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Review

# Towards next generation Internet of Energy system: Framework and trends

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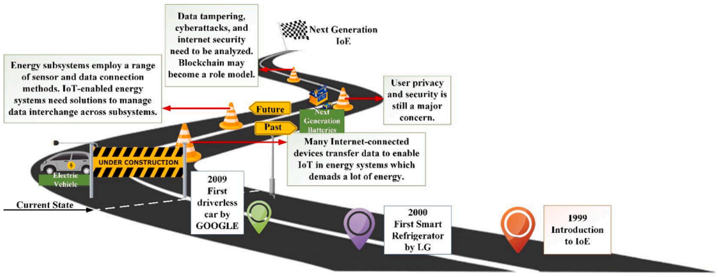
## HIGHLIGHTS

- The internet of energy (IoE) in case of control, communication, networking, and security are analyzed.
- The control issues and challenges of the IoE with their proper control solution are addressed to increase the system reliability, stability, robustness, and security management.
- A path to construct and control the next generation IoE system is constructed by addressing the necessity of future scopes and recommendations.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

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## ABSTRACT

The quickening propensity of growth within the areas of information and communications technology and energy networks has triggered the emergence of a central idea termed as Internet of Energy (IoE). Such a concept relates the internet of things, which is the term used in describing the usage of sophisticated digital control devices with the capability of transmitting data via IT systems. The concept of an interconnected energy network is being formed in the upcoming days through upgrades in the field of intelligent energy systems to control real-time energy optimization and management. The energy industry has had a sustained expansion, reaching the IoE milestone and continuing to this cutting-edge power system, which is the next generation of IoE. A directional pathway from the traditional power system to the IoE has been conducted in this research work by addressing the importance of integrating the smart transmission and communication infrastructure, smart metering, pricing and energy management scheme. A detailed investigation of the IoE with respect to technical angles, such as communication architecture, IoE on the supply & demand side, and IoE protocol based on fundamental elements and essential technologies has been carried out to indicate the blueprint and jurisdiction complexity. The integration, security and energy management challenges may deviate the performance of the IoE technology that has been focused with proper control issues and solutions. Finally, a directional framework to establish the next-generation IoE system has been constructed with future scopes to insure higher resiliency, cyber-security and stability.

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## Nomenclature

| | |
|---|---|
| ICT | Information and communication technology |
| IoE | Internet of energy |
| IoT | Internet of things |
| TPS | Traditional power system |
| TDS | Transmission and distribution system |
| RE | Renewable energy |
| ESS | Energy storage system |
| EMS | Energy management system |
| DER | Distributed generation resource |
| SG | Smart grid |
| MG | Microgrid |
| VPP | Virtual power plant |
| SM | Smart meter |
| DRER | Distributed renewable energy resources |
| CPS | Cyber-physical system |
| FREEDM | Future renewable electric energy delivery and management |
| PV | Photovoltaic |
| WT | Wind turbine |
| DGI | Distributed grid intelligence |
| IEM | Internet equipment Management |
| FID | Fault isolation device |
| SST | Solid-state transformer |
| P2P | Peer-to-peer |
| WPAN | Wireless personal area network |
| RFID | Radio frequency identification |
| Wi-Fi | Wireless-fidelity |
| LAN | Local area network |
| TCP/IP | Transmission control protocol/internet protocol |
| MAC | Medium access control |
| UDP | User datagram protocol |
| HY | Hydropower |
| FC | Fuel cell |
| IEC | Intelligent energy controller |
| USP | User services platform |
| V2G | Vehicle to grid |
| PP | Plug-and-play |
| DESD | Distributed energy storage devices |
| SMI | Smart meter infrastructure |
| HAN | Home area network |
| MDMS | Meter data management system |
| OCPP | Open charge point protocol |
| OCPI | Open charge point interface |
| OADR | Open automated DR |
| DEVS | Discrete event system specification |
| AI | Artificial intelligence |
| GSM | Global system for mobile |
| DLP | Dummy location privacy-preserving |
| CA | Cyber-attack |
| MW | Middleware |
| DI | Data integrity |
| SCL | Supply chain logistics |
| FS | Fog server |
| CS | Cloud server |
| MLSTM | Multilayer long short-term memory |
| EV | Electric vehicle |
| AV | Autonomous vehicle |
| G2V | Grid-to-vehicle |
| GIS | Geographic information system |
| VPN | Virtual private network |
| DRP | Demand response program |
| IBP | Incentive-based programs |
| RTP | Real-time pricing |
| PEV | Plug-in electric vehicle |

## 1. Introduction

The improvement of the technology on which our existence now primarily depends is one way that the world seeks to propel nations toward the progress of life. Technical innovation aims to create new devices and appliances that will improve automation levels while also making human existence more dependable and pleasant. The world's population and technological growth rates have a variety of effects on the energy sector's dependability by driving up power usage pressure and consumption [1]. The traditional power system (TPS) possesses an ongoing integer of limitations. The TPS is often situated far from the consumers, necessitating a lengthy transference line to transmit electricity. The unidirectional communication of this traditional system, which ignores user feedback, causes the power consumption pace and utility price to increase [2].

The manufacturing system of the TPS is highly reliant on non-restorable roots of power which are only found in minimal quantities worldwide. Thus, the day when natural resources are entirely gone from the earth is not far off [3]. The regulating and monitoring capabilities of various sections of TPS are made highly difficult and manual by employing few or no sensors in the TDS [1]. Additionally, the recovery of the power grid in the TPS against various faults or uncertainties is manual owing to the lack of intelligent and automated devices, which increases system complexity and lowers the main grid's management capacity [1].

A microgrid grid enters the scene as a solution to the problems of TPS. By providing clean and safe energy, the application of renewable energy (RE) origins in the MG helps to address the environmental demands while reducing the strain on natural resources [2]. The RE is a promising source that never runs out due to usage and whose demand is increasing daily due to its low cost, frequent acquisition, and recycling capabilities. The effectiveness and efficiency of RE sources are greatly influenced by environmental factors like wind speed and direction, temperature, and sun exposure, which change with the seasons and have various effects on the production of MG. To fill the gap left by one RE source in the functioning of MG and to manage a consistent and dependable power source for the end users, some RE sources and ESS may be installed concurrently [4].

Smart grid (SG) fills the gaps left by both TPS and MG thanks to its two-way communication capabilities in the electricity sector. The smart metering system in the SG evaluates the end users' power use and chooses an advantageous bill based on dynamic charging, communicated to the consumers and distributor to make decisions on the scheduling of the load and generation [3].

With ICT and IoT, various sensors are integrated with TPS in order to identify structure errors and take appropriate and innovative efforts to rectify them accordingly. The security concerns across various units, such as EMS, smart meters (SM), and dynamic pricing, are carefully monitored and managed to improve the power system's dependability, resilience, quality, and efficiency and make it more resilient and adaptable [5].

Due to the complicated infrastructure and security concerns, a significant amount of DER integration in the MG or SG makes regulating the parameters outline more complicated. Another enhancement of the SG that lessens the integration complexity of DER and combines several DER units is the virtual power plant (VPP). It can function as a full-fledged unit with a number of capabilities [6]. VPPs offer significant benefits over TPS regarding adequate transfer infrastructure, substantial adaptable properties, and extreme regulatory structures [7]. Utilizing temporary communication technologies, this cloud-based control entity backed by ad-ministering software organizes the allocation of electricity. The VPPs, however, have several shortcomings regarding intelligence and integrating disparate DERs into large dimensions. When considering the variety in dimensions, kind, and integration of energy resources and loads, the software associated with VPPs encounters several restrictions.

Accurate modeling is necessary to inspect the diverse sectors of the energy structure. To manage the voltage, frequency, and power by strengthening the capacity of its TDS, communication network, Energy storage system, SM, and demand scale needs proper information. A critical possibility for modernizing the global energy network is integrating energy with the internet [8]. With rationalized power production and unidirectional energy flow replaced with more secure, dependable, structured, adaptable additionally sustainable energy networks, the IoE marks a paradigm leap for the current grid structure [9]. The current model of centrally managed electricity production, communication, and delivery is at gunpoint to improve for different reasons, including concern for the environment, which is running away from huge coal and oil-fired producing systems and toward greater use of RE which requires DER assistance. IoE encompasses all types of energy, including thermal and electrical ones, and aims to provide a reliable mechanism for exchanging energy amongst prosumers, much like internet networks do. This will need extensive, sophisticated supervising and management of scattered and sporadic power generation and storage over the information highway [8]. Fig. 1 shows a detailed evolution from TPS to IoE.

Research has been done on the IoE's beneficial applications and operations in several domains. The authors analyzed and contrasted contemporary energy and internet networks and services, highlighting key capabilities and outlining the major technological obstacles that must be overcome to convert the electricity distribution system into a flexible platform for the interchange of electrical energy. The numerous IoT applications, including their effects on power systems, are outlined in [10], which conducts a thorough review. The core terminology related to the IoT is defined in this work, including recognition, transmission, computing, definition, and services. The categorization for IoE utilization in all aspects of energy systems at different levels is addressed in [11].

The functions of IoT in smart grids have been investigated in [12]. A clear description of the many IoE levels in power systems is given in this paper. The demonstration of the necessity of IoT in electric cars is conducted in [13]. Ref. [14] introduces the energy management plans for electric car charging stations, and energy storage installations are presented. This field, however, is characterized by difficulties. The system's safety can be jeopardized by cyberattacks when innovations like IoT and cyber-physical systems are included in power systems, according to [15]. One of the difficulties highlighted in [16] is connecting various devices created by various standards and protocols under a sole IoT platform. The authors of [17] explored software-related difficulties with IoE.

The aforementioned papers address the properties and applications of the IoT in power systems. The proper control structure, modeling, control issues and challenges with their respective solutions are not addressed in these papers. The principal grant of this research article is to focus on all aspects of the IoE that will help the research community to construct and control efficient management for the next-generation IoE for the future world. The aims and contribution of this research article can be listed as,

1. Labeling of the lackings of the Traditional power system to understand its impact on the environment, economic and social life.

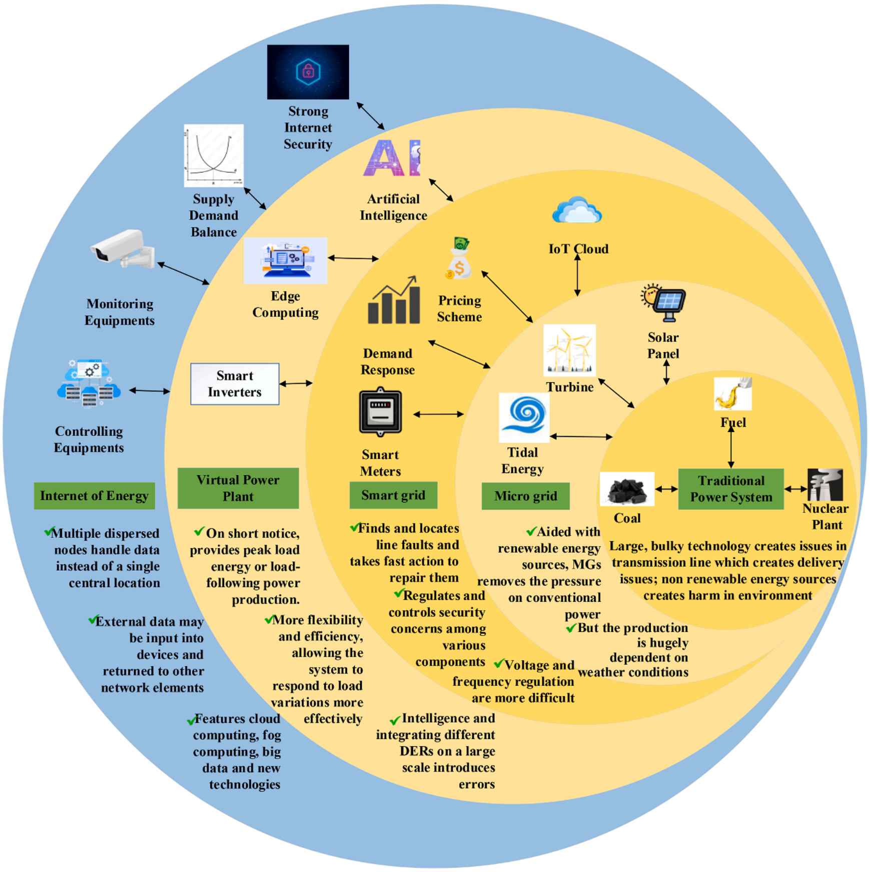

**Fig. 1.** Evolution of IoE from TPS.

2. Investigating the way from TPS to IoE to indicate the necessity and importance of modernizing the existing power system.
3. Analyzing the IoE in case of control, communication, networking, and security to help the researcher to find the lacking of the existing systems and scopes for overcoming the challenges to establish a stable and secure IoE system that will play a significant character in the energy community.
4. Investigating the properties and performance of different key technologies and protocols to improve the power system's dependability, scaling and effectiveness.
5. Addressing the control issues and challenges of the IoE with their proper control solution that not only overcomes the energy problems but also increase the system reliability, stability, robustness, and security management.
6. Directing a path to construct and control the next generation IoE system by addressing the necessity of future scopes and recommendations for improved energy distribution and consumption, cybersecurity, resiliency and pricing scheme.

## 2. Internet of energy: architecture & key technologies

As opposed to traditional power grids, a smart grid is a significant concept that combines associated power grid structures, intelligent networks, and smart observation to dramatically improve energy resource use.

There are, however, some flaws and restrictions. A new age of power supply approach, known as IoE, has been suggested to advance it. IoE creates a vision for the web's progression of smart grids that improves energy utilization efficiency, energy security, and dependability by combining dispersed and scalable sources based on smart grid [25]. It replaces concentrated power production and unidirectional power circulation with a more secure and sustainable energy web. A detailed comparison between TPS, MG, SG, VPP and IoE with addressing their applications has been highlighted in Table 1.

### 2.1. Architecture of IoE

IoE is commonly referred to as an internet-based power system that integrates sources of energy and got all of the flaws of the current smart grid by combining energy and ICT as shown in Fig. 2 [26]. Major issues, including more eco-friendly energy supplies, innovative hybrid energy models, safer and more efficient power generation, and control systems, are often resolved by IoE [25,26].

The spine of the upcoming grid, according to the center of Future Renewable Electric Energy Delivery and Management (FREEDM), will be an advanced energy dispensation framework that may permit a "plug-and-play" combination of SG elements and bi-directional electricity flow. FREEDM is an advanced production of power transformers that uses power electronics to enable bi-directional energy flow [27]. Fig. 3 indicates the components of the FREEDM system.

To fit the FREEDM system into the IoE power system, six key technologies work together to build the system's core, such as distributed grid intelligence (DGI) Software, plug-and-play interface, intelligent energy management (IEM) software, solid-state transformer (SST), internet equipment management (IEM) device, and fault isolation device (FID). The plug-and-play technology enables the addition and deletion of DRERs and DESDs anywhere at any time and from any place. The IEM device establishes a data medium by continuously monitoring loads and other operational devices while accurately referencing each device's control. The IEM software aids in the investigation of DESD and DRER accessibility in the FREEDM system, as well as the computation of pricing data. DGI software provides useful load balancing by effectively transferring energy within load pressure, sustainable energy generation, and energy storage at each point. The SST could be utilized in lieu of typical distribution transformers. The FID provides system security and reliability for a system that is remote from the centralized grid system.

**Table 1**
Highlights of different technologies.

| Technology | Project name | Component used | Capacity |
|---|---|---|---|
| TPS [18] | Bayswater Coal Power Plant, New South Wales | Coal | 11,084 MW |
| | Liddell Coal Power Plant, New South Wales | Coal | 2000 MW |
| | Eraring Coal Power Plant, New South Wales | Coal | 2840 MW |
| | Mount Piper Coal Power Plant, New South Wales | Coal | 1400 MW |
| | Vales Point B Coal Power Plant, New South Wales | Coal | 1320 MW |
| | Doel Nuclear Power Plant, Belgium & Nuclear | Nuclear | 2963 MW |
| | Tihange Nuclear Power Plant, Belgium | Nuclear | 3129 MW |
| | Kozloduy Nuclear Power Plant, Bulgaria | Nuclear | 2000 MW |
| | Embalse Nuclear Power Plant Argentina, Argentina | Nuclear | 648 MW |
| | Angra Nuclear Power Plant Brazil, Brazil | Nuclear | 2007 MW |
| MG [19] | Sundarbans Village Microgrid, West Bengal | Wind turbine | 120 KW |
| | Chhattisgarh RE Development Agency, Raipur | Solar system, Wind turbine | 500 KW |
| | Agnew Hybrid Renewable Microgrid, Leinstar | Solar system, Wind turbine, Fuel cell | 56 MW |
| | Garden Island Microgrid, Perth | Solar system, Wind turbine | 2000 KW |
| | Latrobe Valley Microgrid, Victoria | Wind turbine, Fuel cell | 7500 KW |
| | ATCO Hydrogen Microgrid, Jandakot | Wind turbine | 300 KW |
| | LABEIN's Commercial Feeder, Spain | Solar system, Wind turbine | 200 KW |
| | Continnuon's MV/LV Plant, Netherlands | Solar system | 315 KW |
| | CM Official Resident Microgrid, Bihar | Solar system | 125 KW |
| | Dharnai Microgrid, Bihar | Wind turbine, Fuel cell | 100 KW |
| | Xiamen University DC Microgrid, Fujian | Solar system | 150 KW |
| | RIT Microgrid, New York | Solar system, Wind turbine, Fuel cell | 600 KW |
| | Mad River Park Microgrid, Watisfield | Solar system | 500 KW |
| | California Santa Cruise Island, California | Solar system, Wind turbine | 600 KW |
| | Alaska Power Plant, Alaska | Wind turbine | 500 KW |
| | Hawaii Hydrogen Power Park, Hawaii | Solar system, Wind turbine, Fuel cell | 200 KW |
| | Eigg Island Plant, Scotland | Solar system, Wind turbine | 144 KW |
| | University Of Nottingham Tastebed, UK | Solar system, Fuel cell | 500 KW |
| | Bornholm Multi Microgrid, Denmark | Solar system, Wind turbine, Fuel cell | 55 MW |
| | Sino Danish Microgrid Collaboration, Shanghai | Wind turbine | 200 KW |
| | Goldwin Demonstration Microgrid, Beijing | Wind turbine, Fuel cell | 3730 KW |
| | Royella Solar Firm, Canberra | Solar system, Wind turbine | 240 MW |
| | Hefei University of Technology Microgrid, Anhui | Wind turbine | 1000 KW |
| SG [20] | Pacific Northwest Smart Grid, Washington | Solar system, Wind turbine, Hydropower | 112 MW |
| | Energy Storage with Staying Power, Pennsylvania | Solar system, Wind turbine | 1000 MW |

(*continued on next page*)

**Table 1** (*continued*)

| Technology | Project name | Component used | Capacity |
|---|---|---|---|
| | CCET, Texas | Solar system, Wind turbine, Hydropower | 8500 MW |
| | ADELE, Germany | Solar system, Wind turbine, Hydropower | 200 MW |
| | C2C, UK | Solar system, Wind turbine | 152 MW |
| | Orkney Smart Grid, UK | Solar system, Wind turbine | 26 MW |
| | Decose, Italy | Solar system, Hydropower | 345 MW |
| | Edge, Denmark | Solar system, Wind turbine, Hydropower | 213 MW |
| | Hebei Electric Power Company, Hebei | Solar system, Wind turbine, Hydropower | 4590 MW |
| | Hunan Electric Power Company, Hunnan | Solar system, Wind turbine, Hydropower | 4500 GW |
| SG [20] | CESC, Mysore | Solar system, Hydropower | 152 GW |
| | UHBVN, Hatyana | Solar system, Wind turbine, Hydropower | 132 GW |
| | MSEDCL, Maharashtra | Solar system, Hydropower | 26.2 GW |
| | UGVCL, Gujrat | Solar system, Wind turbine | 1700 GW |
| | Jiangsu Electric Power Company, Nanjing | Solar system, Wind turbine, Hydropower | 12,700 GW |
| | Fujian Electric Power Company, Fujian | Solar system, Wind turbine | 6000 GW |
| | AEP Ohio, Ohio | Solar system, Wind turbine | 2954 MW |
| | Detroit Edison, Michigan | Solar system, Wind turbine, Hydropower | 11,084 MW |
| | APDCL, Assam | Solar system | 90 GW |
| | Narara Ecovillage Smart Grid, Narara | Solar system, Wind turbine, Hydropower | 471 KW |
| | Berrimal Wind Farm, Western Victoria | Solar system, Wind turbine, Hydropower | 72 MW |
| | Mortlake South Wind Firm, Victoria | Solar system, Wind turbine | 157 MW |
| | Aldoga Solar Firm, Queensland | Solar system, Wind turbine, Hydropower | 480 MW |
| VPP [21,22] | FENIX, France | Solar system, Wind turbine | 150 MW |
| | VPP of Siemens Company, Germany | Solar system, Hydropower | 1450 MW |
| | Gresham House Energy Storage VPP, UK | Solar system, Wind turbine | 265 MW |
| | UK SMS VPP, UK | Solar system, Hydropower | 9 MW |
| | Hitachi ABB VPP, Singapore | Wind turbine | 2.4 MW |
| | Stategrids VPP, Jiangsu | Solar system, Wind turbine | 10 GW |
| | Ausgrid and Reposit VPP, New South Wales | Solar system | 10 MW |
| | Smart Energy Australia VPP, Victoria | Solar system, Wind turbine, Hydropower | 1 GW |
| | AGL Virtual Power Plant, Adelaide | Solar system, Hydropower | 5 MW |
| | Sonnen VPP, Italy | Solar system, Hydropower | 1 GW |
| | Pennsylvania Americal Water VPP, Pennsylvania | Solar system, Hydropower | 400 KW |
| | Detroit VPP, Michigan | Solar system, Wind turbine | 0.3 GW |
| | Wasatch Energy and Sonnen VPP, California | Solar system, Wind turbine | 0.06 GW |
| | Swell VPP, California | Solar system, Hydropower | 0.3 GW |
| | Shizen Energy VPP, Japan | Wind turbine | 5.3 KW |
| IoE [23,24] | Scottish Southern Energy, UK | Wind turbine, Hydropower | 1459 MW |
| | A2A, Chivasso Power Plant, Italy | Coal, Fuel cell | 1123 MW |
| | Beijing Jingkai Investment Development, China | Coal | 2.4 MW |
| | Zhangbei Herun Energy Co., Ltd., China | Wind turbine, Hydropower | 240 MW |
| | Jingneng Capital Energy Internet Project, China | Wind turbine, Hydropower | 424 KW |
| | Bord Gais, Ireland | Wind turbine, Hydropower | 445 KW |
| | Salt River Project, Arizona | Wind turbine, Hydropower | 232 MW |

#### 2.1.1. *GRIP architecture*

Integrating a rising number of new grid participants: DRES, demand-side administration structure, and so on into the current functional approach is challenging. Operators are worried about uncertain demand response and unobservable generation from decentralized renewables. The millions of houses, buildings, and industries that make up the Energy Internet cannot be managed by the conventional centralized management model, which can manage numerous observation and authorization points. A new grid with an intelligent periphery, known as GRIP, has been suggested in reaction to these fundamental changes and is based on the three pillars. They are Layered architecture, abstracting commonality, and empowering the periphery. The clusters are organized hierarchically in the GRIP architecture.

Many substations, MG, and maybe industries make up a central transmission grid cluster; each is an individual bundle. A significant core cluster that houses multiple smaller MG, structures, and dwellings comprises a network branch as well as the related administration grid. There may be numerous clusters of smart houses and buildings inside a MG branch housed inside a substation cluster. Clusters are intelligent systems that can acquire actual-time information acquired from the SG, assess their status, take appropriate steps, and make operational control. Here, a basic design of three levels is recommended. The device layer includes sophisticated actuators and sensors. The devices are used by a superior layer known as the service layer to carry out particular services. The application layer sits on top and uses the services offered below to do the cluster's tasks. These tasks will be further discussed in the next section, including managing load and scheduling generation [28].

#### 2.1.2. *Fog based architecture*

A fog-based architecture network is suggested to link IoE and fog nodes in smart cities. The fog calculating approach assists the IoE elements by providing small latency, which speeds up data processing. A two-layer architecture is used here where the initial layers are made up of fog nodes and the second layer handles the traffic from IoE devices and lower latency [29].

- **Fog Node Layer:** By connecting smart city IoE devices to a fog computing environment, the service demands of the consumers may be satisfied. Several physical servers form the fog node, explicitly covering the diameter. Both cable and wireless media can be used to link the fog nodes. The components of a fog node include a CPU, configurable equipment methods, and network assistance. Intelligent sensors gather information about the immediate surroundings, and the fog node analyzes it in real-time and provides information that aids decision- making. Additionally, the fog node helps the radio access network by enabling unicast wireless communication within a specific range. The fog node, which offers storage for memory-based passive applications, can incorporate the local database. This offers the benefit of reduced processing and loading times for demanding IoT applications [30].
- **IoE Layer:** This layer is the ecosystem where users can deploy applications without restrictions. IoT devices are grouped based on their location and what they can do. This contributes to a reduction in time, cost, and energy overheads. The need for processing and integration of software and hardware services will result in a rise in

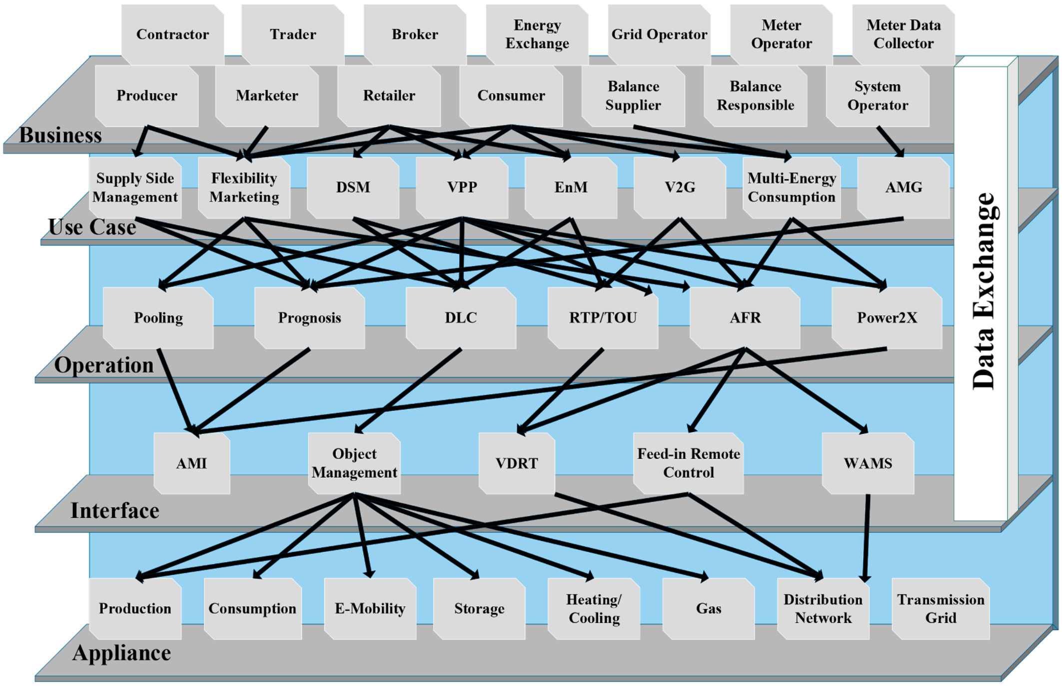

**Fig. 2.** Architecture of energy internet.

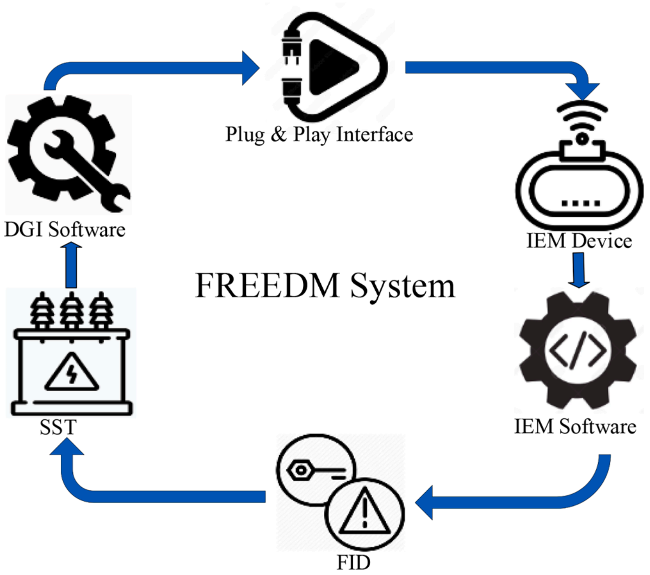

**Fig. 3.** The FREEDM system elements.

the burden of data centers. Peer-to-peer (P2P) TCP/IP transmission takes place when there is proximity between two IoT devices. These devices can connect to the fog node through WiFi, ZigBee, and Bluetooth-like protocols if they are far apart [31].

### 2.1.3. *IoE communication architecture*

The choice of a suitable IoT communication standard is critical since it determines how an IoT device will function. The proficiency of networks and applications is influenced by the standards used [32]. Fig. 4 shows a detailed IoE communication architecture structure. Some standards for various situations and applications are discussed below:

- **Bluetooth:** Bluetooth is a communication standard that is used to create a wireless personal area network (WPAN) having various versions, including 1.0, 2.0, 3.0, 4.0, and 5.0. The most updated version is 4.0, known as Low Energy Bluetooth, and 5.0, which are developed primarily for IoT networks [32].
- **Radio Frequency Identification:** It uses radio wave frequencies in order to transmit physical item recognition. Tags are classified into two categories based on their power supply Active and Passive RFID tags.

Active RFID is equipped with an uninterrupted power supply, like a battery, and can communicate with an RFID reader across extended distances [33]. Because of its modest size, RFID is well-suited for IoT integration.

- **Wireless-Fidelity (Wi-Fi):** In order to communicate within the internet and local area network (LANs), the majority of computer devices employ Wi-Fi. Currently, there are four versions of this standard: IEEE 802.11 a, b, g, and n, each having various speeds, ranges, and functioning techniques. Nowadays, Wi-Fi has turned into the prominent transmission architecture for the IoT environment due to the introduction of new standards, high speeds, and tiny sizes [32].

#### 2.1.3.1. *Networking protocol.*

The protocols applied in every node of a dispersed network must be stated to activate communications. The Transmission Control Protocol (TCP) or Internet Protocol (IP) based communication technologies now in use offer a sufficient amount of bandwidth for real-time observation and the management of an intelligent power system. It can also set up its own "utility-Internet" having complete authorization over the connection with improved privacy and dependability. The primary leveled protocols which might be utilized to implement IoE are discussed in this section [34]. Table 2 shows various network protocol layers.

- **Link layer/ Terminal layer:** The medium for data transit is the Physical Layer (L1), where the connection between two nodes is Data Layer (L2). Regarding wired technologies, the Ethernet protocol (IEEE 802.3) is typically used in SG control systems for quick and

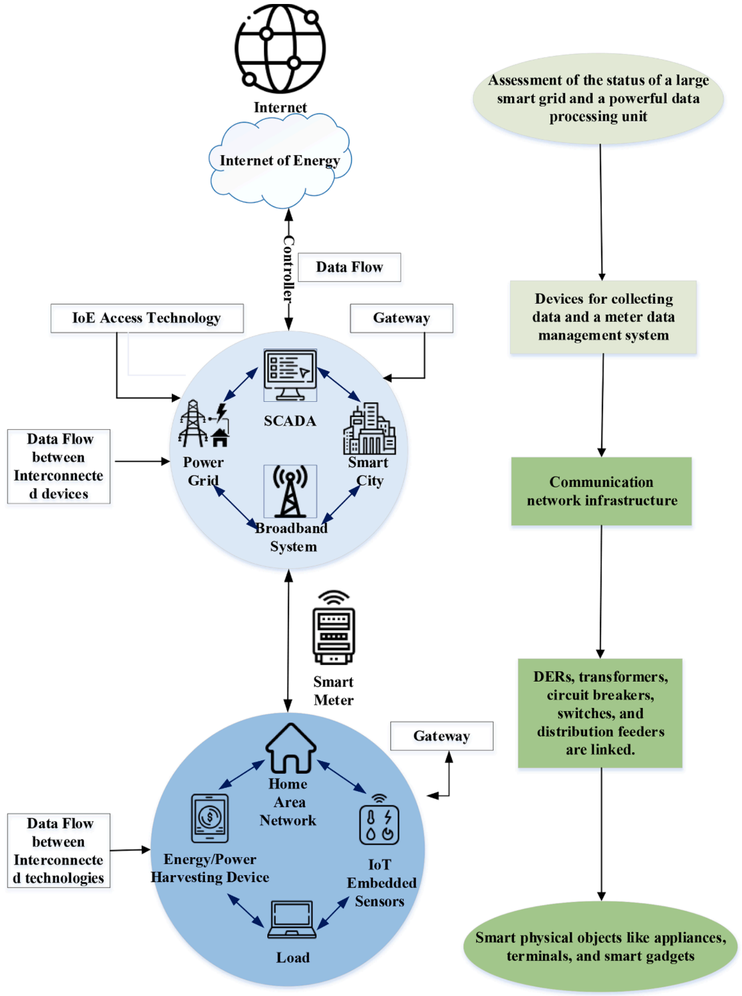

**Fig. 4.** A basic architecture for IoE communication network.

**Table 2**
Highlights of different network protocols.

| TCP/IP model | | | Stack protocols | | | | Security protocols |
|---|---|---|---|---|---|---|---|
| Application Layer | L5 | Process to Process Communication | Multiple Applications | | | | |
| Transport Layer | L4 | Host to Host Communication | TCP/UDP | | | | TLS/SSL, DTLS, SRTP |
| Network Layer | L3 | Inter-network Communication | IPv4/IPv6 | | | Zigbee | IPsec |
| Data Layer | L2 | Link Establishment | Ethernet | POS PPP | RLC MAC | IEEE 802.15.4 | MACsec |
| Physical Layer | L1 | Physical Communication Medium | TDM | SONET WDM | LTE OFDM MIMO | | |

dependable work. Nevertheless, the price to construct this kind of system is high for remote connections. The Medium Access Control (MAC) protocol, an L2 link layer sublayer, and the Ethernet protocol are frequently connected [35].

- **Data communication layer/ Internet layer:** The united power distribution and authorization system has diverse requirements for communication speed, bandwidth, latency, and equipment cost, making it difficult to choose suitable communication technology. The Internet Layer (L3) regulates how packet relaying works by allocating addresses to nodes and scattering frames through channels. Because IP can function freely of the basic physical layer, L1 and L2 layers, any two terminal locations connected by a minimum of one or more webworks supplying a data link among them are connectable by end-to-end SG apps [35,36].
- **Platform layer/ Transport layer:** Host-to-host connections are possible thanks to transport protocols (L4). User Datagram Protocol (UDP) and TCP are both the most used transport layer protocols that deliver a stream of packets between applications in a reliable, orderly, and error-checked manner. The design specifications depend on the weighting of velocity and reliability and the requirement for error detection. TCP is the ideal choice since the power system application needs dependable connections. Instead, TCP's limitations in performing congestion control for several data sources and its naturally delayed acknowledgement may make it inefficient for SMG management, leading to unnecessary packet retransmissions and performance deterioration [37]. Specially adapted Multi-Path Transport Protocol, and Scalable Secure Transport Protocol can overcome these problems.
- **Application layer:** The protocols that facilitate process-to-process connections are found in the application layer (L7), which serves as both the client and application access points. It includes widely used features, including file sharing, directory services, electronic messaging, and remote file access. Domain Name Service, Dynamic Host Configuration Protocol and Network Time Protocol are

examples of application protocols that can be utilized for IoE network administration. International standards have been established for achieving synergy within this layer regarding MG. IEC 61,850 is a great auspicious quality for designing energy communication networks [38].

*2.1.3.2. SDN network architecture.* This modeling introduces a new device named Intelligent Energy Controller (IEC). Its primary responsibilities include organizing local data and sending it to the communication center via the electro- power connection system. The management of local energy is then done using the return data from the data center. Regional clients can inspect pertinent data by viewing these data center outcomes on the IEC. This data contains how much electricity is bought and sold locally, how much it costs to buy and how much it makes, whether or not other people utilize local energy and other relevant data.

SDN is separated into three levels, as seen in Fig. 5. The infrastructure layer is constructed with various networking devices like switches and routers, whose control tasks are administrated by the control layer. The top layer is the application layer, where programmers can easily create various applications as needed. The median layer is the control layer and through a unique agreement, such as OpenFlow, its control plane interfaces to the south to regulate network traffic in the infrastructure layer [39].

### 2.1.4. Vehicle to grid (V2G) communication

This is an IoE-based V2G communication protocol that consists of two phases.

- **User registration phase:** The USP receives the user's registration request and identification ID over a secure connection. The USP generates a profile and additions a new record to its database as soon as it receives the request. A secret key, a series of shadow identities, and a unique pseudo-identity ID are then generated randomly and utilized in the event that contemporaries within the USP and client are lost. The USP then creates a message and delivers it to the user over the encrypted channel. To communicate with the user in the future, the USP records the message in its database [40].
- **Authentication Phase:** The user must go through the authentication procedure to utilize the charging station during this phase. The IoE-based V2G communication ensures protection against impersonation or foreign attack, client security, defense against eve dropping or prevent attacks, etc. [40].

## 2.2. Edge based IoE system

In contrast to transferring data all the way to remote data centers or cloud servers, edge computing refers to the technique of processing data closer to its source or the "edge" of the network. The phrase "Edge-based Internet of Energy" refers to the use of edge computing concepts for energy management and the IoE. Edge computing is an addition to or extension of cloud computing that processes data close to the data source, increasing network performance and efficiency overall with less latency. Edge computing reduces the amount of bandwidth needed compared to processing in the cloud by moving computations to the network's edge.

### 2.2.1. Micro-moments based energy efficiency solution

This infrastructure is implemented using recommender system that gives end users individualized guidance at the right time and a micro-moment analysis that helps identify anomalous energy usage events. In this infrastructure data is gathered by recording ambient conditions, occupant habits, and footprints of electricity consumption. Then, using an ensemble bagging tree (EBT) classifier, it locates aberrant power consumption patterns. Then the recommendation and automation stage is implemented giving end-users individualized advice for endorsing appropriate energy use and gives them the option to monitor equipment. Lastly, statistics and visualization is achieved by enabling the depiction of anomalous consumption data and effectively and engagingly provides end-users with their energy consumption statistics using a mobile app [41,42].

### 2.2.2. M2SP-EdgeIoE framework

The following elements created by the authors make up the M2SP-EdgeIoE framework: (i) data collection: gathers micro-moment-based data for monitoring environmental conditions and power usage; energy disaggregation (ii) detects each device using its power trace after applying Non-Intrusive Load Monitoring (NILM) techniques to separate the primary power consumption into appliance-level data; (iii) Anomaly detection: To identify comparable energy behavior and its environment, micro-moment analysis and classification algorithms are used [43]; (iv) recommendation and automation: generates tailored advice to the

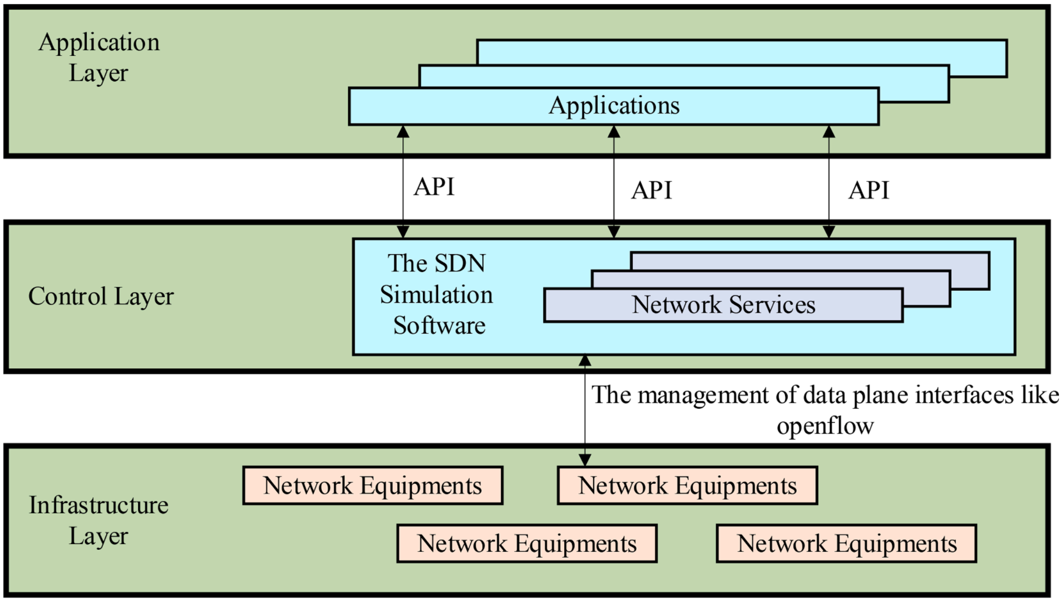

**Fig. 5.** SDN network layers.

end-user to support particular actions to improve energy efficiency along with suggested automation; and (v) visualization: effectively and captivatingly present data, anomalies, and recommendations through a mobile application [44,45].

### 2.2.3. *Edge based IoE in health care implementation*

The need for a health care monitoring system is always great due to the aging population growth and rise in chronic diseases. The development of technology like IoT and cloud has made healthcare more accessible and affordable. Three layers make up the system. The wearable sensor devices' first layer, collects and gathers the physiological data, the transmit layer uses the Internet to send the data collected to the application server and the application server handles data analysis, decision-making, and feature extraction [46].

The installed IoT devices in edge computing-based healthcare systems collect and locally evaluate data from patients. Patient's physiological data is collected by wearable IoT devices, which then send it to application servers. Edge computing brings processing and computing power closer to the source of the data. When internet connections are inadequate for accessing centralized databases, this facilitates data access. As a result, adopting edge computing for the health care system can provide more control and the capacity to use data in close to real-time, which continues to be a promising technique to assist service providers in distributing their network and data in a way that it can be used and shared rapidly and securely [47].

## 2.3. *Key technologies*

An ideal IoE system may consist of various primary and secondary components. The basic components are highlighted in this section.

### 2.3.1. *Router*

Excess energy comes into the grid by energy routers when central supply exceeds local demand. The grid utilizes the E-router to fill in the energy gap when there is a local energy deficit. When a user needs change over time, energy routers are responsible for detecting demand changes and dynamically adapting energy delivery [48]. The E-router may be distinguished into three sorts on the dissimilar types of technological implementations. Fig. 6 depicts an SST-based E-router that converts multiple energy types and voltage volume in the administration network [49].

The MPC router and the SST-based E-router have similar implementation concepts in Fig. 7, but the latter has a distinct structure and is often used in small voltage administration networks of houses and buildings. Fig. 8 shows a PLC-based E-router whose execution differs from the two kinds of energy routers outlined before. It accomplishes time division multiplexing and transfer of power in a residential system, expanding standard PLC technologies [49].

### 2.3.2. *Energy storage system*

Electricity demand does not remain steady throughout the year. The rising demand for electricity causes a disproportion between supply and demand, consequently, the electricity supply being shut down or load-shedding. The extra power generated by the RE is stocked in storage systems, which can provide electricity directed toward the load in the event of a grid breakdown or power shortage. Different forms of ESS, such as batteries, flywheels, and supercapacitors are available to increase power quality, grid operation, dependability, flexibility, resilience, and reduce power imbalance problems [50]. A comparative study of different ESS has been conducted in Table 3.

### 2.3.3. *DER*

The IoE's technological infrastructure might include a wide range of

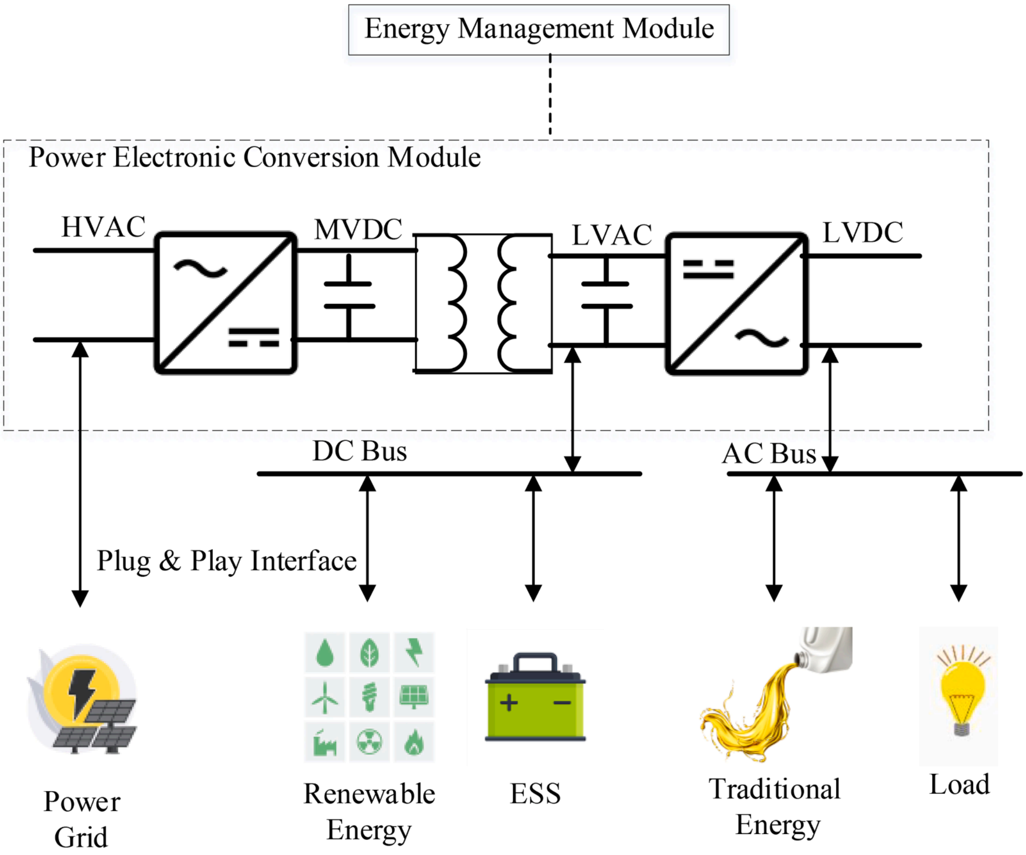

**Fig. 6.** Basic architecture of SST router.

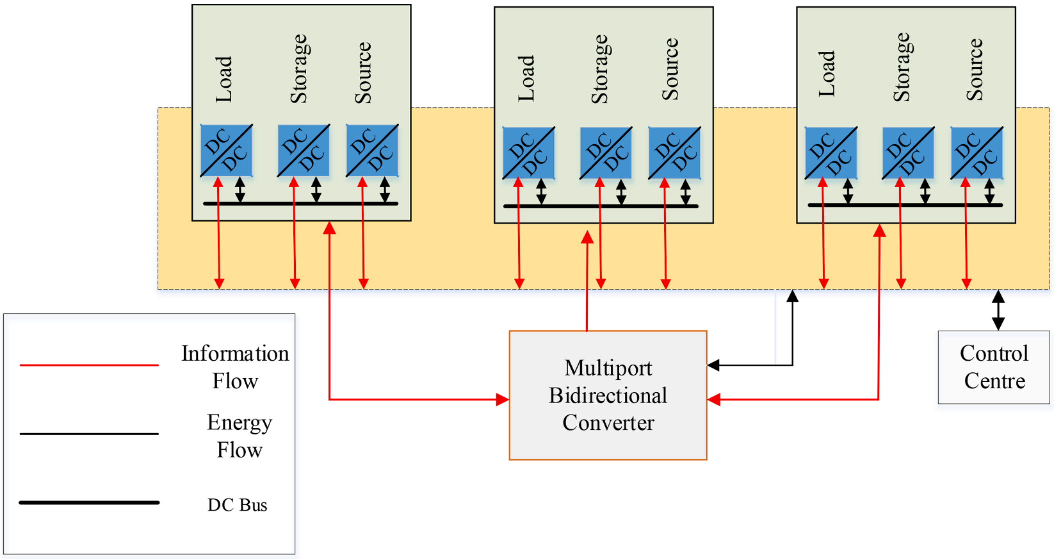

**Fig. 7.** Basic architecture of MPC router.

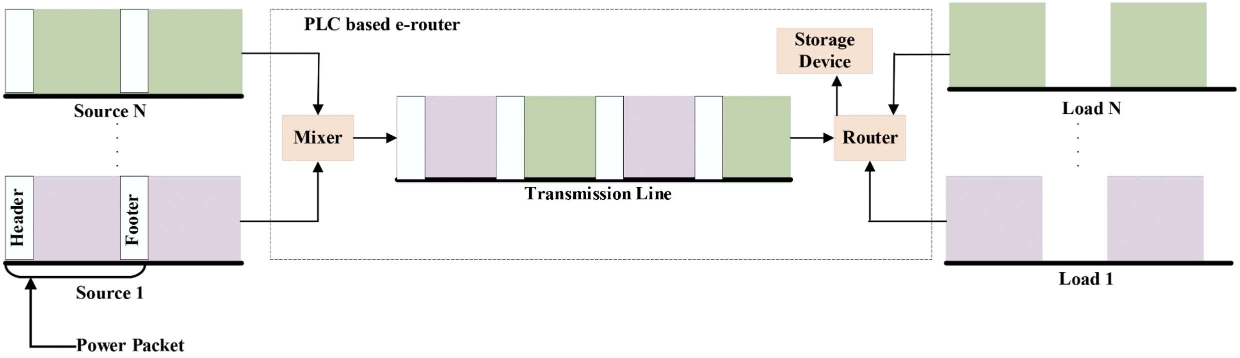

**Fig. 8.** Basic architecture of PLC router.

**Table 3**
Highlights the different ESS [50].

| Characteristics | Battery (Lead-acid) | Battery (Li-ion) | Flywheel | Supercapacitor |
|---|---|---|---|---|
| Capacity | ≈100 MW | ≈ 40 MW | ≈ 20 MW | ≈ 0.3 MW |
| Life-cycle (Predictable) | 2.5–5 years | 4–15 years | ≈ 15 years | ≈ 20 years |
| Response Time | 6–10 ms | 15 ms | 5 ms | 6–8 ms |
| Density of Energy | 25–40 kWh/ton | 0.02–0.2 kwh/kg | 0.05 kwh/kg | ≈ 0.05kwh/kg |
| Density of Power | 35–100 kwh/m$^3$ | 30–1000 w/kg | 1–5 kw/kg | 4 kw/kg |
| Cost of Power | 350–650 $/kW | 950–3500 $/kW | 300–400 $/kW | 150–400 $/kW |
| Cost of Energy | 250–400 $/kW | 650–3900 $/kW | 900–14,000 $/kW | 400–2000 $/kW |
| Efficiency | 65–90 % | 80–90 % | 90–95 % | 90–95 % |
| Advantages | Low cost | High production of power and energy, high productivity | High efficiency with larger power density and | High efficiency with larger power density and life-cycle |
| Limitations | Low energy density | High maintenance cost and requirement of recycling | Low energy density | Low energy density and toxic in nature |

DER, including RE, ESS, and fuel cells. The performance of RE sources is determined mainly by environmental factors, including wind speed and direction, temperature, and solar irradiation, which vary with time and year and have various effects on IoE generation. To fulfill the voids left by one RE source and provide end users with a constant and predictable power supply, many RE sources with a number of ESS may be deployed concurrently [51]. Different RE sources are highlighted in Table 4.

### 2.3.4. *Plug-and-play interface*

Plug-and-play (PP) refers to the capacity to produce energy even from small-scale generating resources such that power delivery to the network is as simple as inserting a plug within a socket [11]. The PP feature is supported by an intelligent communication interface, which detects the connectivity position of a random gadget and allows the grid to accommodate different types of ESS and generation systems [52]. The energy production request message is sent to the energy router by the renewable source when it is plugged in and prepared to provide

**Table 4**
Highlights of different renewable energy [51].

| Attributes | Wind energy | Solar energy | Tidal of water |
|---|---|---|---|
| Fuel Type | Wind | Sunlight | Water |
| Controllable | × | × | × |
| Harmonics | ✓ | ✓ | ✓ |
| Unbalanced Voltage | × | ✓ | × |
| Sag/Under Voltage | ✓ | × | × |
| Flicker/Interruption | ✓ | ✓ | × |
| Life Cycle (Predictable) | ≈ 20 years | ≈ 20 years | ≈ 60 years |
| Production Cost (USD/kW h) | 5–12 | 20–35 | 7–16 |
| Efficiency Achieved | ≈ 60 % | ≈ 30 % | ≈ 80 % |
| Application in Industrial Department | Planning | Planning | ✓ |
| Application in Commercial Department | ✓ | Planning | ✓ |
| Application in Residential Department | × | ✓ | × |

electricity. The local power demand is examined by the energy router, together with the current load demand and power capability of DESD, before the energy router permits entry to the renewable to begin generating electricity [52]. Table 5 compares different technologies used in IoE.

### 2.3.5. *Smart metering*

Smart Meter (SM) is an important element for SG that helps the user to optimize their energy usage and utility charge as shown in Fig. 9. A communication connection and meter information management make up the smart meter infrastructure (SMI) which facilitates the distribution and collection of data between meters and services as shown in Fig. 10. The SMI contains of intelligent sensors, energy management techniques, smart home meters, and smart appliances. The electrical parameters that the smart meter calculates, such as voltage, current, active, reactive, perceived power, etc., would be communicated to utilities so that they may store the data for later retrieval and study [53].

*2.3.5.1. Smart metering infrastructure.* The infrastructure for smart meters connects service providers with client-end field sensors. The customer's property may include gadgets like an intelligent meter, temperature sensing device thermostat and a display, etc. At the same time, the distributor has applications for charging the customer usage [53]. The SMI technology part consists of the following:

- **Communication network:** There are three types of SMI communication networks such as (i) Wide Area Networks (WAN) which manage traffic volume and unnecessary delays, (ii) Neighborhood area networks (NAN) to communicate and transmit information from the smart meter to the data collector unit, and (iii) Home Area Networks (HANs) that allows devices inside end-user premises to communicate and cooperate.

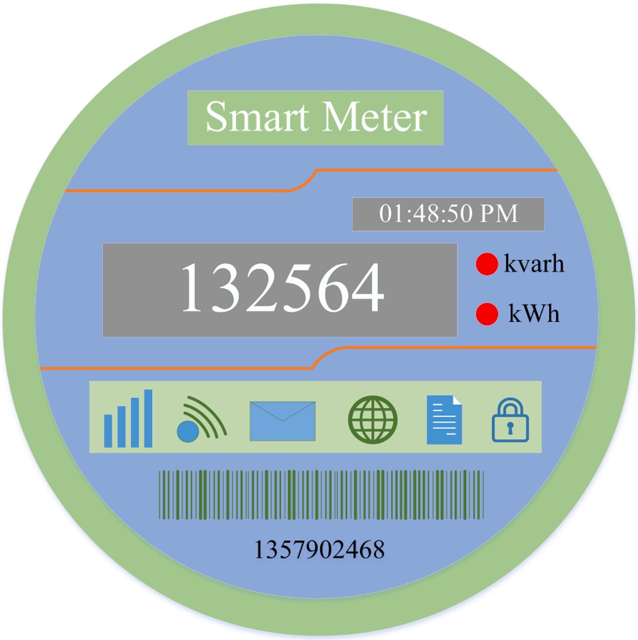

**Fig. 9.** Illustration of smart meter.

- **Meter data collection system:** The control center technology includes software packages for the meter data collection system. Through a communication network, the data collector unit gathers information from smart meters, further transmitting it to the end system. In the event of data transmission failures or a complete blackout, the operator may connect and detach meters using a data collector unit, and this information will be kept in a database.
- **Meter data management system:** A host system known as a meter data management system (MDMS) collects, saves, and asses the calculated data for charging, duration of utilization, day of the week, peak load management, etc. The MDMS provides on-demand meter readings, energy status authentication, and remotely connect/disconnect of remote meters. The data on utilization and affairs collected from the meter end is included in the imported data and is essential for analysis and demand forecasting.

## 2.4. *IoE protocol*

IoE protocol can be divided into two sections which can be described below:

### 2.4.1. *Smart network protocol*

Smart networks may accommodate a wide range of communication protocols. One of the most common usages of smart network protocols is in residential areas, depicted in Fig. 11. IoT networks in the field may

**Table 5**
Highlights the different key technologies used in IoE [52].

| Components | Feature | Activities | Advantages | Issues |
|---|---|---|---|---|
| Router | Solid phase converter, grid management and communication device | Grid-based data administration | Improve dependability, productivity, and privacy | Data privacy, transmission and reception |
| ESS | Comes in various types such as batteries, supercapacitors etc. | Stores produced energy for upcoming usage | Improves grid stability, dependability, productivity, and privacy | Price, heat, and emission power |
| DER | Mainly includes solar and wind energy | Produces energy | Stabilizes power efficiently | Quality of production |
| Plug-and-Play Interface | A monitoring interface | Computer storage | Detects when the ESS is disconnected | Privacy and dependability |
| Smart Meter | Can perform in wired and wireless environment | Optimizes the usages of home appliance, and balances between generation and production | Utilize consumer electricity usage and utility cost | Possibility of cyberattack |

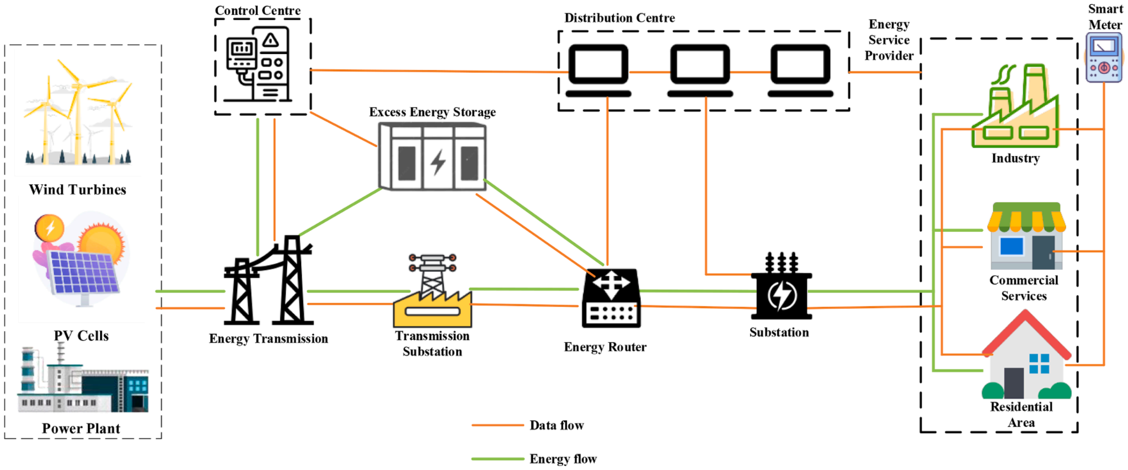

Fig. 10. Smart metering infrastructure.

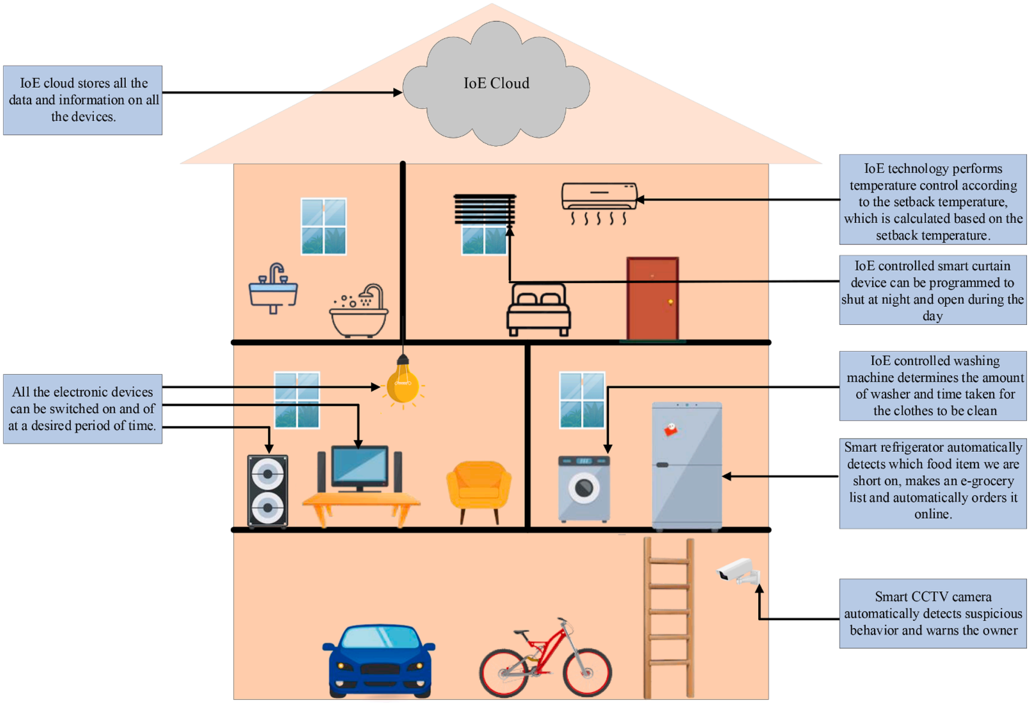

Fig. 11. IoE and residential consumption management.

select a scattering path by creating an information meeting and a connection design through the protocol stack since they are self-aware. The supported routing patterns include proactive, reactive, and hybrid techniques in addition to static, adaptive, flat, and hierarchical patterns. The standard protocols are assessed in two stages [54].

- **Application layer:** To address concerns like extensive information, safety, flexibility, observability, expandability, and real-time adaptation, the creation of IoE infrastructure needs architecture-based work specifications [55]. Since it must support networks with limited resources, application layer protocols are created to give dependable and effective transmission.
- **Infrastructure layer** Any network's backbone is its infrastructure, which keeps nodes linked and current for data transfer. Infrastructure layer protocols are in charge of meeting exact specifications, acquiring divergent policies, matching traffic designs, the proper power consumption, etc.

### 2.4.2. *Standards and protocols of EV charging*

The intelligent charging system connects with the entire system and gives the vehicles the best possible charge. For creating appropriate communication between the entities, a few basic protocols must be followed [56].

- **Open Charge Point Protocol (OCPP):** A protocol based on applications is necessary to establish the foundation for information transmission within the charging point and the main administration point. Vendor-focused and freely downloadable, this application protocol was created by the Open Charge Alliance. It offers additional flexibility for EV drivers' information to be easily obtained. The features of OCPP are transaction management, safety, intelligent charging, message presentation, and creation of warnings in case of failure [56].
- **Open Charge Point Interface (OCPI):** This interface used to facilitate data exchange on charging stations between charging station

owners as well as the e-mobility service. The following is a list of the OCPI's characteristics [57].

  - Updates are being made to the session information and the location status.
  - Using a distance to send orders.
  - Supplying charge information records to offer accurate billing amounts.
  - Using a token exchange to authorize charging stations

- **OADR:** It is intended for information sharing inside the system to analyze the OADR. It is standardized for dispatching and collecting reliable data among DER and the energy management structure's control system to precisely estimate demand during its operation at peak times [56].
- **Global System for Mobile (GSM):** It is the world's most well-known new mobile network. It uses circuit switching as its foundation and runs between 900 and 1800 MHz. Having transmission rate of up to 270 kbps, Gaussian Minimum Shifting Key is a modulation method employed. This protocol's architecture is divided into the mobile handset and the substations of the base station, networking switching and operation support [58].
- **General Packet Radio Service:** It uses the GSM network's packet-based data transfer technology. This network enables faster data transmission rates for IP-based applications than the GSM [59]. This specific networking protocol is used mainly for SG applications in faraway locations.

## 3. Challenges in IoE

Fig. 12 illustrates the applications of IoE in smart power systems. However, integrating IoT into energy systems has its obstacles and challenges [60] as shown in Fig. 13. Table 6 discussed the highlights of the challenges. They are briefly described below:

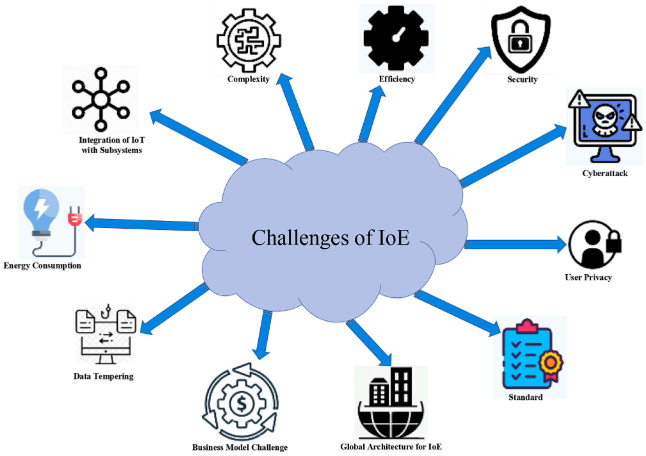

**Fig. 13.** Challenges of IoE.

### 3.1. Energy consumption

Many internet-connected systems need to run to allow IoT connectivity in energy systems. A significant quantity of energy is required to run this system and transport the massive data generated by IoT gadgets. As a result, IoT systems' energy usage remains a significant concern. Various techniques for reducing the power consumption of IoT systems have been attempted. Set the sensors to sleep mode while not in use, for example. Radio optimization methods, including cooperative communication and modulation optimization, have been suggested as a solution for this challenge [61].

### 3.2. IoT integration with subsystems

One of the significant challenges is merging an IoT system into the

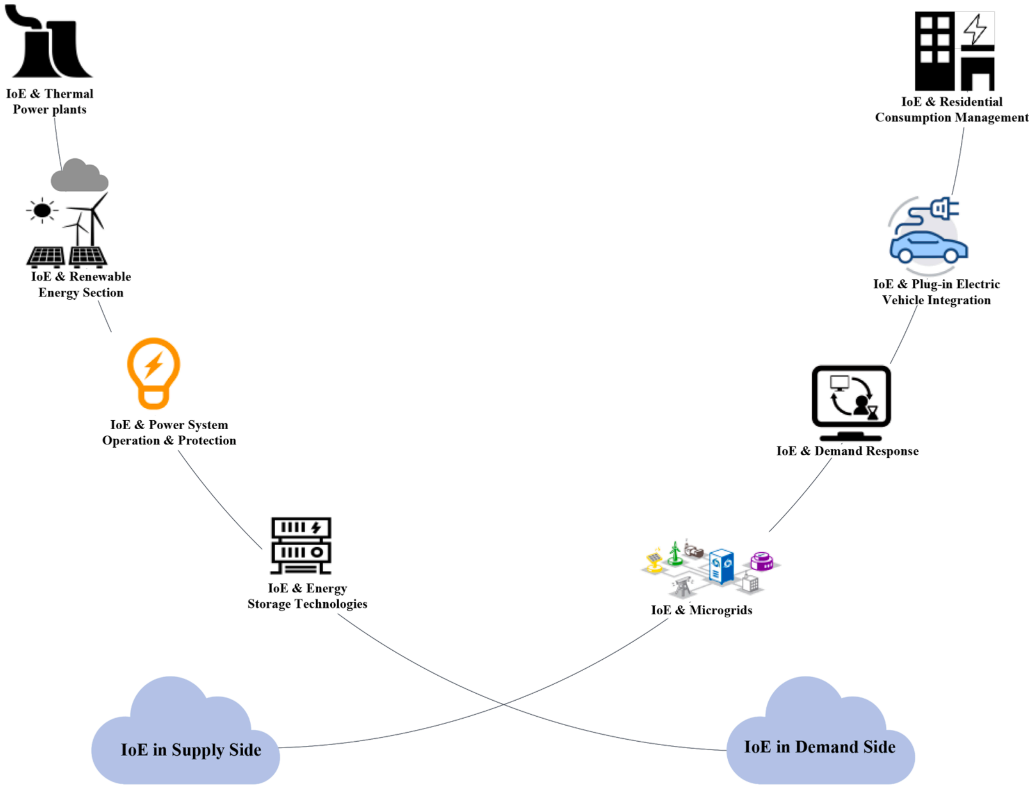

**Fig. 12.** IoE in smart power system.

**Table 6**
Highlights of challenges in IoE.

| Serial No. | Sectors | Issues | Solutions | References |
|---|---|---|---|---|
| 1. | Energy Consumption | (i) Requires high-speed data transmission, (ii) Usage of energy | (i) Radio optimization methods, (ii) Distributed computing methods | [61] |
| 2. | IoT integration with subsystems | (i) Data management for IoT, (ii) Linking IoT with existing model | (i) Developing models for co-simulation, (ii) Modeling of a comprehensive energy system. | [62,63] |
| 3. | Complexity | (i) IoE foundation is a complex set of systems, (ii) Coordinate the regulation of controllable loads. | (i) DSP feature upgrading in control mode, (ii) Sophisticated control technology algorithms | [25,56] |
| 4. | User privacy | (i) Maintaining users' private information | (i) Requesting users' permission, (ii) Developing a DLP algorithm | [64–66] |
| 5. | Efficiency | (i) Establishing communication between each element of a composition that efficiently transmits energy | (i) Developing new framework reducing human interaction in system administration, (ii) Construction of the self-organized system | [67] |
| 6. | Standard | (i) IoT device deployment on a large scale, (ii) IoT device consistency issues | (i) Create a system with a common notion, (ii) Open information models and protocols | [68–70] |
| 7. | Global Architecture for IoE | (i) Providing a trustworthy end-to-end connection, (ii) Common architecture doesn't fit everywhere | (i) Heterogeneous reference architectures, (ii) Open standards can be applied | [71,72] |
| 8. | Business Model | (i) Cannot easily handle a high energy proportion, (ii) It is unable to invoice to track the user | (i) Developing a future service-oriented electrical market | [73] |
| 9. | Data Tempering | (i) Intruder can change energy-related data, (ii) Additional smart devices can suddenly present on node | (i) Building an attack detection technique based on a mitigation strategy | [74,75] |
| 10. | Cyber Attack | (i) IoE system may create inaccurate data, (ii) Contains cyber physical assault | (i) Enabling encryption schemes, distributed control systems | [54,76] |

energy system. Energy industry subsystems employ a range of sensor and data transmission technologies because they are unique. To manage data interchange across the subsystems, solutions are needed [62]. The integration difficulty may be overcome while considering the IoT needs of a subsystem by designing an integrative framework for the power system [62]. Another method for system integration and reducing synchronization lag issues across subsystems for energy systems is to create co-simulation models [63].

### *3.3. Complexity*

Analyzing, evaluating, and constructing a proper communication infrastructure will be challenging. It focuses on individualized energy consumption in the house also the usage of green distributed energy. It will be crucial to coordinate the regulation of all controllable loads due to the Internet's significant share of renewable energy. Therefore, to improve this capacity, it is necessary to enhance the digital signal processing feature. Power electronic equipment's system model should use a range of non-traditional control methods, including fuzzy control, predictive control and neural network control as well as sophisticated control technology algorithms, to increase it dependability and adaptability [25,56].

### *3.4. User privacy*

The term "privacy" describes a person's or a group's expectation of confidentiality while disclosing personal information to a third party, such as an energy provider. It is thus difficult to get accurate information on the number of energy consumers and the quantity and variety of equipment that utilize energy. Smart home appliances and smart meters may provide more insight into energy systems than just energy use. Information about a consumer's location, including whether or not they are at home, and habits like sleeping and waking hours, may compromise their privacy [60,64]. The idea of a brand-new dummy location privacy-preserving (DLP) algorithm has been proposed. This algorithm evaluates various privacy needs of various users as well as computing costs to effectively maintain users' position secrecy [65,66].

### *3.5. Efficiency*

Relying on the network structure, supervision principles, and system, IoE has varying scalability, resilience, and other qualities [25]. A world powered by the IoT suggests that a sensor should be used to gather information about each unique item and that each sensor's power source should be identified. To keep thousands of these detecting junctions operating, a huge amount of power would be required where the maintenance of efficiency is essential. A new framework for IoT systems has been created to solve this issue, reducing the need for human contact in architecture and conserving energy. For this, a self-organized thing is devised to maximize energy efficiency [67].

### *3.6. Standard*

IoE includes various technologies and applications communicating in real-time while complying with multiple standards. The inconsistency between IoT gadgets that adhere to different standards creates new difficulty [68]. It includes standards for processing unstructured data, privacy concerns, and regulatory standards for data marketplaces [69]. One method to overcome the difficulty of standardization in IoT-based power systems is to design a process with a shared idea that all participants can use and access evenly. A further option is for the parties to develop open data structures and protocols for the standards. Standards will thus be accessible to everyone and supplied without charge [70,77].

### *3.7. Global architecture for IoE*

IoT projects enable transmissions for associated services at any time, place, or self-contained manner. This indicates that they were created with complex, decentralized, and mobile characteristics based on their application needs. As a result, designing architecture presents an additional challenge for IoT-enabled energy systems. A reference design cannot be a one-size-fits-all solution for all IoT applications, given their distinct characteristics and requirements. As a result, heterogeneous reference architectures that are open and adhere to standards are required for IoT systems. Users should not be restricted to using fixed and end-to-end IoT connections due to the architectures [71]. System structures are created depending on the usage of the system [72].

### *3.8. Business model*

Traditional grid economic models rely on huge centralized producers and utility firms that control a significant part of the market from generation to customer premises that readily handle a high fraction of distributed renewable generating or power storage for technology and market reasons. New business ideas are necessary to create a more marketplace and enable peer-to-peer driven energy transfers. A significant barrier to developing a future service- oriented electrical market is the deregulation and transformation of the current energy market [73].

### *3.9. Data tempering*

An intruder can change conveyed data, such as previous variable pricing data, by changing peak time energy usage prices into the cheapest rates, overloading the power network and raising residential energy usage. The security affects the information dependability of the system in the case of distributed state estimation. Additional smart devices may be present there. Each device's transacted information must be secure, as erroneous data injection could result in cascading failures and possibly a widespread blackout. To avoid erroneous injection, a mitigation strategy based on the cooperation of views and an assault detection technique based on adaptive features were developed [74,75].

### *3.10. Cyber attack*

Cyber-attack (CA) on power systems are increasingly a widespread concern that has spawned a new study topic. CA mentions unauthorised entry to the system with the intent of causing harm or stealing data [54]. ICT not only makes intelligent gadgets more user-friendly, but it also causes specific security issues by encouraging cyber crime [76]. The cyber-physical system integrates the cloud network with the physical component so that users may control or access their gadgets from anywhere in the globe via the network connection. However, it has evolved into a cyber-physical assault whose primary goal is to gain entrance to any smart architecture and infuse fake information to alter the system's behavior and cause harm. CA on SG or an IoE system may create inaccurate data regarding power use, utility charges, and other parameters, which has a technological and financial impact on end users and service providers by wasting energy and raising utility charges [78]. Any misalignment in the electricity system's frequency pattern might harm grid equipment as well as client appliances [54].

### *3.11. Middleware*

MW is a software framework that permits communication between application units while being application- independent. MW refers to a gateway that serves as a connection point between the various IoE components. Since industrial networks are subject to computational and resource limits, low MW adds complexity and expense. Industrial networks have a lengthy lifespan, therefore challenges with heterogeneity include semantic disputes, global heterogeneity, new/unknown gadgets and numerous devices communicating. These areas include data management, resource discovery, and event management, all of which are connected to functional needs [54,55].

### *3.12. Data integrity (DI)*

Data accuracy concerning modification, tempering, and change is data integrity. DI problems can be generated purposefully by an attacker or unreliable hardware, software, or networks. DA attacks seek to add or modify information to deceive the affected network into making wrong choices. Additionally, statistical analysis is used to spot inaccurate capacity, although associated faults make it simple to go around it [54,79]. From time to time, various techniques have been involved in maintaining the data integrity of any specific IoE system.

#### *3.12.1. Blockchain based*

*3.12.1.1. Edge cloud-based EBIQS model.* This model is based on supply chain logistics (SCL), having three layers for this architecture: IoE device perception, Edge blockchain and cloud blockchain. Fig. 14 shows a detailed basic EBIQS model. In the first layer, logistical assets, including personnel, goods, pallets, and trucks involved in SCL activities, are given IoE devices so they may be recognized, felt, communicated with, controlled over, and monitored. The connection module, sensors, and batteries of an active Bluetooth tag enable the entire data origin process from data production (sensing) through data transfer. The cloud-based solutions concentrate different computer resources to tackle issues, and the enormous IoE data they create are geographically spread [80].

*3.12.1.2. An AI-based blockchain model.* This blockchain-based access control system has a network architecture that can identify and counteract harmful IoE attacks. Data is safely gathered from various IoT smart devices installed in various IoE applications and then kept in a

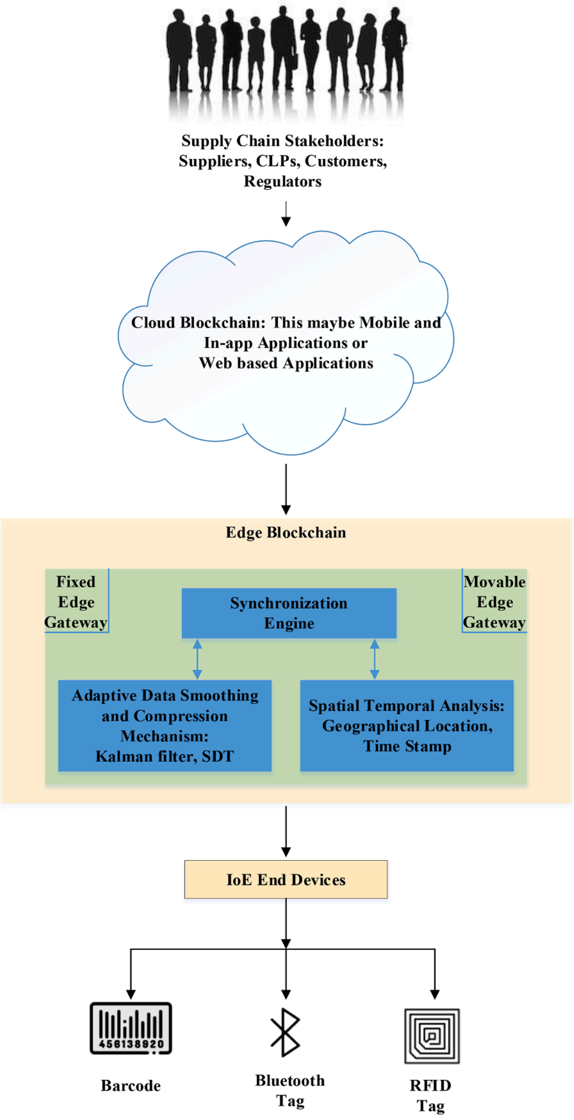

**Fig. 14.** EBIQS model.

blockchain or other data repository. The related cloud server (CS) receives secure blocks from the fog server (FS) created using the produced transactions. The blocks are sent to the CS using the associated cloud server's public key. The mined block is then added to the blockchain by CS using a well-known consensus mechanism (for example, PBFT and RSPCA) [81].

### 3.12.2. Multilayer long short-term memory network-based model (MLSTM)

The straightforward and effective model architecture trains all data-driven models during the attack detection stage. As a result, the model has demonstrated its practical applications and now operates in real-time. MLSTM uses two layers and obtains the most remarkable results across all criteria. Perhaps because of the complexity of the data structure, the support vector machine cannot perform well. While the K-Nearest neighbor algorithm put up reasonable efforts, it falls short of the convolutional neural network and MLSTM. The artificial neural network does not perform optimally because of the short model depth, although the convolutional neural network only uses two layers to obtain outstanding results. Even with a window size of 50 (0.05 s), MLSTM outperforms the convolutional neural network with a more significant analysis window length, MLSTM achieves a better result [82,83].

## 4. Applications of IoE

IoT technology can used in a variety of applications throughout the energy sector. However, for IoT implementation in the energy industry, a few cutting-edge trends and applications are needed. The applications of IoE are discussed below:

### 4.1. Energy efficiency

The Internet of Energy (IoE) has indeed revolutionized energy efficiency, making it one of its primary applications. Beyond the imperative of utilizing green and renewable energy sources, it is crucial to minimize energy wastage and formulate strategies for optimizing this valuable resource. Informing end-users about their energy consumption footprints and offering guidance on behavior modification constitutes a significant step toward achieving this goal [84]. In recent years, global energy consumption has surged dramatically, with the building sector alone accounting for over 40 % of the world's energy usage. The Internet of Things (IoT) is poised to connect everything, including household appliances, mobile devices, sensors, etc., facilitating data exchange and significantly impacting energy efficiency systems. IoT plays a pivotal role in various energy-efficiency ecosystems through remote data collection and control [85]. The initial phases of a robust energy-efficient framework involve collecting and recording data related to indoor and outdoor conditions, energy consumption, end-user behaviors, and preferences. This data empowers energy efficiency systems to leverage IoT technology effectively. Furthermore, IoE enables precise management and optimization of energy consumption by integrating cutting-edge technologies like demand response systems, smart grids, and real-time energy monitoring.

This supports load shifting, peak demand reduction, and the efficient utilization of distributed energy resources, empowering consumers and companies to make informed decisions regarding their energy consumption patterns [86]. With the increasing use of smart meters, IoT sensors, and machine learning technologies, energy-saving recommendation systems are demonstrating their potential as a viable means to promote sustainability and reduce carbon emissions. Their development coincides with the evolution of sophisticated Internet systems [87]. Detecting anomalies in energy consumption represents a critical initial step in the development of effective energy-saving technologies, which can ultimately lower total energy costs and reduce carbon emissions. Consequently, it is imperative to devise effective strategies for identifying unusual usage in buildings and providing end-users and administrators access to this information. IoE identifies inefficiencies and streamlines processes, reducing energy waste and transmission losses while fostering a more sustainable energy environment. It achieves this through predictive maintenance, data analytics, and automation [88].

### 4.2. Anomaly detection

Energy efficiency is widely recognized as a cost-effective solution to address various energy-related concerns, including economic and social repercussions stemming from high energy costs, energy security, global warming, and climate change [89]. Presently, a significant challenge in the quest for reduced power consumption lies in understanding, diagnosing, and visualizing abnormal energy usage patterns within households. An imperative application within the realm of the Internet of Energy (IoE), anomaly detection plays a pivotal role in enhancing system stability and energy efficiency [90]. IoE possesses the capability to detect anomalies and deviations within energy consumption, production, and distribution patterns by amalgamating real-time data streams with advanced analytics. This system promptly identifies irregularities, such as equipment malfunctions, grid instability, or unauthorised access, by establishing baseline behaviors and employing machine learning techniques. Anomaly detection, also known as fault detection and diagnosis (FDD), entails identifying occurrences or observations that deviate from expected patterns or behaviors, often offering insights into the health of the system under investigation [91].

These anomalies can take various forms, including outliers with values significantly different from nearby energy consumption data, potentially attributed to equipment malfunctions, transient disturbances during equipment activation, or momentary sensor data interference [92]. Another form of anomaly is contextual, where unusual energy consumption trends emerge over a specific timeframe, which may be acceptable at an individual level but signify a broader issue [93]. Accurate anomaly detection supports energy-saving initiatives, timely equipment maintenance, and adaptive operational strategies, preventing unnecessary resource losses and substantially enhancing overall energy efficiency. Identifying anomalies and their sources is pivotal in achieving resource loss reduction [94]. Anomaly detection not only curtails excessive energy consumption but also prevents minor issues from escalating into major ones. Through proactive interventions and early identification, potential disruptions can be mitigated, further elevating energy efficiency. By minimizing energy losses and downtime, IoE's anomaly detection not only safeguards the integrity of energy infrastructure but also optimizes efficiency, ultimately culminating in a more resilient and efficient energy ecosystem [95]. To facilitate efficient energy use, it is imperative to document anomalous consumption patterns. Hence, implementing energy monitoring systems and benchmarking procedures can reduce abnormal behaviors and footprints [96]. The development of sophisticated anomaly detection systems tailored for energy consumption holds promise in unveiling novel forms of anomalous patterns, further enhancing energy efficiency and conservation efforts [97].

### 4.3. Behavioral change

The Internet of Energy (IoE) holds significant potential for driving behavioral change in how individuals and businesses manage their energy resources. By providing real-time data on energy production, consumption, and pricing, IoE empowers consumers to take more control over their daily energy usage. Armed with this knowledge, customers can make wiser energy choices, resulting in behavioral shifts that prioritize sustainability and efficiency. Recommendation systems play a crucial role in this transformation by continuously assessing user contexts and activities against a set of rules, taking user goals and preferences into account, and prioritizing recommended actions. It's essential for these recommendation systems to be transparent to build user trust and encourage the adoption of their suggestions [45]. For instance, REHAB-C is a recommendation engine designed to assist customers in developing more energy-efficient behaviors and altering their current energy usage patterns. These recommendation systems aim to examine user profiles, process available options, consider other users' profiles and contextual conditions, and then offer the most suitable alternatives.

IoE also promotes energy-saving behaviors, such as load shifting to off-peak hours and prudent use of energy-intensive equipment, through user-friendly interfaces and mobile apps. These practices help reduce energy costs and alleviate stress on the grid during peak demand, ultimately enhancing overall grid resilience. IoE's integration of various technologies for data gathering, interpretation, and behavioral change is reshaping the building energy sector [98]. The concept of "micro-moments" encapsulates users' interactions with building appliances, highlighting the profound impact of collecting and analyzing big data on energy utilization across sectors and research areas. Furthermore, IoE's ability to collect and analyze consumption data empowers users to set energy-saving goals and track their progress, fostering positive behavioral changes that contribute to a more energy-conscious and environmentally responsible society [99,100].

### 4.4. *Energy disaggregation (Non-intrusive load monitoring)*

The Internet of Energy (IoE) critically depends on the implementation of energy disaggregation, sometimes referred to as Non-Intrusive Load Monitoring (NILM). Non-intrusive load monitoring is a crucial, cost-effective technique for keeping track of power usage and addressing a number of issues that arise while moving to a competitive, efficient, and sustainable energy environment [88]. It is the technique of determining individual device usage footprints within a building from the total power consumption recorded at the main power entrance without the installation of individual smart meters for each appliance. NILM is designed to deduce the device-wise consumption from an aggregated consumption that is obtained from the primary supply [101]. An effective classifier and feature extraction module must be used in conjunction to create an effective NILM system. The feature extraction module must be able to capture the unique consumption fingerprint of each electrical equipment. It transforms energy management by offering a non- intrusive way to identify the individual energy use of different equipment in a domestic or business context [102].

The Internet of Things (IoE) uses cutting-edge analytics and machine learning techniques to assess the entire energy consumption data from a single point of measurement, such as a smart meter, and then disaggregate it into specific insights about which appliances are consuming energy and when. This degree of detail enables customers to fully comprehend their energy consumption trends, spot inefficiencies, and make well-informed decisions to optimize energy use. NILM is a potent substitute for creating a robust, accurate, and scalable load monitoring system for the home market that is simple to set up and doesn't cost more. Additionally, the benefits of NILM are not just restricted to end users; they may also improve operational effectiveness, assist providers in reducing operating costs, and enhance public health and well-being [103]. By providing end users with real-time consumption footprints, modifying their energy use behaviors, and further detecting problematic equipment, NILM systems play a crucial role in aiding end users in reducing their energy consumption. Energy disaggregation not only improves energy efficiency but also makes load forecasting, predictive maintenance, and demand response possible. By enabling effective appliance management and knowledgeable energy-saving techniques, this process helps to create a more sustainable and responsive energy ecosystem [85].

### 4.5. *Energy visualization*

Energy visualization is a key application in the Internet of Energy (IoE) environment, providing a compelling way to improve energy efficiency and user involvement. The rapid economic growth and improved living standards have led to increased household energy consumption, underscoring the pressing need for energy conservation to protect the environment and address climate change. The development of an Internet of Things (IoT) system that tracks customers' energy usage patterns and promptly provides energy-saving recommendations can influence user behaviors positively [104]. IoE facilitates the real-time display of energy consumption trends, production, and distribution through data analytics and user-friendly interfaces, empowering individuals and organizations to gain deeper insights into their energy consumption for more informed decision-making. Users can monitor and manage their energy use in real time using energy dashboards, interactive applications, and graphical representations [105].

IoE, following the footsteps of smart grids, has become a prominent technology in the energy industry. It harnesses the internet to build a distributed smart energy infrastructure, aggregating, organizing, optimizing, and controlling energy data from various edge devices. This data is used for demand and supply forecasting and fine-tuning energy usage habits through sensor and communication technology. Beyond increasing awareness of energy consumption, this transparency encourages behavioral changes that reduce consumption during peak periods, optimize load distribution, and enhance overall efficiency [106]. Data visualization tools can gradually modify people's behaviors by incrementally reducing their energy consumption, with the most effective tools featuring well-designed visualizations accompanied by sound advice. Furthermore, energy visualization fosters the adoption of renewable energy sources, as users can witness the direct impact of their choices on the environment and energy costs, ultimately contributing to a more resilient and sustainable energy ecosystem [107].

### 4.6. *Security and privacy issues*

In the context of Internet of Energy (IoE) applications, security and privacy concerns are crucial. IoE exposes a number of vulnerabilities that need to be fixed as it uses linked devices and data streams to enhance energy management. There are issues with data privacy and potential breaches due to the enormous volume of data created, including real- time energy usage trends and user activity. The IoE has significant issues as a result of security assaults on resources, data, networks, users, and applications. Major security issues include these security assaults as well as additional difficulties like risk management and network assurance. An unreliable or compromised IoT platform provider will invariably cause security and privacy concerns [108]. Unauthorised access to this data might jeopardize individual privacy while also allowing bad actors to learn more about occupant preferences, perhaps creating a security concern. The inclusion of smart grids and energy systems into IoE further increases the danger of cyberattacks directed at crucial infrastructure. These systems are vulnerable to breaches that might cause power outages, financial losses, and even safety risks. The integrated internet-based smart grid and energy resources inherit all the security flaws of the current smart grid. The smart grid's security framework is no longer sufficient to fulfill the security requirements of the energy sectors. IoE is envisioned as an integrated platform with power flow and multidirectional communication methods for enhancing the smart grid. Real-time data collection and analysis are done using IoT technology for smart energy management. To protect the integrity of IoE systems, it is essential to implement strong cybersecurity measures, such as encryption, authentication, and intrusion detection [109].

Striking the correct balance between data sharing for efficiency and safeguarding user privacy remains a big problem, demanding strict data protection laws and user permission methods to guarantee that people have control over their data. Applications based on blockchain that prioritize privacy in the IoT ecosystem and energy trading have generated a lot of attention. Blockchain users are vulnerable to privacy threats due to the distributed nature of the technology and the shared ledger's availability of transactional data. Blockchain's trustworthy end-to-end capabilities enable us to add accountability and dependability characteristics to IoT transactions [110]. Recommender systems (RSs) have grown in popularity as a result of the growing usage of the Internet of Things (IoT), mobile phones, linked devices, and artificial intelligence (AI), in part due to their capacity to evaluate large amounts of data and influence user behavior. Recommender systems are often utilized in a variety of application fields, such as social networking, e-commerce, healthcare, and energy conservation [111]. The analysis and mining of enormous volumes of user data, including demographics, preferences, social activities, etc., is necessary for these applications. Vehicle to Grid (V2G) technology, in its broadest sense, refers to technologies that make it possible for electrical energy to flow back and forth between automobiles and the electrical grid. When the grid needs electricity, electrical energy can travel from the grid to the vehicle to charge the battery or it can go in the other manner [40]. Analyzing security risk and energy use is still difficult. The low-power sensor nodes may slow down the delivery of data to distant data centers due to imbalanced energy consumption. In conclusion, even though IoE has enormous potential for improving energy efficiency, resolving its security and privacy issues is essential to fostering confidence, defending user data, and preserving the dependability of energy infrastructure [112].

## 5. Road towards next generation IoE

There are several benefits to using current IoT technologies to provide energy-effective solutions. However, innovative ideas and trends are required for IoT deployment in the energy sector. Some over-the-top ideas may be to enhance security and privacy by creating sophisticated encryption and authentication techniques to safeguard IoE devices and data, to create standards and protocols to provide seamless communication between various IoE systems and devices, to study how edge and fog computing can be more fully included in IoE to improve real-time processing, lower latency, and maximize resource consumption, to examine how encryption, optimization, and data processing may be affected by quantum computing in the Internet of Energy [93,107]. Fig. 15 shows a road map towards the next generation IoE system. The future of IoE is discussed below:

### 5.1. *Next generation vehicle*

The growing number of EVs on the road annually indicates that more people are interested in using them as alternatives to current vehicles, including cars, motorcycles, and other vehicles. Because EVs may serve as both a power supply and a burden on the grid, it is feasible to determine the condition [113]. Besides, autonomous vehicles (AV) are self-driving vehicles that are neither controlled nor influenced by humans. These self-driving vehicles use embedded sensor technology to minimize collisions, energy use, contamination, road congestion, and public contact. Sensors, radars, and cameras aid autonomous cars in continually detecting vehicle locations, roadways, barriers, dangers, and traffic. These vehicles are environmentally friendly and can identify traffic jams, obstructions, and the optimal path to get to a location in the lowest amount of time [54]. It can be used to deliver power to the grid during peak demand. As a result, one of the most widely adopted concepts at the moment is the incorporation of an EV power system into the IoT [113]. Additionally, the IoE idea is critical for demand flexibility. Because of the rising demand for and widespread use of electric cars, the flexible energy revolution should be promoted and executed (EV) [114]. According to Navigant Research, light-duty EVs will reach to 6400 thousand in 2023. The connection between EVs and the power grid not only promotes the vehicle-to-grid (V2G) but also increases the grid-to-vehicle (G2V) usage [115].

### 5.2. *Next generation energy resources*

The IoE is made up of several renewable power sources that are wired into the grid to provide clean energy. The cost of these renewable energy sources is declining due to technological improvement, which contributes to the yearly expansion of the global economy. The wind power system harnesses the wind's energy and converts it into electricity. The ideal fossil-fuel-free option is a RE that is responsible for clean and environmentally friendly energy generation. RE sources like wind or tidal turbines, PV systems, bio-gas and mass with modified technologies and materials can be properly utilized to take an important role in the energy production sector [113].

### 5.3. *Next generation batteries*

The batteries help the grid be more effective by supplying high-grade electricity, ensuring consistent supply, and maintaining grid stability. When the grid is overloaded and unable to balance supply and demand during peak periods, batteries or energy storage are pretty valuable. The advancement of new technological batteries such as NanoBolt lithium tungsten, Zinc-manganese oxide, Gold nanowire gel electrolyte, and Organosilicon electrolyte can play a vital role in the energy sector. Customers may recharge their electric vehicles' batteries which can be supplied to the grid during peak hours to maximize their economic gain [113].

### 5.4. *Cyberattack avoidance*

On an industrial, IoE systems are designed to run continuously, to minimize excessive downtime or stoppage during peak hours which

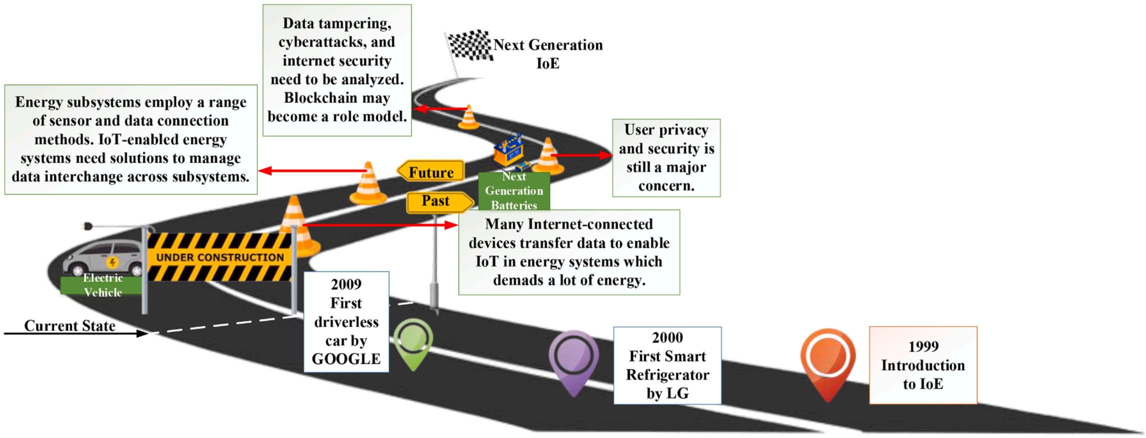

**Fig. 15.** Roadmap to next generation IoE.

requires continuous monitoring of audit, accountability, or service availability to overcome any vulnerable assault. The creation of big data can enhance security walls. Furthermore, packet storming, server/client credentials, security layout, integrity verification, and authentication stages are some of the methods presented to protect TPS-based systems [116]. On the other hand, a watchful system requires open-minded measures, including secrecy, verification, serviceability, accountability, and audit [54].

### 5.5. Block chain

The majority of today's IoT solutions depend on a centralized cloud platform [117]. A lot of IoT devices must be connected in most IoT applications, which is difficult to synchronize. Furthermore, because of the centralized structure of IoT, when the server is attacked, all connected items are easily hacked and compromised, resulting in system security risks, and privacy concerns for users [118]. Although a blockchain is not an information defense system, its unique qualities can give information data with more anti-interference and secrecy. The energy internet information system technology may be built on block technology. After the packet, each perceptual device is encrypted with different private keys. The data route has significant redundancy since the information node chain of the entire system creates a mesh topology [119].

Blockchain is a decentralized and regularizing system. Every IoT node must verify to the blockchain consensus platform that it is pursuing the same aim as the others. The storing of verified transactions plays a vital role in not to lost information. As a result, each member of the blockchain is instantaneously informed of any changes in each block [120]. Blockchain consensus techniques which can create a safely distributed database [118,121]. More significantly, blockchain allows things to store and exchange software upgrades. The modification of the block is very critical when the blockchain is updated. As a result, blockchain can provide IoT-based solutions with updated availability, and innocuousness [122]. The deployment of blockchain in the energy industry can accelerate IoT effectiveness, boosting energy security and efficiency. People can easily exchange energy with one another. Another benefit is that by monitoring a region's use data [123].

## 6. Conclusion

Numerous advancements are being made in the administration, distribution, and transmission of electricity thanks to modern civilization. More effective techniques and advanced computer technologies are being utilized to forecast varied expenditures and converted the power system into a smarter one with the proper integration of ICT. IoE is a relatively new and attractive architecture for delivering energy that is quite versatile, long-lasting, pragmatic, and efficient. This research work analyzed the evolution of the power system that aids researchers by directing a route showing the growing flow of the IoE to cut utility costs and power consumption by adequately scheduling the loads. The modeling criteria and difficulties of the IoE infrastructure, energy consumption management, communication architecture, supply and demand ratio as well as security requirements have been investigated that will help the researchers to find the lacking and to understand the importance of upgrading of the existing power systems. The investigation of design and control challenges of the IoE in case of integration, cyber-security, energy management and pricing scheme has been carried out with their control solution to increase system resiliency and stability. The necessity and importance of the upgradation of the IoE to the next generation IoE system has been analyzed in this paper by constructing a directional framework, technological improvement and future recommendations.

## CRediT authorship contribution statement

**Muqit Farhan:** Investigation, Resources, Writing – original draft. **Tanzim N. Reza:** Investigation, Resources, Writing – original draft. **Faisal R. Badal:** Formal analysis, Investigation, Writing – review & editing. **Md. R. Islam:** Formal analysis, Investigation. **S M Muyeen:** Conceptualization, Supervision. **Z. Tasneem:** Formal analysis. **Md. Mehedi Hasan:** Formal analysis. **Md. F. Ali:** Formal analysis. **Md. H. Ahamed:** Visualization. **S.H. Abhi:** Visualization. **Md. Manirul Islam:** Visualization. **Subrata K. Sarker:** Formal analysis. **Sajal K. Das:** Conceptualization, Supervision. **Prangon Das:** Formal analysis, Visualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

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

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