data was used for the research described in the article.

Acknowledgement

This work is supported by the Universiti Tenaga Nasional (UNITEN) BOLD 2025 Highly Cited Researcher (HCR) Program under the project code of J510050002 -IC - 6 BO LDREFRESH2025 -Centre of Excellence (HCR). The article processing charge of the manuscript is supported by the UNITEN BOLD Publication Fund with the project code of J510050002 -IC - 6 BO LDREFRESH2025 -Centre of Excellence.

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