# Research on energy management and its control strategies of microgrid

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**Abstract: In this paper, the microgrid which is composed of photovoltaic cells, microturbine, storage device and load is researched. On the basis of analysis of the typical structure of microgrid and the operation modes of every microsource, the program of energy management is presented and designed, and its control strategies are researched under the condition of both grid-connected mode and islanding mode. Several algorithmic examples have been studied through simulation, and the simulation results verify the correctness of the energy management's control strategies. The research results indicate that it can ensure the high efficiency and stability operation of microgrid through the coordinated control of energy management.**

***Key words: microsource, energy management sytem, control strategies, operation modes***

## I. INTRODUCTION

In recent years, with the increasing emergence of worldwide energy pressure and various disadvantages of extra-large scale power system, Technology of Distributed generation which is represented by solar energy power generation system and wind energy generation system has got more and more recognition. However, some bottleneck problems exist such as high cost of single machine being connected into power grid, difficulties in controlling; a great impact on the network exists in the development. An effective solution to these problems is to develop microgrid technology. Microgrid is a system which is composed with load and microsource and expressed as a single controlled unit to network and a customizable source to user. Microsource is the core unit of microgrid, the electric energy switching, grid-connection and necessary energy control of which is accomplished by power electronic equipment. In insuring the normal running of microgrid under the condition of both grid-connected mode and islanding mode, it is a key problem in research of microgrid technology that how to manage these individual sources reasonably in order that microgrid can meet the demands of users in power quality and achieve ideal economic efficiency effects.

It is an effective way in researching and developing energy management of microgrid in order to ensure flexible running mode and high-quality power supply service, solving all problems such as voltage control, load flow control, load distribution when system is disconnected, stability and operation. In this paper, according to the analysis of the typical structure of microgrid and the operation modes of every microsource, the program of energy management is presented and designed, and its control strategies are researched under the condition of both grid-connected mode and islanding mode. Several algorithmic examples have been studied through simulation, and the simulation results verify the correctness of the energy management's control strategies.

## II. MICROGRID STRUCTURE AND WORKING WAYS OF MICRO SOURCES

### *A. Typical Microgrid Model*

As shown in figure 1, microgrid structure for office district of small capacity is designed combining with the typical microgrid structure proposed by CERTS. In this figure, there are three feeder lines in the microgrid, line A and B are in connection with the sensitive load and general load, line C is only in connection with general load. The microsources connected with feeder lines A and B are photovoltaic cells, microturbine, and storage device. When light is plentiful, photovoltaic cells can provide free clean energy, because the output of photovoltaic cells is changing intermittently with the meteorological conditions, in order to ensure continuous supply of load, storage devices are installed in microgrid, and microturbine can provide energy for load when there is no output of photovoltaic cells and storage device. Microsources are installed in different position of the feed lines instead of in the public place; this access mode can reduce the line loss and provide terminal voltage support to feed lines. Circuit breaker, power and voltage controller are installed in each microsource outlet, adjusting their power output for the regulation of the feeder trend under the control of the energy management system.

In order to ensure uninterrupted power supply of important sensitive load of microgrid. When such power quality problems as voltage disturbance or the power failure are monitored, static switch S1 acts and microgrid switches to the island operating mode. At the same time, under control of the energy management system, each microsource adjusts its output power to ensure normal operation of microgrid. For the normal load on feeders A and B, C, the system will remove them correspondingly based on the power balance needs of microgrid.

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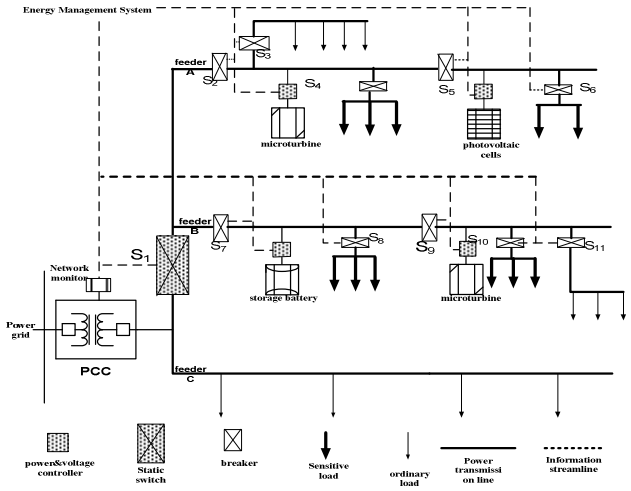



Fig.1 Frame of the Microgrid

## B. Working Mode of Microsource

Distributed generation, according to the use of energy and power mode in different ways, can be divided into two types: One is DC source, such as photovoltaic cells, fuel cells, storage device, etc, which need to transform DC into standard AC through the *inverter*, to supply load or be incorporated into grid. The other is AC source, such as microturbine, which supplies load directly or is incorporated into grid. The microsource in this paper adopts photovoltaic cells and microturbine and lead-acid battery representatively as the research object.

*1) Working mode of photovoltaic cells*

Working mode of Photovoltaic cells can be divided into MPPT mode and fixed power mode.

*a) MPPT mode:*

Output power integrated into grid of Photovoltaic cells is real-time controlled by Controller, and Photovoltaic cells may generate electricity with the greatest power probably under the role of MPPT control algorithms

*b) Fixed power mode:*

Photovoltaic cells are operated in the set power. If the set power is higher than the biggest power output of photovoltaic cells, photovoltaic cells will be operated in fixed power mode.

*2) Working mode of microturbine*

Microturbine with PQ and VF control functions can regulate the power output quickly according to the load changing. There are two kinds of operation mode: high output operation and low output operation. The operation mode is decided by the energy demand of load in island state.

*3) Working mode of lead-acid battery*

Storage battery has two kinds of working mode.

*a) Recharging mode:* storage battery is charged normally until it is full when the remaining capacity of battery is 0. When the storage battery works as an adjusting power, remaining capacity should be checked at all time before the operation, and it cannot be charged temporarily, especially when the battery works in the island mode and the residual capacity is 0.

*b) Discharging mode*: In the island mode, when sensitive load demands higher energy, and the energy output of photovoltaic is not enough, storage battery is demanded to provide energy through discharging. Discharging controller has PQ and Vf control function in response to the change of load, can provide good power supply quality.

# III. MICROGRID ENERGY MANAGEMENT SYSTEM AND ITS CONTROL STRATEGY

## A. Microgrid Energy Management System Functions

Microgrid energy management system integrates data processing, programming, command distribution and combining microgrid function, including the management of the microsource, energy storage management, loading management, breaking and combining network control functions.

*1) Microsource control function*

Microgrid has self-adaptive function regulating power by adjusting the power-electronic conversion and controller fast tracking the active and reactive power changes. And it can adjust its energy output and maintain system power balance.

*2) Management of energy storage devices*

management has such functions as Battery's charging and discharging, voltage, power management, detecting electrical storage charge and discharge status, it can manage the charging and discharging system depending on requirements of system, and can control the output voltage, the active and reactive power, and participate with the active and reactive power control.

*3 ) Load management*

It can be to distribute microsource output according to the detected load , maintain the balance of microsource and load, remove normal loads to ensure the normal power supply for sensitive loads in the operation of island mode of the microgrid,

*4) Mode switching and on-off control*

When testing large electric network calls, micro-grid will automatically run the transition from the island mode to the Grid mode. When failure happens after combining grid and in the exterior of micro-grid, it can be determined the fault severity through the main network to communicate with the microgrids. If exceeding self-regulation extent, the corresponding microgrid can break with the main network and run into the island mode. It can achieve a seamless transition between two modes of operation. Based on the working state of micro-grid, it can send the switching logic signals of microsource, load, and the circuit breaker.

*5) Monitoring function*

The controller uploads respective status information through the communication line, including the network parameters of the PCC point, the output characteristics parameters of the microsources, circuit breakers' on-off state, the all power parameters of loads, according to the comprehensive data processing through energy management system. It can establish microsource switching, working mode switching, power output and other regulations, the circuit

breaker on-off and other control strategies. Then, these settings and control commands will be sent to regulation device for maintaining the normal operation of micro-grid.

*B. Energy Management System And Its Control Stragies of Microgrid*

In microgrid, the objective of energy management is to effectively control a variety of microsources to ensure that microgrid can meet the energy quality requirements at different operation mode. And it can achieve lower system operating costs, improve operating efficiency. The micro-grid has two operation modes including network and island. According to the design of the micro-grid structure, different strategies of energy management have been designed for the network and island modes, to ensure the stable operation of micro power grid.

*1) quantitative express of microsource operation condition*

In order to realize design program of energy control strategy, Aiming at Energy management control coordination strategy, operation condition of photovoltaic Cells、storage device and micro-turbine are quantitatively processed and the following regulations are made:

*a) Illumination condition SL of photovoltaic cells: lighting is defined as 1,and no lighting is defined as 0.*

That is SL＝1 or SL＝0。

*b) Micro-turbine：Low operation and high operation condition：*

$$P_G = \frac{P_r}{P} \times 100\%$$

In the formula： PG is the percentage of Real-time output power and rating power of micro-turbine；

Pr is the Real-time output power of micro-turbine；

P is the rating output power of micro-turbine；

When PG < 30%, micro-turbine works in low operation mode

When PG > 70%, micro-turbine works in high operation mode

When PG > 90%, micro-turbine works in full-load mode.

c) *Storage Battery state-of-charge SOC：*

$$SOC = \frac{Cr}{C} \times 100\%$$

In the formula：SOC is the percentage of Real-time output capacity and rating capacity of storage battery；

Cr is the capacity being used that is measured in load (A·h )

C is the rating capacity of storage battery when it was produced (A·h)

Then the state-of-charge of storage battery is as below several conditions：

When SOC>90%，Battery has been filled with electricity；

When SOC>50%，Battery can discharge；

When SOC<10%，Battery has no discharge capacity, if the conditions permit , it should be recharged immediately.

*2) Networking mode control strategy*

*a) Operation objective*

In the network mode, it should ensure the normal power supply for all loads. Renewable energy should be used as maximizing principle, and minimizing the utilization of primary energy. In the low load periods, the battery should be charged, and fill the valley.

*b) Control strategy*

At network operation period, the coordination programs of micro-grid energy management:

- PV holding MPPT mode;
- Detecting the charge status of storage device is to determine whether electrification. When the battery is not fully charged and at low load period, it should be charged, and stop if battery is full. In the network mode, the reactive power is regulated only by the energy storage device, and compensated to maintain the power balance.
- Microturbine stops running in a networked mode, does not participate in power.

According to the control strategies of energy management in grid-connected mode, normal supply of load should be ensured, while Micro-turbines don't participate in power supply. The control strategies are mainly applied to Photo Voltaic cells and storage battery. control strategies are shown as table 1.

Table 1 The control strategies of energy management in grid-connected mode

| **Operation conditions** | | **control strategies** | |
|---|---|---|---|
| ***Lighting conditions SL*** | ***Charging state of storage-battery SOC*** | ***Photo Voltaic cells*** | ***storage device (battery)*** |
| 1 | ＜0.1 | MPPT | Charging mode |
| 1 | ＞0.9 | MPPT | Stop charge |
| 0 | ＜0.1 | Stop generating | Charging mode |
| 0 | ＞0.9 | Stop generating | Stop discharge |

*3) Island mode control strategy*

*a) Operation objective*

When voltage swell, sag, unbalance and harmonics and other power quality problems or scheduled maintenance happen, the micro-grid transits into the island operation mode. At this time, the voltage and frequency will be controlled by the internal microsources. The microsources take Vf control to participate in the regulation of active and reactive power for maintaining the stability of system voltage and frequency. Energy management system often uses the way of adjusting microsource's typical working mode and interrupting normal load and other measures to ensure the stable operation of micro-grid.

*b) Coordination program of microgrid energy management*

- Interruptible loads should be removed to ensure that reliable power supply to sensitive loads by microgrid, and to ensure the normal operation of sensitive loads;
- PV remains MPPT mode as possible (work in restricted power mode if required)
- According to the operational status of energy storage, it can manage the switching and power generation capacity of the micro-gas turbines. As part of the energy absorbed by energy storage devices, remove part of the micro gas turbine. As energy released by the energy storage device, input part of the micro gas turbine to power;
- Energy controller detects the load power demand and reactive changes. It can take active and reactive power regulation by the micro gas turbine or energy storage device to maintain microgrid system voltage, frequency stability, and ensure the quality of power supply.

According to the control strategies of energy management in islanding mode， control strategies are shown as table 2

Table 2 The control strategies of energy managemen in the islanding mode

| **Operation conditions** | | | **control strategies** | | |
|---|---|---|---|---|---|
| ***Lighting condit-ions SL*** | ***Charging state of storage-battery SOC*** | ***operation state of micro-turbine PG*** | ***Micro-turbine*** | ***Photo Voltaic cells*** | ***storage device (battery)*** |
| 1 | ＜0.1 | ＜0.3 | Operation in low output mode | MPPT mode | Charging mode |
| 1 | ＞0.9 | ＜0.1 | Operation in low output mode | Fixed power mode | Stop charge |
| 1 | ＞0.5 | ＜0.3 | Operation in low output mode | MPPT mode | Discharg-ing mode |
| 1 | ＞0.5 | ＞0.7 | Operation in high output mode | MPPT mode | Discharg-ing mode |
| 0 | ＞0.5 | ＜0.3 | Operation in low output mode | Stop generating | Discharg-ing mode |
| 0 | ＜0.1 | ＞0.3 | Operation in low output mode | Stop generating | Stop discharg-ing |
| 0 | ＜0.1 | ＞0.7 | Operation in high output mode | Stop generating | Stop discharg-ing |

## IV. SIMULATION AND ANALYSISING

### *A. Simulation model*

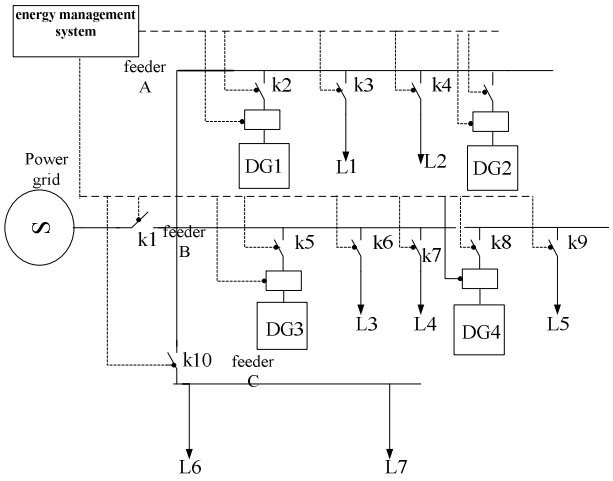



Fig.2 The circuit structure diagram

Using PSIM simulation software, building the simulation circuit shown in Figure 2, the inverted powers and batteries adopts PQ and Vf sag control strategy. The maximum power of photovoltaic cells in standard light is 85kW, microturbine is rated at 600kW (420kW for the microturbine output is the high operating mode, less than 200kW is the low operating mode), battery charge and discharge can be completed in 2.0s under constant voltage. In order to simplize the study when researching battery discharge, you can replace the battery by DC voltage source, ignoring the dynamic process of charging and discharging. The battery can also use the same grid-connected inverter and control circuits with photovoltaic cells and microturbine.

Rated voltage amplitude of distribution network is 220V, rated frequency is 50Hz, and the grid is assumed to be infinite, the sensitive load power consumption is variable between the 50kW/10kvar and 600kW/350kVar, the maximum power of normal load consumption is 700kW / 400kVar.

### *B. Simulation analysis in different operation modes*

a) Example 1 Operation in microgrid-connected mode

From the control strategy of network operation we know that the normal supply of all loads should be ensured, and the maximum utilization principle should be applied to the microsource using renewable energy. Storage device should be charged when its capacity is low to ensure the normal supply of all loads.

As it can be seen from fig.3, in microgrid-connected mode, photovoltaic cells keep on operating in MPPT mode, while storage battery starts charging at the 1.0s, and stops charging after 1s when the capacity of batteries is full, as for the signal of charging-discharging , “1”presents charging, “ 0”presnts stop charging.

b) Example 2 Microgrid operates in island mode, output of photovoltaic cells is less than load consumption, storage battery has no energy storage

Microgrid turns from microgrid-connected mode to island operating mode in 0.5 s, and demand of sensitive load reduces at 1.5s and increases at 3 s, operation result of them is shown in fig.4

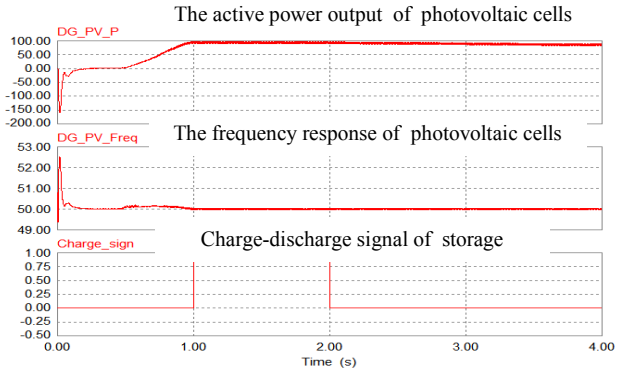
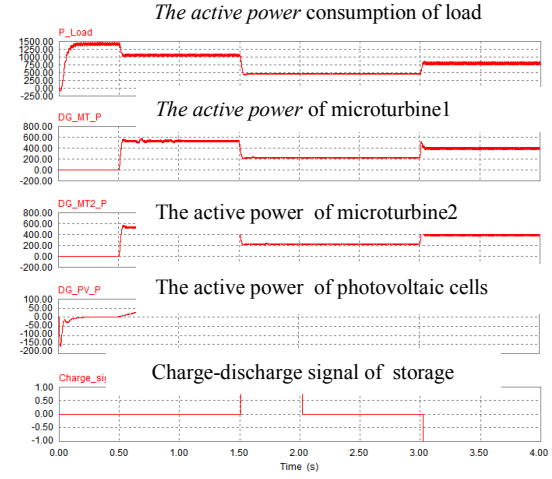
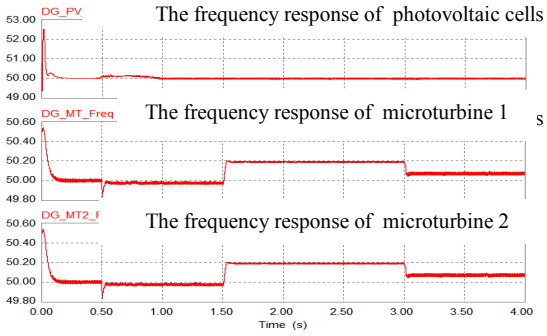



Fig.3 Operation results in the microgrid-connected mode




(a) load power consumption, power output response of microsource and battery Charge-

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(b) The frequency response of microsource

Fig. 4 Operation results of microgrid when the microgrid is reconnected and disconnected

General load should be cut-off immediately and switch microturbine on when microgrid's operation mode is turned from grid-connected into island mode. As shown in Fig. 4(a), at the mode of microgrid-connected before 0.5s, microturbine stop working and photovoltaic cells keep working in MPPT mode in grid-connected mode. At the mode of microgrid-connected after 0.5s, power output is adjusted according to the power demanding of sensitive load. At 1.5s, the power demanding of sensitive load reduces, microturbines work in low output mode, while energy storage in battery is 0, and photovoltaic cells keep working in MPPT mode until 2.0s. At 2.0s, the battery is full, while the load power demand reduces; the working mode of photovoltaic cells is fixed power mode. In the 3.0s, the load demand increases, micro-turbine, photovoltaic cells and battery run at high output mode, MPPT mode and discharging mode respectively. For battery charging and discharging signal, "-1"stands for discharging. From Fig. 4(b) we can see that it can get a better frequency response through changing the mode of microsource according to load power.

### *C. Analysising of simulation results*

The simulation results show that through the coordination control of energy management system, it can make reasonable allocation of power supply in the storage and each microsource either in normal operation mode or in island mode to ensure good energy quality and normal operation of microgrid.

## V. CONCLUSION

In this paper, the structure of microgrid put forward by CERTS is researched as a reference model, on the basis of analysis of the typical structure of microgrid and the operation mode of every microsource, the program of energy management is presented and designed. Its control strategies are researched under the condition of both grid-connected mode and islanding mode. Several algorithmic examples have been studied through simulation, and the simulation result verifies the correctness of the energy management's control strategies, and can ensure the high efficiency and stability operation of microgrid.

## References

[1] LU Zongxiang, WANG Caixia, M1N Yong, ZHOU Shuangxi, Lü Jinxiang, WANG Yunbo. Overview on Microgrid Research [J]. Automation of Electric Power Systems, 2007,(19) .

[2] SHENG Kun, KONG Li, QI Zhiping, PEI Wei, WU Han, XI Peng. A survey on research of microgrid-a new power system [J]. RELAY, , 2007,(12).

[3] LASSETER R H ,PIAGI P. Microgrid: a conceptual solution Proceedings of IEEE 35th Annual Power Electronics Specialists Conference: Vol 6 , Jun 20-25,2004 ,Aachen ,Germany:4285-4290.

[4] WANG Hengshan, XIAO Zhaoxia, WANG Shouxian. Synthetical Control and Analysis of Microgrid [J]. Automation of Electric Power Systems, 2008,(7 )

[5] ZHANG Jian, AI Qian, WANG Xingan. Application of Multi-agent System in a Microgrid [J]. Automation of Electric Power Systems, 2008,(24)

[6] J. P. Lopes , C. Moreira , and A. Madureira , "Defining control strategies for microgrids islanded operation," IEEE Trans. Power System., vol. 21, no. 2, pp. 916–924, May 2006.

[7] F. Katiraei, ,M. R. Iravani, " Power Management Strategies for a Microgrid With Multiple Distributed Generation Units " Power Systems, IEEE Transactions on Volume 21, Issue 4, Nov. 2006 Page(s):1821 – 1831

[8] YIN guiliang, YANG Lijun,WANG Jun. Distrubuted Generation Technology. BeiJing: CHINA MACHINE PRESS 2008.

[9] LASSETER R H ,PIAGI P. Microgrid: a conceptual solution Proceedings of IEEE 35th Annual Power Electronics Specialists Conference: Vol 6 , Jun 20-25,2004 ,Aachen ,Germany:4285-4290.

[10] F. Katiraei, M.R. Iravaniand P.W. Lehn. Small signal dynamic model of a microgrid including conventional and electronically interfaced resources. IEEE Transactionson Power Delivery,vo1.20,no.1 2007:248~257