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Design of clustered MEN based on effective use of multi-energy

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Abstract. This paper put forward a new concept--- “clustered MEN”, based on multi-energy complementarity, which abandons the concept that microgrids must be connected to the big grid. Firstly, this paper expounds the basic concept of multi-energy microgrid and how to improve its reliability and flexibility. Next, it focuses on the analysis of its implementation methods, including topology design using the concept of “energy hub”, and the enumerations of objective function and constraints. Finally, this paper explains how to cluster the microgrids by energy routers, the stratified structure of cluster the microgrids and its characteristics. This paper provides ideas for the concept of multi-energy systems and smart cities.

1. Introduction

In recent years, with the development of distributed generation (DG) and support from government, microgrid is emerging [1, 2]. The Multi-Energy Network (MEN) can achieve coordinated optimization and control of distributed energy devices, then ultimately realize the complementarity of various energy sources such as electricity, heat and gas, which improving the energy efficiency [3]. However, due to the problems of DG power quality and reliability, there are many challenges in the grid-connected and dissipated generation of distributed power [4, 5].

At present, the cluster research of microgrid is mostly focused on microgrids of electricity, such as DC microgrids [6, 7]. However, there are relatively few cluster researches on multi-energy systems. Most of the integrated microgrids that contain multiple energy sources are locally consumed or converted into the large grid [8, 9].

This paper put forward a new concept--- “clustered MEN”, that is, to dilute the view that microgrid must be integrated into the large grid. By reasonable design of topology and complementary of multi-energy, microgrid can improve the utilization of DG and even run independently. Then microgrids are clustered by the use of energy routers to further amplify the complementary role of microgrid, so that the clustered MEN is more robust.

As for topology design, this paper establishes a comprehensive goal considering economy, environment and reliability, based on regional energy optimization allocation principles [10], and uses the concept of “Energy Hub” to complete the construction of microgrid from scratch. In this paper we will show the validity and future potential about clustered MEN.

2. Multi-Energy Microgrid

The multi-energy microgrid established in this paper mainly includes the following types of energy:

- a. Generation with Fossil Energy, such as thermal plant/gas engine.



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- b. Generation with Sustainable Energy, such as PV /wind generation.
- c. Battery Energy Storage, such as lead battery.

The microgrid configuration above may be referred to as a smart area, which includes smart grid, heat supply network and transportation network.

In order to make up for shortcomings of DG such as power quality and reliability, the microgrid in this paper proposes the following solutions:

2.1. HEMS

HEMS(Home Energy Management System) includes the home network(such as LED, television washer, air conditioner, etc.), home gateway, heat pump, fuel cell, sustainable energy(such as PV and wind generation) .

Among them, the consumption of PV is the most important problem. Therefore, the user's behavior needs to be adjusted. For example, the using time of washing machine and electric cooker should be when PV is sufficient, water heater heats in advance using PV generation. The optimized plan of electricity will improve the PV proportion of self occupied, reduce electricity costs finally, improve the economy of the user.

2.2. Units smart meter

A Smart House consists of smart appliances due to installation of smart cards, which act as communication icon between Smart Meter and appliances. Number of such Smart Houses are connected with a Town Server. This Town Server is able to control power, provided by service provider and power generated by Regenerative sources. Smart Houses are controlled by Town Server using Smart Meter.

2.3. Energy storage system

Battery can realize the coupling and decoupling between different energy networks. Battery can store energy and release it when needed, it enables the different energy networks to be interconnected through the battery. In addition, battery will also realize the energy network's Decoupling. battery can release the stored energy at an appropriate time to achieve time decoupling; The stored energy is transferred between different energy grids for proper transportation and spatial decoupling.

2.4. Electric vehicle (EV)

As a new generation of transport, plug-in hybrid electric vehicle (PHEV) and battery electric vehicle (BEV) has received widespread attention and development due to its ability to store energy and replenish . The wind -EV bidirectional complementation will reduce the abandoned wind energy and contribute to realizing clean energy charging and improving wind energy utilization. EV is used as a social infrastructure, for example, EV supplies energy to HEMS while there is energy shortage in home, accordingly, HEMS supplies energy to EV while there is energy surplus in home. In this way, the reliability and flexibility of microgrid is greatly improved.

3. Topology designing and objective function

This paper uses the key conception of "Energy Hub" to complete the construction of microgrid from scratch, and totally complete the choose of investments and the power flow between different energy Internet .

3.1. Energy hub

The Swedish Federal Institute of Technology has built the concept of an energy hub (EH) capable of coupling various energies such as electricity, heat and gas [11]. The introduction of energy hubs stems from our mathematical requirements for the coupling of input and output energy. When the system is running, users and managers pay more attention to input energy and output energy. The conversion

process can be approximated as a black box, so that a local energy Internet can be abstracted as shown in figure 1.

The energy hub can abstractly represent the conversion process. Where P_m represents the n-th type of input energy source of the local energy internet, and L_n represents the m-th type of output energy obtained by the user side [12].

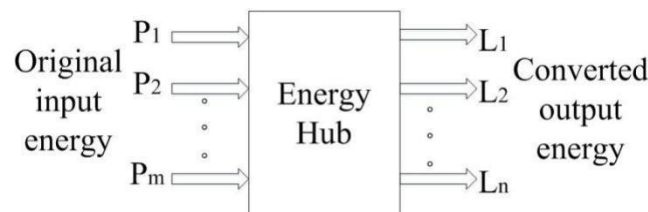


Figure 1. Input-output port model of energy hub.

The function includes various conversion processes in the hub, such as energy conversion, transmission, and storage. Therefore, energy hub can be summarized as the following three parts:

d. Energy transmission equipment: only transmit energy without different forms of energy conversion, such as power transmission lines, gas network pipelines, hot pipe network;

e. Energy conversion equipment: to achieve the conversion and coupling of different kinds of energy, such as gas turbine to convert natural gas into electrical energy, wind turbine to convert wind energy into electrical energy;

f. Energy saving equipment: it can be divided into electric storage devices and heat storage devices. the EV mentioned before is also energy saving equipment to some degree.

In an EH, the coupling between output energy sources L and input energy P can be formulated nonlinearly as follows:

$$L = f(P) \quad (1)$$

For an EH with M types of input energy and N types of output energy, Eq. (1) can be rewritten as follows:

$$\begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_M \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1N} \\ c_{21} & c_{22} & \cdots & c_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ c_{M1} & c_{M2} & \cdots & c_{MN} \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_N \end{bmatrix} \quad (2)$$

where c_{MN} denotes the coupling factor. the coupling factor is a combination of the dispatch and efficiency factors.. Efficiency is determined by the characteristics of the energy converters. The dispatch factor represents the operating status of the EH. The parameters and costs of the energy converters to be selected is shown in table 1.

Table 1. The parameters and costs.

No.	Type	Parameters	Capacities (kW)	Costs (Euro)
1	CHP	0.3, 0.45	300, 450	430, 000
2	AB	0.8	900	76, 500
3	CERG	3	400	48, 000
4	WARG	0.7	400	48, 000
5	HP	2	400	60, 000
6	EB	0.9	400	48, 000

Then establish the branch energy flow model and energy flow equations for the EH [8], then, whether to select a device, whether the device or the fracture is connected, can be represented by a 0-1 matrix.

3.2. Objective function and constraints

3.2.1. Objective function. The objective of EH planning is to minimize the overall cost, including the economic costs C_1 and the environmental costs C_2 :

$$\min Y = C_1 + C_2 \quad (3)$$

C_1 includes the investment cost of energy converters and storage devices C_I and the operating cost C_{COM} :

$$C_I = C_I + C_{COM} \quad (4)$$

$$C_I = \sum_{i=1}^N \alpha_i S_i \quad (5)$$

where i is the index for energy converters or storage devices and N is the total number of energy converters and storage devices to be selected; α_i is the unitary investment cost of the i -th energy converter; S_i is the installation capacity of the i -th energy converter of the i -th energy converter.

$$C_{COM} = \sum_{t=1}^T \frac{1}{(1+\varepsilon)^t} \sum_{i=1}^N S_i (E_{F,i} + E_{OM,i}) \cdot T_i \quad (6)$$

where t is the time period and T is the total number of planned years; ε denotes the interest rate used in calculating the annualized investment cost; T_i is the annual operating hours; $E_{F,i}$ is the unitary fuel cost; $E_{OM,i}$ is the unitary operating cost.

$$C_2 = \sum_{t=1}^T \frac{1}{(1+\varepsilon)^t} \sum_{i=1}^N S_i \cdot \lambda_i \cdot T_i \sum_{k=1}^K Q_{i,k} (V_{i,k} + F_{i,k}) \quad (7)$$

Where λ_i is the Power factor of the i -th energy converter; k the index for pollution and K is the total number of pollution $V_{i,k}$ and $F_{i,k}$ is the unitary environmental value of the pollution and the amount of fine.

3.2.2. Constraints.

a) Equality constraints

Internal energy hub meets the constraints of the hub itself as (1)

b) Inequality constraints

The range of output of each distributed power supply and conversion equipment:

$$P_{i-\min} \leq P_i \leq P_{i-\max} \quad (8)$$

4. Clustered by energy router

The optimization of energy flow is inseparable from the real-time transmission of information in a microgrid and between microgrids, so energy router is needed.

Energy router is the core equipment of the energy internet, including energy, information, customization and the function of system operation needs. Energy switch enables secure connection of energy subnets and energy routers. While the Energy switch performs detection and management of the entire network, it also submits relevant information (such as energy production consumption and

storage methods) to energy routers, ensuring the efficient use of resources and equipment and achieving a balance between supply and demand. It can work in the grid, interconnection and island three different modes.

In a separate HEMS, excess electricity from PV generation is disconnected, but if microgrids are clustered, excess electricity is transferred and used in neighboring houses, which completes the optimization of transfer among regions. With the help of energy router, different microgrid can be clustered to realize the optimization of transfer Among regions.

As shown in figure 2:

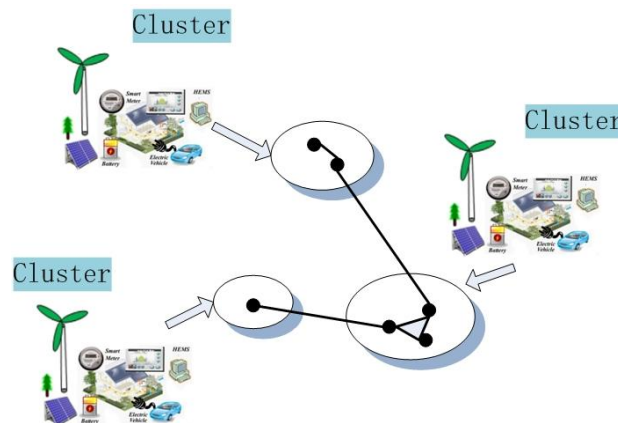


Figure 2. The The structure of Clustered expandable microgrids.

The structure of Clustered expandable microgrids. will be:

- Construction of an appropriate scale distribution grid (The first cluster)
- Expansions of clusters according to increase of regional demands (The second cluster)
- Interconnections of clusters by electrical routers (Tie- lines and Inverter control)

For instance, as shown in figure 3, the output of PV is larger in fine area and the output of wind generation is larger in rainy area, and energy demand in the office district is concentrated and daytime load is higher than nighttime. Therefore, there are differences in DG's output and users' demand in different microgrids, we can included that:

- Energy management in larger areas is more effective than that in a single house.
- Excess electricity stored in battery in sunny areas can be transferred to houses that require electricity. It is not necessary for a battery to be installed in an individual house. If one battery is installed for every few houses, then the installation cost will be decreased.
- Demand in residential areas is larger in the morning and night, while demand in commercial areas is larger in the daytime, by transferring electricity between areas, electricity can be used effectively.

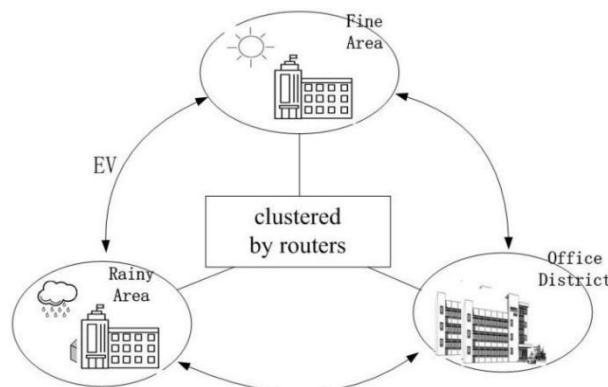


Figure 3. Regional complementarity in clustered MEN.

5. Conclusions

Large power grid has many advantages such as long transmission distance, large capacity, low loss and so on, but at the same time, it has problems such as difficulties in scheduling, resonance and system security. Therefore, this paper focus on the concept of “clustered MEN”, which abandons the concept that microgrids must be connected to the big grid. Then this paper describes the implementation mode of clustered MEN from the aspects such as device level, target level, and interconnection layering planning:

- a. HEMS, Smart Meter, Energy Storage System and EV can all optimize the multi-energy flow.
- b. “Energy Hub” to complete the construction of microgrid from scratch.
- c. Microgrids are clustered by the use of energy routers to further amplify the complementary role of microgrid.

This paper is just a sketch of clustered MEN. The hub model needs to be improved, the reliability index is not taken into account in the objective function, we will continue our study.

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