A Micro grid design for a kind of household energy efficiency management system based on high permeability

Siwei Li\textsuperscript{1,a}, Jun Li\textsuperscript{2}, Zhuochu Liu\textsuperscript{1}, Min Wang\textsuperscript{2} and Liang Yue\textsuperscript{1}

\textsuperscript{1}Beijing Guodiantong Network Technology Co., Ltd., 100070, Beijing, China
\textsuperscript{2}State Grid Zhengjiang Electric Power Supply Company, 310007, Zhejiang, China

Corresponding author : 46187686@qq.com

Abstract. After the access of household distributed photovoltaic, conditions of high permeability generally occur, which cut off the connection between distributed power supply and major network rapidly and use energy storage device to realize electrical energy storage. The above operations cannot be adequate for the power grid health after distributed power supply access any more from the perspective of economy and rationality. This paper uses the integration between device and device, integration between device and system and integration between system and system of household microgrid and household energy efficiency management, to design household microgrid building program and operation strategy containing household energy efficiency management, to achieve efficient integration of household energy efficiency management and household microgrid, to effectively solve problems of high permeability of household distributed power supply and so on.

1 Introduction

With the rapid development of distributed power supply, there are increasingly more small-capacity distributed photovoltaic entering ordinary Chinese families, distributed photovoltaic access is directly embedded into household electrical network\cite{1,2}. Domestic household distributed power supply access on household distributed power supply has been increasingly more widespread, relevant household distributed power supply access projects that have been carried out domestically, household distributed power supply access shows high permeability, uncontrollability, fluctuation and other characteristics, relevant domestic companies have carried out flexible and friendly control, increasing energy storage device and other methods to achieve characteristics of distributed power supply control, fluctuation and so on, but there are no related researches about conditions after high leakage rate access of distributed power supply. Household energy usage management has always been at extensive status, mainly lacking incentive mechanism and initiative control management. The rapid development of smart home and household energy efficiency management just makes up for the rational application of household energy use. This paper will introduce a kind of household microgrid design on the basis of distributed power supply high permeability, to achieve household energy management through the combination of household energy efficiency management philosophy and household microgrid\cite{3-6}. 

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
Currently, Zhejiang Province and Anhui Province have carried out household photovoltaic power generation system construction, forming contiguous and village-style development trend, but the construction of large area of distributed photovoltaic systems has also brought a lot of problems. The majority of people in the country are the elderly, with a small number of household appliances, and farming has characteristics of seasonality and intermittency. Jiaxing City Zhejiang has invested in the construction project of 300 household photovoltaic, with a total price of 18 thousand yuan for 2kWp of photovoltaic capacity. The government has invested 6000 yuan, and the bank has received 12 thousand yuan of financing, with annual household energy production of about 2100Kwh. 80% of electric energy is unable to eliminate on its own, but needs grid-connection. The user annual electric consumption is 1200Kwh, with photovoltaic permeability of above 50%. Jinzhai County Anhui are establishing clean energy demonstration country, combined with poverty alleviation and development, to implement "photovoltaic poverty alleviation" on a large scale, with a total price of 24 thousand yuan on 3kWp photovoltaic capacity, 8000 yuan of government investment, 8000 yuan sponsored by PV enterprises, annual user energy production of 4200kWh, annual electricity consumption on its own of 2400kWh, photovoltaic permeability of above 40%, which cause low-voltage grid reverse power. Thus, power grid operation safety and energy elimination after unordered access of high permeability distributed power supply have become major problems of county power network.

2 The overall architecture design

2.1 Component structure

Conventional household microgrid generally contains small capacity photovoltaic, energy storage systems, inverters, electric energy meter and microgrid control units, to achieve coordinative running of each generating unit and electrical unit through microgrid control unit. Household microgrid containing household energy efficiency management adds smart home (household energy efficiency), energy efficient appliances and other devices based on traditional household microgrid, to build household microgrid containing household energy efficiency management through the effective integration of household microgrid and household energy efficiency.

![Household micro-grid structure](image-url)

Overall household micro grid mainly includes energy level and information control layer. The energy level mainly serves for household cold, heat, electric energy supply, and the information control layer mainly assistants energy supply and demand to achieve safe and stable operation, energy fine supply and relevant comprehensive services. On the energy flow transfer aspect, in addition to conventional equipment of photovoltaic, energy storage, etc, new type energy storage media of heat and cold accumulation have been added. On information flow transfer aspect, besides microgrid controller and smart socket, control equipment of interactive service terminal, etc. are integrated[7].

2.2 System architecture
Household micro-grid system adopts standard structure design, for integrating the traditional energy storage system, micro-grid control device and PV inverter, and also uses PLC/WI-FI communication technology to achieve reliable communication of the entire household intelligent terminal. The entire system includes system application layer, network transport layer, equipment support layer and safety management layer, with equipment support layer as the main bottom facilities for household energy efficiency management and household microgrid, through effective integration of device and device, device and system, system and system, to constitute bottom supporting structure. Network transport layer is mainly the node unit for household microgrid system communication transmission. Currently, the communication modes of main products in the market are ZIGBEE, Z-WAVE, WI-FI and PLC, with the use of terminal networking convergence to establish communication channels, and upload to background system through HGU uniformly. System application layer is household energy efficiency management system mainly containing distributed power supply, including electricity usage inquiry, energy efficiency analysis, smart home, distributed power supply access management, household energy management, value-added service, etc. While accomplishing synchronous transmission of energy and information through service contents, it achieves two-way interaction between electricity and power grid [8].

![Household micro-grid system architecture](image)

**Figure 2. Household micro-grid system architecture**

3. Electricity supply mode analysis
Based on the energy supply form of PV high permeability, household micro-grid operational control with household energy efficiency management should be conducted strictly according to logical-strategy, to reduce PV high permeability effectively through energy storage, heat storage and load scheduling.

3.1 Power supply properties
The household photovoltaic power generation system has small capacity between 2 and 3kWp, which is connected to municipal grid through micro-inverter conversion, and its energy flow is mainly balanced through its own system to achieve uniform distribution of household energy. But with the impact of climate change and other factors, the volatility of household photovoltaic power generation system has obvious changes, to conduct energy coordination combined with energy storage system, and constitute a user-independent micro-grid system, and achieve effective supply and balance of energy through interaction between power supply and loads. Energy storage system has energy output and smoothing input, which is easy for energy management and control. Through conventional BMS control equipment, it can achieve current and voltage-sharing of the system, to solve the problem of distributed photovoltaic fluctuation effectively, and the household micro-grid system can integrate the household distributed photovoltaic system well.

3.2 Load characteristics
Household load is mainly divided into power classification, control level classification and temperature classification. The power classification is mainly composed of motor, resistance heat and electronic circuit; the control level classification is mainly composed of important load and interruptible load; temperature classification is mainly composed of non-constant temperature load and constant temperature load, among which constant temperature load has good grid modulation response resources. Household water heater heat the water in resistance heating way, whose power absorption occupies a large share of the total power consumption, with working method affected by device control and artificial operation. It has great randomness of start-stop with thermal storage performance, meanwhile, it is substantially affected by voltage of power grid on regulatory aspect, which makes it the main object for household power elimination and temperature control regulation. Therefore, on household microgrid power elimination and control aspect, constant temperature interruptible load with motor and heat resistance should be selected.

| Classification | Electrical characteristics | Significance of power elimination management |
|----------------|--------------------------|---------------------------------------------|
| Motor          | Have a huge impact current, produce harmonic | Promote the domestic power instantaneous elimination |
| Resistance heat| Great power and stationary power characteristics | The long process of deployment of household electricity use have a great advantage |
| Electronic circuit | Power characteristics have a great randomness | Meaningless |

3.3 Characteristic analysis of the energy supply of household micro-grid

On single household microgrid power supply management aspect, it mainly constitutes household micro-grid system through household distributed photovoltaic, integrated access device and load containing integrated access device, on power supply management aspect, it uses "delivery- storage - supplement" of distributed power supply to achieve the power supply application mode of household microgrid, on electricity aspect, it mainly achieves single household electricity mode study based on the electric-equipment interaction of household HAN and electrovalency and other external factors.

Single household microgrid is composed of on-line operation and off-grid operation modes. During on-line operation, power supply method mainly achieves distributed photovoltaic and electric supply. After the distributed photovoltaic permeability has reached certain numerical value, microgrid control unit starts mode switch function, and the power supply method is mainly based on the output characteristics of distributed photovoltaic and supplements electric supply on the basis of load characteristics, to achieve functional P/Q control through adjusting distributed power supply inverter and achieve model outputs of distributed hotovoltaic power generation system energy supply, distributed photovoltaic electric supply and so on. During the off-grid operation of the household microgrid, the power supply method is mainly under joint control of distributed power supply and energy storage system output. On household microgrid aspect, single household microgrid power supply method mainly consists of distributed hotovoltaic power generation system energy supply, distributed photovoltaic and electric supply, energy storage system energy supply, joint energy supply of distributed photovoltaic and energy storage system.

On the energy mode of single household microgrid, it uses distributed power supply household energy collection terminal to adjust household power load energy, electricity mode combined with time, usage and other characteristics, with household energy dispatching methods of trip pattern, economic model, comfort mode, energy saving mode and so on, to get electricity policy for main household current consuming apparatus, and achieve single household energy use mode, and increase household distributed power supply energy consumption.

4 The control strategy design
With PV high permeability, 80% of household photovoltaic power generation systems can't consume by itself and return the energy. In order to solve the above problems, household microgrid should be built, combined with household energy efficiency management technology, to form consumption carriers making full use of renewable energy. On household energy efficiency control aspect, it encodes the household loading equipment, by integrating load characteristics of high energy-consuming household appliances with intelligent air-conditioning load and water heater load with output forecast of distributed power supply, assessment of distributed energy storage status, electrovalency incentive mechanism and so on, to achieve the fitting of household load and distributed power supply processing, and establish household energy efficiency optimization model containing distributed power supply and energy storage.

4.1 The overall operation strategy
The operating mode of household micro-grid focuses on on-line operation. On energy regulation strategy aspect, under the condition of ensuring user comfort, the microgrid control center is combined with its own load characteristics, and to adjust its electricity mode, response to household microgrid demand and restrain distributed power voltage fluctuation actively, to increase the power elimination and voltage stability of microgrid, and form load consumption strategies based on household microgrid operation status and household power load condition. The household micro-grid control stratege as shown in figure 3, P-Q monitor is active power and reactive power monitor, U is the voltage, f is the frequency, P is the power. PCC, DG, SOC, PV is the abbreviation of point of common coupling, distribution generation, state of charge and photovoltaic.

The overall operation mode of household micro-grid is determined through mode decision, and the operational status of each subsystem is confirmed with the use of grid monitoring device, to get the real-time status of delivery, storage, application of each system, and then according to the overall operating plan goals containing energy efficiency management system of distributed power supply, the operation strategies [9] are formulated.

![Model of the overall operation strategy for a household micro-grid](image)

4.2 Temperature loads control strategy
Economical operation, energy-saving operation, photovoltaic consumptive operation, integrated operation and other operation strategies formulated by the household energy efficiency management system of microgrid containing distributed power supply, based on household electric-equipment status and various indoor sensor test data, under the prerequisite user comfort, when the grid-connection permeability of household micro-grid system is high, the household microgrid power elimination can be achieved through temperature control of load usage time and distributed photovoltaic/ energy storage output curve fitting technique. As show in figure 4 is the temperature load and system output fitting curve, $t$ is the time, $T$ is the temperature, $P$ is the power.
When the household micro-grid system has high grid-connection permeability or it is under off-grid operation, adjust the trigger status of power system according to the system voltage excursion, indirectly cut/close the load for short time, and match the load output effectively through the vertical movement of over-voltage. Temperature loads include cooling and heating and many other modes, therefore the response strategy should be set with cooling regulation and heating regulation modes correspondingly. In the following part, it will take the heating mode for example to make detailed descriptions.

4.2.1 Control methods of the residential constant temperature load based on household microgrid. Typical household water heater mainly heats with the use of thermal conductivity in the water heater through electric supply, and the heating effect has characteristics of gradual rising, which is mainly transferred through electric energy in terms of energy transfer. On the balance of energy conversion:

\[
\sum_{j=1}^{2} \eta_j Q_H = Q_P - Q_{san}
\]

(1)

In the formula: \(Q_H\) is the heat required for water heater power consumption, \(Q_P\) is the heating capacity of electric power, \(\eta_j\) is heating efficiency of water heater, \(Q_{san}\) is the dissipation heat loss during heat preservation of water heater.

The household microgrid water heater containing adds distributed power supply output and response strategy at energy conversion stage, which increases the energy utilization efficiency, delays the appearance of peak value of household electrical network effectively, mainly transferred through electric energy. On the balance of energy conversion:

\[
\sum_{j=4}^{4} \eta_j Q_H = Q_P + Q_{DG} - Q_{san} - Q_{DR}
\]

(2)

In the formula: \(Q_H\) is the heat required for water heater power consumption, \(Q_P\) is the heating capacity of electric power, \(Q_{DG}\) is the processed heating capacity of distributed power supply, \(\eta_j\) is heating efficiency of water heater, \(Q_{san}\) is the dissipation heat loss during heat preservation of water heater. \(Q_{DR}\) is the heat dissipation in response to demand controls.

Through effective control of distributed power supply of household microgrid, it achieves energy interaction between interconnection power and household constant temperature load. How to effectively improve the \(Q_{DG}\) ratio is the key to achieve elimination of distributed power supply of household microgrid. \(Q_{DG}\) makes effective monitoring and monitoring management of the distributed power supply output mainly by using household energy efficiency management system containing distributed power supply. On the control method of constant temperature load of household microgrid, through testing integrated access voltage, frequency and other information of household household photovoltaic. Through photovoltaic power generation, energy storage, electrovalence, constant temperature load, other monitoring and controlling, with the use of coordinative optimization control strategy, to control the constant temperature load of household microgrid.
4.2.2 The capacity of residential controllable load's participating in voltage response. Under the premise of ensuring user comfort, according to size of entire system voltage excursion of household microgrid, it adjusts trigger temperature, and cut off the load for a short time, for the quick recovery of micro-grid voltage and preventing the expansion of accident. Temperature loads water heater mainly uses electricity and heating to provide hot water mode, therefore the main response strategy should be response to the heating mode. Broadly, for resident constant temperature controllable devices actively participating in power grid response, under normal operating state, their internal temperature is uniformly distributed, but the trigger temperature value was slightly different. The device quantity at the operational status or outage status becomes more stable, with relatively stable but slightly different power absorption. The curve of load direct control system under the heating load modulation of thermostatic water heater as show in figure 5, V is the voltage, \( V_0 \) and \( V_T \) represent the voltage before and after regulation.

![Figure 5. Household microgrid constant temperature load (air-conditioning) control methods](image)

When the temperature of water heater is under lower trigger temperature \( T^- \), the water heater starts to work, until the temperature of water heater reaches upper trigger temperature \( T^+ \), when it stops work [10,11]. The electric heater consumes electric power only at working hours, otherwise not. As can be seen in Figure 5 that under the load direct control strategy, the trigger temperature changes along with the system voltage excursion, when the pressure declines, the upper and lower trigger temperature \( T^+ \) and \( T^- \) of the control system move downward at the same time. On the one hand, the upper trigger temperature \( T^+ \) of control system makes downward shift, which is equivalent to delaying the start of electric heater; on the other hand, when the lower trigger temperature \( T^- \) of control system makes downward shift, which is equivalent to stopping heater work in advance. This dual response can help quickly restore the system to a stable state. Similarly, when the system is lightly loaded, and the voltage rises, the upper and lower trigger temperature \( T^+ \) and \( T^- \) of control system move upward at the same time, namely starting the electric heater which is at off-state in advance, and delays the turn-off of heater which is working, so as to achieve exchange with household microgrid power, and make full use of the micro-grid operation control strategy [12-15].

From the research project, it can be concluded that temperature control can effectively respond to household microgrid power fluctuations, and also through direct load control and voltage response, the operation control of household microgrid which is based on the increase of energy using rate of household microgrid can be achieved, and to achieve efficient use of household microgrid.

5. Conclusions
In this paper, it made a detailed description of the household micro-grid construction program, explained the system architecture and interaction method of system software platform of household energy efficiency management containing distributed power supply, and formed the entire control strategy of household photovoltaic microgrid containing household energy efficiency, and achieved optimization of the use of household energy, and also put forward a control method of temperature loads responding to micro-grid voltage excursion, and effectively increased the quick recovery of micro-grid voltage, to prevent the expansion of accidents.
References

[1] Q/GDW-518. Technical Guide for Intelligent Power Utilization Service System[S]. 2010.

[2] Li Siwei, Yu Jiancheng, Tong Dali, et al. Research and effect analysis on residential air conditioner load management mode [J]. Electrical Application, 2015, TM925.12.

[3] Lin Hongyu, Zhang Jing, Xu Kunpeng, et al. Design of interactive service platform for smart power consumption[J]. Power System Technology, 2012, 36(7): 255-259.

[4] Cui Chuang-jian, Li Bo, Li Siwei. Design of General Interactive Service Platform for Power Users[J]. Telecommunications for Electric Power System, 2012, 09.

[5] Liang Shichun, Zhang Xiaodong, Lin Peifeng, et al. A Prediction Algorithm of PV Power with Hybrid Energy Storage[J]. Electric power, 2014, 47(3): 24-27.

[6] Wang Ji-ye, Li Siwei. Design of Smart Home Energy Efficiency Management System based on the Intelligent Interactive Power Service Platform[J]. Electric Power IT, 2014, 47(3): 48-54.

[7] Li Yong, Han Wei, Wang Yanhong. The Analysis and Comparison of Boiler Thermal Efficiency Correction Method Based on GB 10184-88 Code[J]. Electric power, 2014, 47(3): 48-54.

[8] Zhao Ting, Gao Kunlun, Zhang Xiaokun, Xu Xiaokun. Research on technical framework and cybersecurity protection system of IOT in smart grid. [J]. Electric power, 2012, 45(5): 87-90.

[9] Ai Zhen, Hang Yuqi, Yang Xi, Liu YongXiang. Research on load control technology of central air conditioning system based on demand response[C]. Power communication technology and smart grid communication technology, 2013(5).

[10] Zhang Ying, Ma Hongzhong, Chen Kai. No-load transformer vibration analysis and testing [J]. Electric Power, 2012, 45(5): 30-33.

[11] ANGEL A. AQUINO L, RAY K. A. Control framework for the smart grid for voltage support using agent-based technologies[J]. IEEE Trans on Smart Grid, 2011, 2(1): 161-168.

[12] PEDRASA A, SPOONER D, MACGILL I F. Coordinated scheduling of residential distributed energy resources to optimize smart home energy services[J]. IEEE Trans on Smart Grid, 2010, 2(1): 161-168.

[13] NEGENBORN R, HOUWING M, SCHUTTERER B, et al. Adaptive prediction model accuracy in the control of residential energy resources[C]. Proceedings of 2008 IEEE International Conference on Control Application. Pisa, Italy: IEEE, 2008: 311-316.

[14] HAAS R, NAKICENOVIC N, AJANOVIC A, et al. Towards sustainability of energy systems: a primer on how to apply the concept of energy services to identify necessary trends and policies[J]. Energy Policy, 2008, 36(11): 4012-4021.

[15] Wen Quan, Li Jinghe, Zhao Jing. Air-conditioning load calculation methods and its application[J]. Demand Side Management, 2005, 7(4): 16-18.