Advanced Energy Systems Based on Energy Hub Concept

Hossein Shayeghi and Amir Mohammad Moghaddam

Abstract Energy systems in the past alone were providing consumer's needs, and their management did independently. By industrialization of the lifestyle and high dependence of human societies into energy and on the other hand, a lack of fossil resources, system exploitation seeks to use multi-carrier energy to meet the needs of their consumer's needs. Therefore, the use of multi-carrier systems with the advancement of technology became possible to increase the reliability of the system in the presence of different energy sources. Of course, the critical and challenging issue in it is the way of managing these systems on a large scale. The concept of an energy hub, which is like a virtual box including production, conversion, storage, and consumption of various carriers, has been introduced and the high potential for the operation of multi-carrier systems and optimal management of them possess. This chapter aims to introduce a comprehensive energy hub and its application in the management of multi-carrier systems and express its advantages in preserving the existing resources for posterity alongside the increasing demand for consumers with the lowest cost of operation without limitation its size. Energy hub is used in various sectors such as commercial, industrial, and even agricultural, and can integrate with the integration of these small network hubs from Micro Hub, which are called Macro hub. Moreover, the management of these hubs has dealt with detail.

Keywords Multi-energy systems · Energy hub · Advanced energy system · Micro hub · Macro hub

H. Shayeghi (✉) · A. M. Moghaddam
Energy Management Research Center, University of Mohaghegh Ardabili, Ardabil, Iran
e-mail: hshayeghi@gmail.com

A. M. Moghaddam
e-mail: ammoghaddam1389@gmail.com

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Nomenclature

Acronyms

BEMS	Building energy management system
BTU	British thermal units
CHG	Closed green house
CHP	Combine heat and power
DER	Distributed energy resources
DG	Distributed generation
DSM	Demand-side management
EH	Energy hub
ESS	Electric storage system
HEMS	Home energy management system
HVAC	High voltage alternative current
IEMS	Industrial energy management systems
MES	Multi-energy systems
PV	Photovoltaic
OEF	Optimal energy flow
OPF	Optimal power flow
TOU	Time of use
V2G	Vehicle to grid

1 Introduction

The vital energy of the current industrial societies is an essential factor in the development *of countries.*

Besides the advancement of technology and machine life style, this needs to be more intuitive and more important in the day-to-day. Consequently, producing clean, safe, and reliable energy sources has been one of the severe difficulties of every country.

Energy is the most fundamental requirement of the current industrial societies and an essential factor in the development of countries. The most fundamental sources of energy supply during recent years were fossil fuels. The conversion of fossil fuels produces electrical energy in thermal power plants, and with low efficiencies and relatively high losses are transported to consumers by transmission lines. In these systems, intelligent protection, control, and data gathering tools are installed and used locally.

However, now, the power grid uses smart grid technology to be smart and operate automatically. In addition to traditional network capabilities (production, transmission, and distribution), the smart grid can store, interact, and make decisions.

The smart grid increased efficiency in the supply of demand and economic efficiency of existing equipment and no need to improve systems. Also, the smart grid has caused the integrity of renewable energy resources and mainly distributed energy resources on demand-side.

With the advancement of technology and increasing the efficiency of prime movers as well as improving market conditions for the use of high-performance technologies such as micro-turbines and internal combustion engines, the benefits of the distributed energy resource (DER) is used to form CO-Tri-generation. These compounds produced the hopes of making multiple clean energy systems (MES) with high affections. With the help of this equipment and DER, management and operating of such systems can optimize for economic, technological, and environmental benefits.

Using the DER on demand-side, in addition to reducing losses and costs due to energy transfer, increases the security and reliability of supply of local loads and also contributes to the active participation of consumers in demand-side management.

Demand-side management (DSM) is a comprehensive theory that combines load improvement plans, energy conversion, energy efficiency, and demand response.

Renewable energy source (RES), which is considered the most essential DER, is the ability to supply consumer demand during peak energy hours that can be reduced consumer dependence on the leading network.

Transfers of the consumer load of the peak-load into low-load reduce their energy costs and reduce network demand size. On the other hand, reducing unnecessary loads in a certain period, such as the peak demand period or the system's use demand, can be stored more energy and decreased costs.

Although to achieve the benefits of the said concept, which do with the help of DSM, the equipment used in the network and smart grid requires an integrated management model. The energy hub defined as a structure that generates, converts, store, and consume various carriers in it. Energy hub has a high ability to manage and control systems with several centralized inputs.

An extensive study has been conducted in the concept of energy hub and has proven that the use of several energy carriers to provide consumers needs better performance than systems that independently supply consumer's needs and control.

The energy hub has no size limit and can include many cases such as a residential house, spacious residential complex, commercial buildings, shopping malls, hospitals, industrial units, greenhouses, and even the whole city.

So, after introducing the overall energy hub plan, in part 2, the comprehensive energy hub with the introduction of its elements, the advantages of the energy hub for the whole system is introduced. In Sect. 3, the various types of energy hub classification have discussed, and it has described the residential, commercial, industrial, and agricultural hubs, and in the last section, the overall classification of the topics has been studied.

2 Concept of Energy Hub

For the first time, the energy hub theory introduced in the connection of a project called A Vision of Future Energy Networks (VOFEN) [1]. This task intended to describe future energy systems in the long term (20–30 years).

Many conceptual designs have published concerning the production, transfer, and distribution of integrated energy by using DER, which created the concept of an integrated energy hub. An integrated word means the use of various energy carriers in the system. This concept has shown in Fig. 1.

$$\begin{bmatrix} I_1 \\ I_2 \\ \ominus \\ I_3 \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} & \ominus & C_{1n} \\ C_{21} & C_{22} & \ominus & C2n \\ C31 & C32 & \ominus & C3n \\ C41 & C42 & \ominus & C4n \end{bmatrix} = \begin{bmatrix} L_1 \\ L_2 \\ \ominus \\ L_n \end{bmatrix} \quad (1)$$

As you can see in Fig. 1, in the matrix model of the hub, the input matrix is defined as a column matrix, each element of this matrix corresponds to an independent input. By multiplying the input matrix in the coupling matrix, which is a square matrix and each element is related to the elements used in the hub, the output matrix will be achieved (Eq. (1)) [2].

2.1 Basic Concept

The basic definition of energy hub is an integrated platform of energy producers, consumers and transmission equipment. Each system that has the following characteristics can call energy hub [3].

- Input and output
- Conversion
- Storage

The hybrid energy carrier system considers as a system of energy hubs that interconnected by several networks. In the realm of an energy hub, the energy transmitted by network and stored or converted into the energy hub to meet the demands. A more perspicuous definition of an energy hub presents in [1].

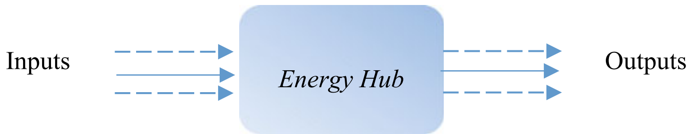

Fig. 1 Energy Hub concept

2.2 Elements of Hub

The main characteristic of the energy hub has three main elements:

- Direct connections
- Converters
- Storage

Direct connection is used to transmit a direct incoming carrier to the hub output without any conversion. (e.g., electricity voltage).

The upstream grid is an example of this type of component. Besides that, converter relates to devices that change the sort of energy carriers. For example, in the boiler, gas is as input and produces heat in its output.

The third element used in the hub refers to energy storage equipment, which can have various technologies. For example, electrical storage has a direct storage technology (e.g., supercaps, superconducting devices) or indirect (e.g., batteries). [3].

In Fig. 2, the complete model of the energy hub is shown with electrical and gas as inputs; and electrical, cooling, and heat as outputs. This model uses converters and storage, such as transformers, boilers, electrical/thermal storage inside the hub, for meeting the demand in output.

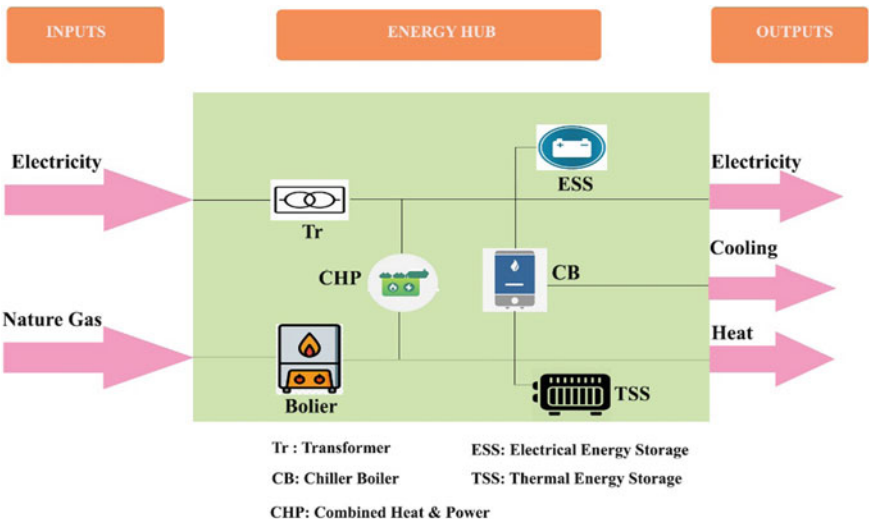

Fig. 2 The energy hub with different elements

2.3 Potential Benefits

According to definitions of an energy hub, a simple structure represented in Fig. 1. In this structure, each energy demand can meet by multiple energy carriers. In simple words, it means the energy hub is not only used one carrier to demand supply but also a combination of two or more carriers is used to supply demand, and this characteristic improves the degree of freedom and also increase reliability and security of consumer's demand. Using different carriers and various combinations of them can be used to optimize consumer's demands optimally.

Implementation of the energy hub can reduce operating costs because energy hubs choose the most energy-efficient carriers, or a combination of them to increase efficiency.

Other potential benefits of the energy hub can be improved load flexibility. Redundant ways inside the hub offer a specific degree of freedom in supplying the loads.

The hub can replace for an unattractive energy carrier, for example, high-tariff electricity. So, from a system view, the load looks to be more flexible in terms of its price and demand performance; also, the actual load on the hub output remains constant [3]. On the other hand, the use of various energy carriers to provide different demands can help expandtion the application of the energy hub and improve system performance.

For example, the use of energy that wasted in various carriers due to the structure of converters and other equipment can increase the system productivity. Therefore, one of the main advantages of an energy hub is the optimal use of multiple carriers to provide optimal demand.

3 Different Types of Energy Hubs

The energy hub has a high potential for increasing system productivity by taking different carriers and using various technologies. The energy hub divided into two parts of micro hubs and Macro hubs in terms of control. Micro hubs are located within the Macro hubs and controlled by them.

The micro hubs consist of four sections, tailored to the consumption pattern and the amount of demand, including residential, commercial, industrial, and agricultural. [4]. The energy hub categories are shown in Fig. 3.

Integrated management of these sections can have many benefits for both their own and the whole system. For example, the consumption pattern is different in the residential and industrial sectors. The residential peak demand occurs during the early night hours, whereas the industrial sector consumption is almost constant.

The use of DSM, especially the demand response (DR) programs and the RES, is of the great potential that can provide to the residential sector in addition to providing the need for their needs. The relation between these two parts usually established by

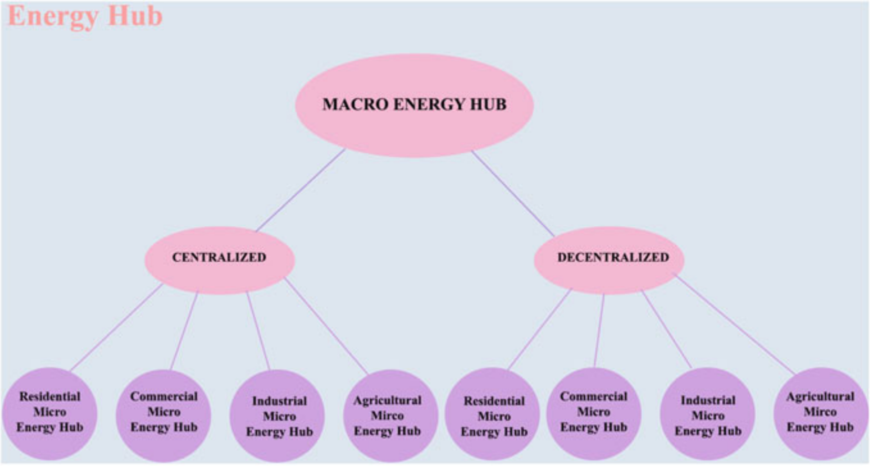

Fig. 3 The energy hub categories

electrical and gas. In the residential sector, it can also help consumers to meet the demands of the wind turbine and can be stored in the storage device and transferred to the industrial sector with the use of the RES, such as air turbines and PV throughout the day.

There are many methods for integrated management of multiple systems, but using the concept of energy hub is one of the best methods. With this method, the overall system optimization rate increases significantly [4].

3.1 Micro Energy Hubs

As mentioned earlier, the micro-hub consisted of four public groups. In this section, we will introduce and study the features and challenges facing these four groups. We also discuss the impact of energy hubs on solving these challenges.

(A) **Residential**

According to statistics published in Energy Information Administration (EIA) in America in the year 2018, 40% of the energy production has consumed in the residential sector [5].

For lots of reasons, including large transmission networks, extensive distribution, and poor management of power consumption by consumers, low efficient appliances, the energy in the residential sector are matched with its demand and consumption. The losses of electricity-related are 47% of this consumption [5]. Therefore, the residential energy hub is forced to use various carriers and efficient suppliers to meet the needs of consumers and reduce losses and operation costs.

In recent years, the use of multi-energy systems in the residential hub has increased dramatically, in which at least two different carriers are being used to meet consumer demand. Generally, two carriers used for the supply of demand that extensively utilized in the articles are electricity and gas. Energy hub is a suitable option for energy management in the residential sector [4].

There are lots of researches that show using an energy hub concept in them. An example of the energy hub model for smart homes with uncertainty in market pricing can find in [6]. In this study, a smart apartment building considered with ten homes, and each home has 12 appliances. The objective function considered as minimizing operation costs, and the results provided an optimum dispatch of equipment and timing of appliances have shown.

In [7] a multicarrier hub has been investigated to reduce the economic cost and CO2 emissions in a residential building with the influence of renewable resources. The system has been used electrical grid and natural gas network, a gas boiler, a heat pump, a photovoltaic plant, and a photovoltaic/thermal (PV/T) system, and has also been used an electrical storage to increase the efficiency.

According to the resource constraints, like scarcity of fossil fuel resources, uncontrolled increase in demand, expansion of environmental concerns and market deregulation, energy price in the residential sector is increasing.

In the traditional methods, demand responding is made directly by adjusting production schedules, But the organization and development of giant thermal power plants to meet the peak demands, besides the high costs of operation, environmental pollution problems, and deep affection, is not a reasonable approach anymore [10].

In the residential sector implementing the demand response consider as an option for energy management in buildings. Demand response has gained some penetration within the electricity market and is represented as “intended electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of instant demand, or total electricity consumption” according to it [8].

Implementation of demand-side management programs in the system is facing problems such as the lack of proper infrastructure of electrical network transmission equipment [9] and incentives for active participation of consumers in these programs, which has caused no variability or a profound change in consumer demand. Since billing based on a monthly average rate aggregated over a large number of customers [10]. A reflection of the price fluctuations of the power pools as long as the bills determined by the average monthly rate of a large number of consumers, it cannot be a benefit for residential consumers to change their energy demand in peak hours.

Several solutions like time of use, real-time pricing incremental block rates, critical peak pricing, and demand charges, have been introduced to solve the pricing issue. Of course, energy prices are not the only effective factor in the demand-side management program; i.e., consumers in the residential sector do not feel comfortable to spend time to analyze consumption decisions and managing household devices to save money [11]. According to the definition, as shown in Fig. 4, the analytical model of the residential energy hub is presented in two parts.

Residential consumers do not want to spend time to analyze consumption decisions. Therefore, the existence of an integrated management system that makes these

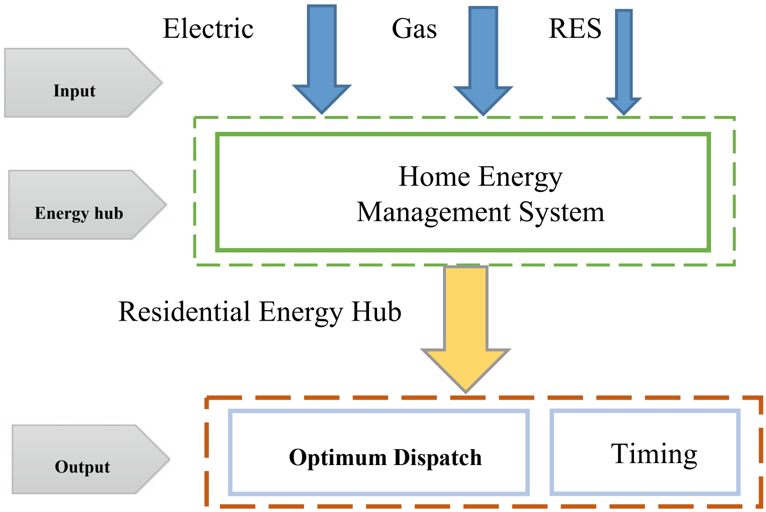

Fig. 4 Analytical model of residential energy hub

tasks feel felt. Recently, a system introduced as a home energy management system (HEMS) that performs all necessary measures. The HEMS uses a variety of parameters to prepare an optimized and scheduled energy consumption plan. These parameters include the price of energy in the market, climatic conditions, temperature. With using HEMS, it is possible to import various objective functions such as cost, emissions, load shaping, etc., which provided to the system. In [11] challenges, the methods of modeling and optimization of various types of HEMS are presented.

Using HEMS makes it easy to combine with multiple carrier systems and smart grids and improves performance and efficiency in the home energy system. Also, using HEMS facilities, home participation is increased in the DR program. Thus it can be a smart home as a small model of smart systems that are looking for optimal management of energy consumption and active participation in demand-side management (DSM) programs [12].

An intelligent decision-making system based on mathematical models used by a part of the Home energy management system for optimal management of energy consumption in buildings, and also makes successful participation in the program Of DSM [13]. In addition to determining the final level of the comfort and priority of consumers, this model has also used environmental information such as energy prices and weather forecasts. The interesting thing about this model is its actions to a real home in Ontario Canada, which has been energy saving as much as 45% and a 15% reduction in consumer peak demand. Instead of engaging local loads in demand-side management programs, it can be possible to control residential sector loads.

As shown in Fig. 5, residential loads are divided into two categories: responsive loads and non-responsive loads. Their responsive loads divided into four subgroups,

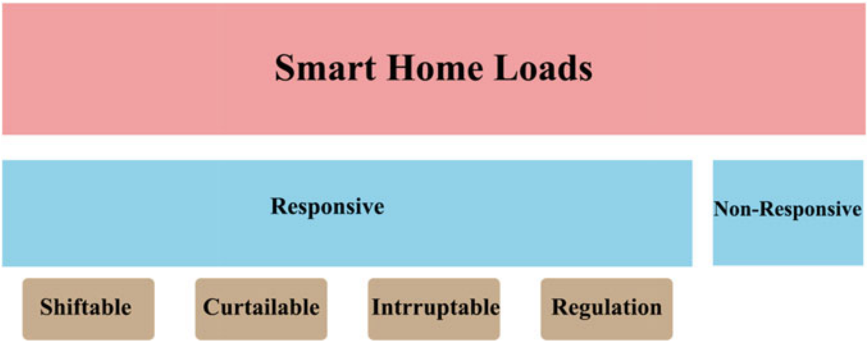

Fig. 5 Classification of the smart home loads

which include: shiftable loads, curtailable loads, interruptible loads, regulating loads. Shiftable loads are items where their energy consumption consumed in a specific timeframe and the opportunity of transferring this consumption at another time. (such as washing machines and dishwashers). Curtailable loads include a load that is possible to reduce the amount of consumption during peak hours. (such as dimming the lights) Interruptible loads are a bunch of loads that can be interrupted and have postponed their use to other times. (e.g. electric cars charge).

The regulating loads refer to the loads that allow programming at operating intervals with a slight change in the defined level. (such as heating and cooling demands). The effect of DR programs on both responsive and non-responsive loads has studied on [14]. In this paper, a residential building that includes CHP and PHEV represented as an energy hub. The energy hub model has investigated for optimal operation with the objective function of minimizing the cost of consumer's payment by taking TOU (Time of Use).

In the high energy price periods, a part of the demand is supplied by CHP with lower operating costs, while in the low energy price periods, the electricity supplied from the primary grid and PEV charged during this period.

Instead of providing the specified production schedule, it is done by changing the amount of shiftable load from peak demand to low-demand at the cost of economic savings consumers.

To take advantage of the benefits of the RES at smart home, the use of PEV and ESS for this purpose has a high potential. The PEV can also play the role of the ESS that helps reduce the cost of system operation, can also improve the energy exchange between PEV and the grid (V2G) by optimal management of the charging time and discharge of PEV. Integration of RES in a smart home requires a coordinated and comprehensive control system to be associated with the rest of the equipment especially PEV, ESS and responsive loads.

(B) **Commercial**

With the rise of commercial and residential buildings, the demand for electrical energy increased, which leads to an increase in the price of this patrol energy. On the other hand, greenhouse gas emissions increased with the activities of these centers. In these conditions, the existence of optimization and energy consumption management system profoundly felt and caused extensive research in this field.

Commercial buildings are a symbol of economic progress. Large commercial towers are competing in developed and developing countries. It should note that these buildings are great energy consumers and they should pay special attention to the energy efficiency issue in designing, building and operating them.

In traditional energy systems, electrical demand generally supplied by the high-power network of electrical energy and the thermal need provided by a gas boiler. However, with the increasing in the price of electric power and the emergence of new technologies in the field of distributed production resources, it was attempted to provide the electrical demand in place and by DG.

Energy production in the place of commercial buildings rose. As mentioned in the previous section, multi-energy systems (MEH) and RES systems are the perfect options for distributed generation (DG) in commercial buildings.

The main point in such an optimization algorithm is the analysis of system behavior and its evolution with more precision in a distance that leads to the supply of demand with optimal production and earning maximum profit.

Increasing the efficiency of commercial buildings is the key to energy-efficient consumption and reduction of environmental impact.

Many parameters can have a return on the energy consumption of buildings. Also, many methods help improvement of them. The full category of these different methods can found at [15].

In this paper, various methods are presented to improve the efficiency of commercial buildings, which are divided into three groups: technological effects, the culture and behavioral training of the occupier, and establishment of building energy management system (BEMS). In [16], the bi-level risk aversion function is considered for a commercial macro hub, which minimizes the load of the network and the economic cost and gas emissions of the greenhouse in a fixed amount.

In commercial buildings, the need for a comprehensive energy management system to determine the optimal timing, active participation in DSM programs, and the benefits of a smart grid feel.

A BEMS introduces for optimal operation of a commercial building to minimize the cost of energy, increase efficiency, and to reduce emission in [17]. According to the obtained results, it has shown that combining different technologies and integrated energy management systems of this building, the building's peak demand and energy costs reduced while the lower GHG emission obtained.

Therefore, BEMS can manage by information such as forecasting weather, production rate, and pattern of consumption to cause optimal commercial building performance. The BEMS used in the analytical model of commercial energy hub has shown in Fig. 6.

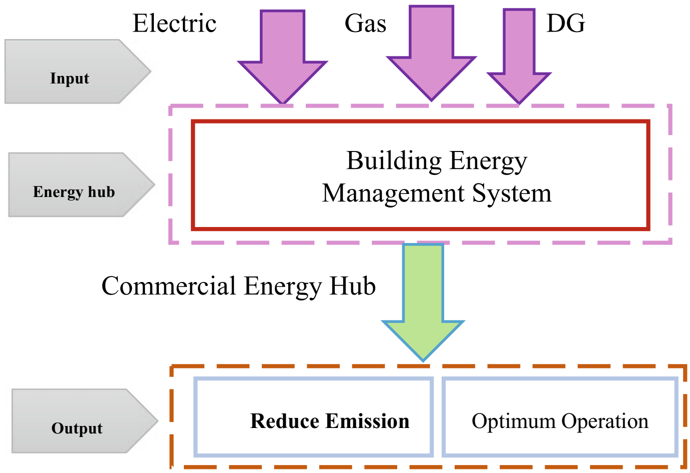

Fig. 6 Analytical model of commercial energy hub

The result is integrated management, cost reduction, peak shaving, reduction of environmental impact, and participation in DR programs.

BEMS correct operation performed with the impact of three items:

- Forecasting the load and weather
- Using different energy carrier
- Use of RESS and ESS

The most important advantage of commercial loads is the predictability of their consumption curve.

In residential loads, the consumption curve changed hourly and quickly, but changes in the consumption curve of commercial loads replaced daily weekly or even seasonal.

For example, in an office building, the consumption curve is divided into two parts of weekdays and weekends, which are followed by a fixed shape in each group. This feature of commercial loads has a high potential for managing demand and participation in DR programs. dependence on climate prediction can make vision changes during seasons changes.

In the commercial sector, the most impact on the load rate is thermal loads because most heating equipment will generally consume more than other energy equipment [18, 19]. The maximum demand for HVAC has been conclusively associated with climatic conditions and has also shown evidence that is responsible for the increasing demand for HVAC [20].

With the influence of distributed energy resources, it is necessary to obtain weather information for optimization algorithms due to the continuous output of this equipment to weather conditions.

In summary, due to the high cost of energy, environmental safety precautions, and the need to use high energy efficiency equipment in commercial buildings, different methods for reducing costs and emission in this sector Have been used. Among these methods, the use of an integrated energy management system such as BEMS has taken more attention. Finally, the modeling of a BEMS will be available in a commercial section, taking into account the electrical energy Storage System (ESS), MES, RES, DSM, and uncertainty in the form of an energy hub.

(C) Industrial

The biggest energy consumer in the world is industrial sector. By changing the lifestyle and tendency to industrialization, increasing industrial countries, and adding energy consumption in developing countries, the amount of energy demand in the industrial sector has significantly increased.

Increasing demand in the industrial sector is high because of growing the population, increasing the demand for consumer goods, and also increased the use of electric vehicles.

World industrial sector energy usage increases by more than 30% from 2018 to 2050, reaching about 315 quadrillion British thermal units (Btu) by 2050 [5].

The primary solution for increasing energy efficiency and reducing emission in the industrial sector is the use of heat generated in the form of waste losses and energy auditing in different parts of consumption. Energy auditing is in the form of series power consumption. By specifying the consumption and allocation of the energy index to each of these sectors, energy auditing can plan for optimal consumption and energy storage opportunities.

For example, technology and methods used to increase energy efficiency and reduce emissions in the Chinese power plant. Alternatively, reducing the GHG release at the Thai ceramic production plant, exploration of energy-saving potential in the China power industry has been studied.

In addition to the mentioned methods, there are many methods to improve the efficiency of the industry sector. Methods such as monitoring consumption, proper and incentive policies, using high-efficiency equipment, improving the environmental conditions of factories and such as these.

Basically, the efficiency improvement methods for the industrial sector are divided into three categories: technical and technological conditions, effective policies and behavioral training, industrial energy management systems (IEMS). The first case includes the energy audit, the use of techniques and methods such as variable speed control for electric motors, waste heat reuse, Co-Tri generation, use of high-efficiency equipment. The next case includes incentives for the governments for industry owners to improve the efficiency, laws, and preventive measures such as obtaining taxes for carbon emissions, encouraging the use of the RES in industries, recruitment Interns, and improving the productive culture of the workplace. For more details on this subject, refer to [21]. The analytical model of this method is depicted in Fig. 7.

In [22], the concept of energy hub has been used to supply electrical, thermal, and water demand, a cement factory. The energy hub is optimized by the genetic algorithm (GA to provide demand and reduce cost and pollution, increasing efficiency. Results

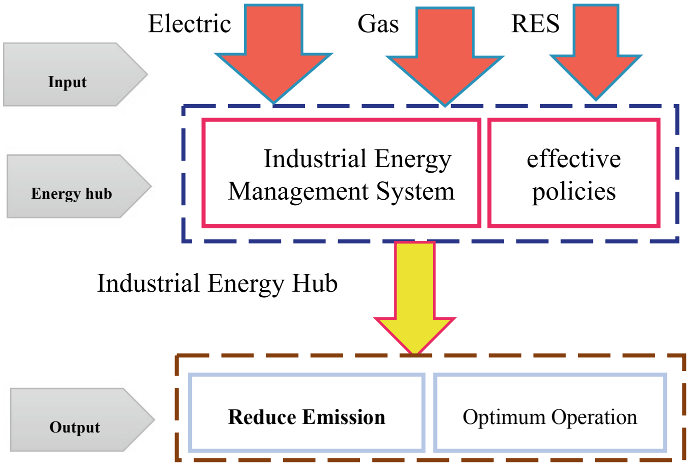

Fig. 7 Analytical model of industrial energy hub

show that the total annual cost of about 36,000 $/year decreased and exergy efficiency increased by a rate of 36%, as well as CO2 emissions decreased to 21,620 tons/year.

Industrial Energy Management System (IEMS) is integrated management to supply the amount of consumption. The primary purpose of this system is to reduce the cost of operation, reduce emissions in a way that does not enter into the system performance. Many technologies have been used to deploy in IEMS. A general overview of the management of various energy systems and their positive impact on energy storage in different residential and industrial sectors in [23] performed.

According to the findings obtained from previous research, most methods of reducing the cost of operation and energy storage related to techniques such as MES, DSM, and the influence of the RES. Therefore, in the industry, to benefit from DER, DSM, MES, and getting more energy efficiency, it requires IEMS to manage production, transfer, storage, and consumption.

The most prominent characteristic of industrial loads is its predictability, which is considered a decisive point in terms of planning and management. Besides, the possibility of using the RES in this section is more comfortable than the other parts.

Also, the cost of setting up and investing the RES in the industrial sector is higher due to the need for greater power.

Generally, the preferences of industry owners have cost to environmental safety precautions. Therefore, government policies to encourage industry owners to adhere to environmental safety precautions and on the considering of penalties for emission can have a significant impact on the use of renewable resources.

Accordingly, the effect of protectionist policies for the optimal combination of power system for an industrial unit in Italy in [24] has studied. The results show that the use of PV system without government supportive and incentive policies due to its high cost is almost impossible. Also, the use of wasted heat for thermal and even electrical demand by CHP and other RES in the form of DSM and especially the DR programs can bring many advantages to the entire system.

The use of DR programs in the industrial sector is facing challenges. The reason for this is the difficulty of using various electrical, gas, water, raw materials in the industrial area. Moreover, the balance issue is critical and requires special attention. Therefore, this section requires an optimal management system to make technology and different energy requirements in the most efficient way possible.

In [25] a MILP model has been studied for the management of industry demand to participate in the DR program in spite of responsive loads and participation in day-ahead electricity markets. Considering various objective functions such as minimizing cost, increasing profits, reducing losses, and environmental impact can be an optimal operation of industrial units.

Unlike the high potential of the industrial sector for optimal operation and management in the form of industrial energy hubs, very little research has conducted in this area. In [26] a comprehensive model of the optimal management of industrial energy hubs in the form of smart grid was presented. Mathematical modeling of this system involves minimizing the cost of energy. The model has applied in flour mill, and a water pumping facility, which showed that the model presented in combination with control tools and communication better performance in the form of industrial energy hubs in connection with the Smart network.

Due to the need for energy-saving and improving the efficiency of equipment in the industrial sector, an IEMS is needed to benefit from the different methods of improving energy efficiency.

The combination of smart grid with IEMS, considering the demand schedule and uncertainties, the use of DER, and many other technologies can be provided in the platform of an industrial energy hub model.

(D) Agricultural

The agriculture sector is the most crucial productive part of any country. The agricultural sector is in direct contact with people's food and must pay special attention to this section for food security.

The use of primary energy in the agriculture sector is less than in other sectors. Energy consumption in the agriculture sector has increased due to the need for food, lack of mechanized system, the lack of technology improvement.

To achieve sustainable agriculture, the challenges of energy consumption and efficiency, production cost, environmental impact will resolve.

Many methods to address these problems have been introduced to make them easier to check in two categories that include improving the traditional system performance and using alternative systems such as Greenhouses.

In each of the two categories, we can improve the performance of the agriculture sector by using different methods. Many studies show high losses in the energy consumption efficiency of the agricultural sector.

The energy carriers used in agriculture are mainly electricity and gases that use in both direct and indirect forms. Direct consumption of energy carriers mainly uses

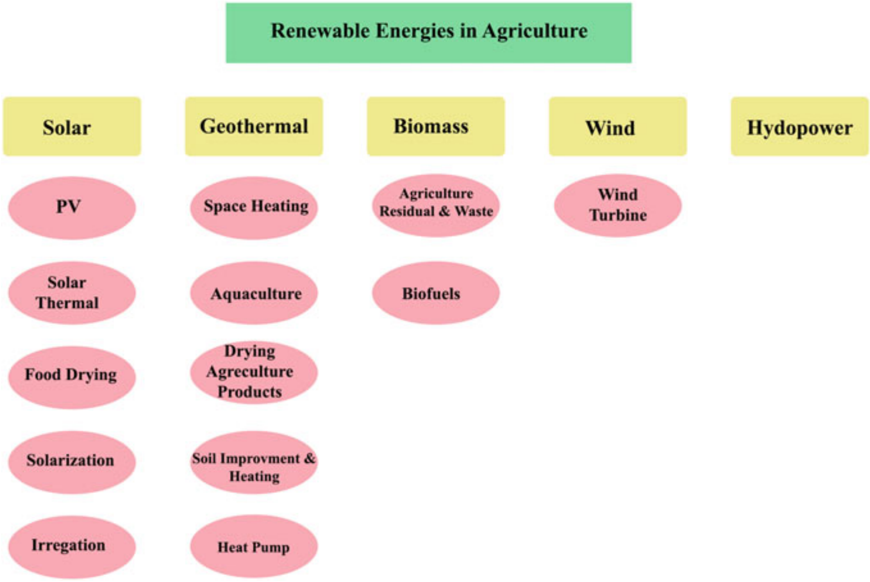

Fig. 8 Application of RES in the agricultural sector

for the energy supply of pumps and fuel for agricultural machinery. Besides these, it makes uninterrupted use of these carriers for heating and ventilation of greenhouses, livestock, and chickens. Indirect consumption of energy carriers also includes the use of carriers in the process of production of consumer and intermediary institutions required by the agriculture sector.

Energy efficiency and product affordability are dependent on these inputs. Therefore, the optimization of quantity and combination of these methods has a significant impact on improving productivity. Solar, wind, biomass, geothermal, which are renewable sources used in the agricultural sector is shown in Fig. 8 along with the application of each part of the sector.

In [27], the use of the particle swarm optimization (PSO) algorithm has been investigated to achieve an optimal combination of energy hub components and optimal scheduling of natural gas, wood chips, biomass, and electrical energy. Its objective function is to reduce the operation cost and emission of CO2. The results showed that the PSO algorithm has efficiency for optimum scheduling. Also, the gas turbine is superior to the biomass production unit in reducing the cost of operation.

According to most of the studies in the field of agricultural energy hub, the best use of fossil fuels to supply electrical needs with the possibility of using renewable energies and fuels Renewable, such as biogas, bioethanol and biodiesel, which can be used in a CHP to supply electrical demand, is consumed in this section.

Also, considering that the agricultural lands are in remote areas, using the RES can be reduced on the transfer and distribution of electric energy costs to these areas.

The largest application of renewable resources are in agricultural units, which will cause many benefits, such as reducing energy costs, reducing environmental impact, and thereby producing green.

Solar energy in the agricultural sector can be used to produce electricity, heat, cold, and drying of agricultural products. Biomass can apply for the energy supply of CHP or CCHP.

The geothermal energy can be used in agricultural works, including heating greenhouses, adjusting the temperature of agricultural products, drying agricultural products, and also in heat pumps for thermal and cooling demand. In addition to traditional windmills, the wind turbine can use for providing electrical demand without the cost of transmission and distribution. For more information on the application of the RES in agriculture, see [28] for more details.

In addition to the use of the RES recently, smart methods have attracted much attention. These quick methods include smart metering, intelligent networks with improvements in monitoring, control, and measurement, improves efficiency, sustainability, reliability, and optimal distribution of energy resources. Smart technologies are not limited to smart networks but also helps create a new structure of Smart Farms and Smart agricultures. Therefore, information gathering and communication technologies can be used in the agricultural sector to monitor and control the physical information of Farms and products.

The various models of wireless communication technologies and their applications in different agricultural sectors can find in [29]. According to the findings, there are no comprehensive models for optimal management of Smart Farms Energy management and Energy exchange between adjacent systems.

Based on the ability of energy hub in integrating various energy systems, with the presence of various energy sources, there is a great potential for the use of various energy carriers in smart farms, despite the ability to integrate these resources into the energy hub, which makes it possible to use smart technologies in the form of smart agricultural energy hubs.

Greenhouses that are known as small-scale Farms have good potential in the production of agricultural products by controlling the conditions and approaching it to the optimal state. On the other hand, the greenhouse has many advantages, such as the possibility of multi-product harvesting during the year, less impact of climatic conditions, integrated management, and better cost control. Based on high costs allocated to this section, poor management of infrastructure and operation of greenhouses has reduced the efficiency of resources used.

For the management and control of greenhouses, various objectives such as reducing costs, reducing energy consumption, reducing environmental impact can be considered. The methods of improving efficiency in greenhouses have been proposed in [30]. With closed greenhouse system the maximum improvement of greenhouse performance achieves.

Keeping the CO2 and humidity at optimal levels is challenging and has a high energy loss. One of the best solutions for this problem is the use of the Closed Green House system, which has no connection with the outside. CGH has a high potential for the use of renewable resources and is also independent of climatic conditions.

The use of the CGH concept in the application of RES and integrated management can improve sustainable agriculture anywhere in the world, and in addition to the production of green products, to provide the demand for nearby buildings. In this study, the CGH shows to increase production and improve in addition to efficient use of energy, as well as the use of RES to reduce environmental impact and green manufacturing. The concept of this method has shown in Fig. 9.

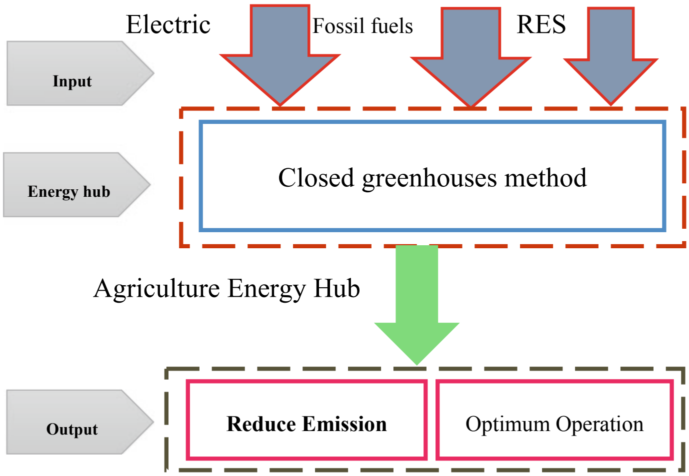

Fig. 9 Analytical model of agriculture energy hub

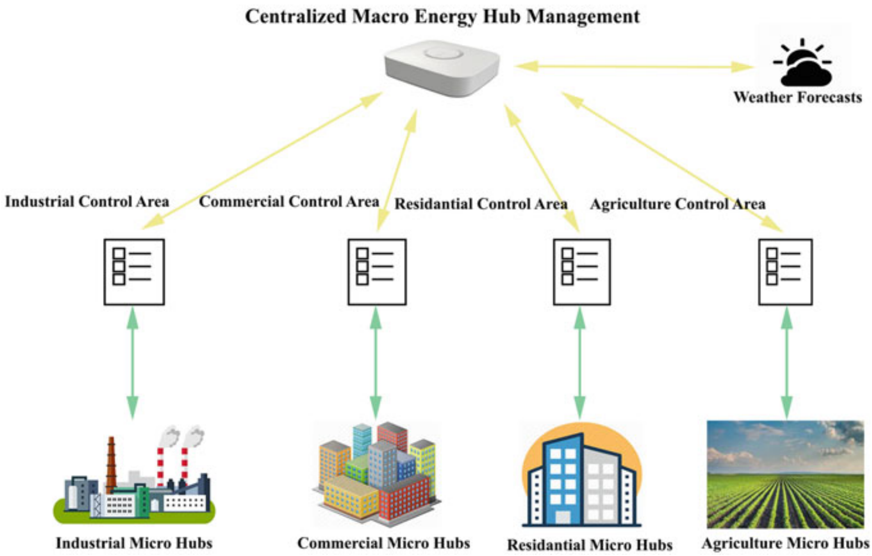

Fig. 10 Centralized macro energy management structure

As it can see, the agricultural sector has a great ability to use RES and increase its efficiency through local multi-carriers, smart technologies, and integrated management, especially in CGH. A few types of research have conducted in the field of energy hub in agriculture.

Considering the concept of energy hub for agriculture sector in the form of agricultural hubs, it is possible to obtain many advantages from the integrated management of the agricultural hubs system, such as optimum operating, reducing environmental impact, and the integration of RES can reduce energy cost, after all, produce an environmentally friendly product.

3.2 Macro Energy Hubs

Using the concept of energy hub, it can be modeled without limitations on the size of different systems. The entire energy hub has a supportive concept and divided into two categories of Micro Energy & Macro Energy. With the increase in the number of micro-hubs, the need for an integrated and coordinated management system will be at a higher level to form a continuous network of energy hubs. This network is called Macro Hub.

Macro hubs are a set of energy hubs that manage and control them in a coordinated manner. By the concept of macro hubs, huge energy systems are modeled, like residential complexes, industrial towns, and even the entire city. Macro hubs are integrated model of micro-hubs, which their management can be achieved a lot of advantages for the entire system, as well as any of the micro-hubs.

These sector's integrated management increases the efficiency and reduction of losses, fossil fuel consumption, environmental pollution, and total system costs. There are many ways to integrate energy carriers, but one of the best methods is to use the concept of an energy hub.

Optimization opportunities for the entire system are provided by modeling these systems in the form of macro hub. The energy hub considered a supernode that connects various energy carriers.

The advantage of modeling using the energy hub can consider the priority of each consumer, such as the total system constraints in the model and the optimization.

In any financial systems, the cost of consumers considered, the energy system is not exception by this rule and reducing the bills cost and energy consumed is the attention of consumers while the institutions of the supplier this energy, such as power companies, in addition to minimizing cost and increasing profits, should consider the power quality, peak shaving and the modification of the consume curve.

In order to optimize macro hubs, it must be considered the priorities of the entire system, which optimization problem is a double-layer hierarchical problem. Therefore, in addition to optimizing the micro-hub in the macro hub, we must also consider optimizing the micro-hub. Their consumer preferences and constraints considered at the micro hob level, and the issue of the optimal power flow (OPF) and in the overall state of the optimal energy flow (OEF) issue at the macro hub level concedes.

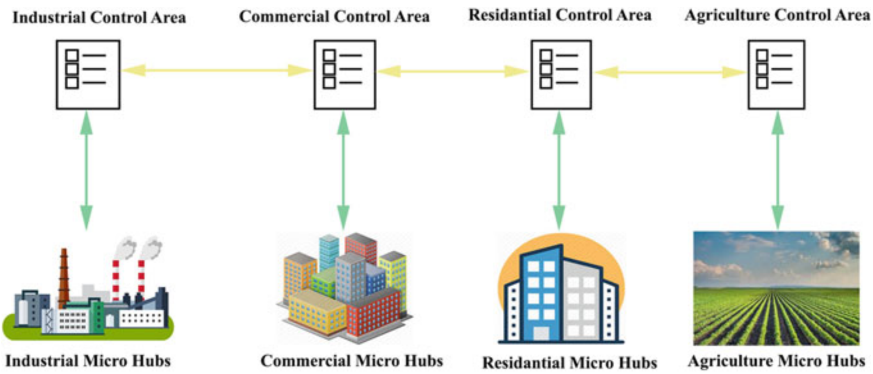

Fig. 11 Decentralized macro energy hub structure

Macro hub management and control do in two ways: centralized and decentralized. In the centralized model, that has shown in Fig. 10, the optimization issue for optimal macro hub performance and optimal functional conditions of each component define and responsible for data collection and signal processing, and sending control information is Central management unit. This unit adopts all decisions related to the optimum operation of the macro hub.

With the enlargement of the system scale and increasing the number of components and energy carriers, increasing the number of variables in the optimization problem and data needs to be processed, volume, cost and time calculation of them increased, and in some cases, the optimal response will be hard at a reasonable time, and the ability to control and monitor online is lost.

On the other hand, some representatives of active participation in central control programs are not allowed to access all the system representatives, information, and control of the equipment. In such circumstances, a decentralized or distributed system discussion occurs while shown in Fig. 11.

In this decentralized system, the nature of the optimization problem is not changed and will only divide into several sub-issues, which solve each sub-sections in parallel to reduce the calculation time and processing in a large scale system. On the other hand, this type of system and its division to sub-issue can increase the reliability of the decentralized system, as the disruption in the control area will only affect the same area and it will have a slight impact on the entire system performance whilst in a centralized system, the shape of the data collection and processing can have an effect on the overall system performance.

4 Conclusion

At this search, reviewing the concept of energy hubs was comprehensively investigated. Advanced Energy systems have been able to improve performance and efficiency in these systems by using the concept of an energy hub. More on the introduction of residential, commercial, industrial, and agricultural micro hubs and the challenges and characteristics of each of these sectors of energy consumption discussed. In the next stage, we discussed the management of these micro-energy hubs, which led to the formation of a network that is called Macro hub.

In the residential sector, due to long transmission and distribution lines, poor energy consumption management, low efficiency of energy consumption equipment is significant and requires integrated and optimal control. However, in recent years, with the renewable influence, energy storage systems, increasing the efficiency of equipment has improved the performance of these systems.

In the commercial sector because of a fixed consumption pattern that changes on a weekly, monthly, and even seasonal basis, energy management is more convenient. than the residential area and has a high potential for the use of the RES in this sector. Also, the commercial sector has large thermal loads such as HVAC, which requires optimal control of resources and cost reduction and emission. The industrial sector has a more predictable consumption pattern than the rest of the areas. On the other hand, due to the hardness of production scheduling, the existence of various energy carriers as inputs, the use of DR programs in this section is more complicated. Also, due to the need for high power, the implementation of the RES systems has a high cost. Therefore, the need for supportive policies on behalf of the Government for the industrial sector and increasing the efficiency of equipment to reduce the impact of the RES and increase the hope of participation in DR programs.

Energy plays a fundamental role in agriculture sector. Fossil fuels are the second source of energy sources due to the high potential of using renewable resources in this sector. in the agriculture sector, using the CGH system, high efficiency by contributing to the RES can be achieved. Three critical characteristics in all the studied sections are the same, including the improvement of equipment and techniques, policies and behavioral training, integrated energy management systems.

Energy management systems have more impact than other characteristics of the energy system. So, there is a high potential for the energy hub model in the integrated management of energy systems to benefit from DSM and especially DR programs and renewable resources and storage.

In addition to integrated management of various carriers in the form of the micro hub, integrated management of different micro hubs in the way of the Macro hub has technical, economic, and environmental advantages.

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