COMBINED COOLING AND POWER MICROGRID SYSTEM WITH MW CLASS MICRO TURBINE IN CHINA

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ABSTRACT

Micro turbine (MT), which is a clean, high efficiency and the best choice applied in Distribution Generation (DG) or Combined Cooling, Heating and Power (CCHP) system, has a wide application prospect in China. Aimed at the national 863 plan “The key technology and demonstration project of grid-connecting issue for a MW level CCP distributed energy MicroGrid”, this paper detailed introduces the design experience of the CCP (Combined cooling and power) MicroGrid in the aspect of grid-connecting voltage, MT type choosing, MT capacity and grid-connecting mode. Firstly the structure of CCP (Combined cooling and power) system of demonstration project is introduced; secondly, some schemes are presented in terms of design technology of MT grouping, grid structure, operation mode, protection coordination and settings. Comparisons of the schemes are analyzed in terms of advancement, feasibility, economy and reliability. Finally, design frame of MicroGrid Energy Management System (MEMS) is put forward to guarantee the high efficiency and advancement of CCP system running.

INTRODUCTION

Consortium and Electric Reliability Technology Solutions (CERTS) brought forward the conception of “MicroGrid” in 2002, as to solve the security and reliability of public grid with Distribution Generation [1]. Recently, many countries including U.S.A, E.U, Japan and China reinforce the developmental technology and demonstration projects of MicroGrid [2]. E.U. has planed MicroGrid development, and established experimental platform with different scales of MicroGrid in Greece, Germany, France and Spain. Power System Engineering Research Center (PSERC) supported by U.S. Department of Energy and National Science Foundation, has developed research in technology of DG system and established CERT MicroGrid system. New Energy and Develop Organization (NEDO) in Japan has established four MicroGrid projects, Aomori, Aichi, Kyoto and Sendai [3]. In addition, some countries and companies are also developing demonstration projects of MicroGrid. Even though there are some CCHP systems established in China, such as Energy Center of Pudong international Airfield, Shanghai, CCHP project of Beijing Distribution Center of Natural Gas, there is little successful grid-connected running case due to many factors. These systems operate following the rules of “determining electricity with heating” or “grid-connected with no supply to grid”, avoiding the problem arisen by sending power to the grid.

In 2007, associated with Tianjin University and Beijing Sifang Automation Company, China Southern Power Grid Company undertook national 863 plan “The key technology and demonstration project of grid-connecting issue for a MW level CCHP distributed energy MicroGrid”. The project, which is to be built in Foshan power bureau, not only initiates a new operation mode for the promotion and application of Chinese CCHP distributed energy technologies, but also provides experimental basis for the mutual influence research between MicroGrid and the main power grid.

To complete constructing of this demonstration project, the following requirements should be satisfied: The design scheme should insure the reliability and economy of long-term interconnected operation between MicroGrid and main grid and provide platform and realization means of optimization running of CCP system. This paper researches the technical issues of MT grouping, grid structure, operation mode, protection coordination and setting, and optimal control operation; contrastively analyzes the possible technical schemes from technical advancement, feasibility, economics and reliability. Finally, in order to ensure efficiency and advancement of CCP system, MEMS design frame is proposed.

SYSTEM SCHEME DESIGNED

Electrical System

The demonstration project consists of three buildings, including dispatching building, office building and testing building. Figure 1 shows the structure of the power supply system:

(1) Dual power supply design is used for the dispatching building. Figure 1 shows the structure of the power supply system:
building. In normal operation, 10kV bus connecting switch 700 and 0.4kV bus connecting switch A3 are open. Through the main transformers T1 and T2, the Chandiaojia line from Foshan substation and the Chandiaojibing line from Shiwan substation supply power to the loads of bus LM1 and LM2 respectively. The power loads of office building are supplied by Chandiaojibing line individually through transformer T3. The power loads of testing building are supplied by a low voltage switchboard from the distribution house of dispatching building.

(2) Switch 700 which is installed between bus M1 and M2 is a backup automatic switch. Connecting switch A3 between LM1 and LM2 needs manual operation, and forms the mechanical interlocking with the incoming switch A1 and A2. The important loads, like fire elevator and emergency lighting adopt dual power supply design. C1 and C2 are mechanical interlocking. If T1 is taken as the main power source, C1 is closed and C2 is open (if T2 is taken as the main power source, C1 is open and C2 is closed). Other loads, like common lighting, air conditioner and new fan, adopt single power supply design.

Based on the results of cooling and electrical load forecasted of the three buildings, the power and cooling supply scheme is proposed through the optimization calculation and comparison of a large number combination scheme in full work conditions. As figure 2 shows, 600-800kW MT and double-effect absorption chiller are adopted to make up the CCP (Combined cooling and power) system. When MT is connected with grid, its power generated is supplied firstly to the electrical loads of testing building and part loads of dispatching building, while the shortage is supplied by the power grid; through double-effect absorption chiller, the waste heating produced by MT is transformed to cooling air that is firstly supplied to the cooling demand of office and dispatching building, and the shortage is supplied by the central air conditioner. The cooling load of testing building is always supplied by electrical split air conditioners.

**MICROGRID TECHNOLOGY SCHEME**

**Micro Turbine**

The maximum unit output of MT is no more than 300kW globally. In order to meet user’s capacity demand, MT with small capability can run parallel to form a group. MT mainly has two kinds of structure, with gear-box and without gear-box. In brief description, it is called type I and type II MT [4][5]. Type I MT with conversion mode controller has flexible control mode, while the mode conversion of Type II MT depends on the state of its grid-connected switch [6][7]. Type II MT connected with grid through synchronous generator has larger short current than that of Type I connected through converter, when fault occurs to external system. It has direct influence on type selecting and collocating of superior protection. Even though Type II MT can transform seamlessly, its conversion terms are much stricter than that of Type I MT. It needs not only to adjust cooperation between protection of MT and system, but also a brake resistance box when running at island mode. Type I MT can not transform seamless, but it supplies small short current which has little influence on protection collocating and type selecting of switchgear. There is also little influence on MT from other 10kV line fault [8]. According to these analyses, Type I MT is recommended for this project.

Five schemes based on Type I MT are presented in Table 2. Scheme 1 and 2 adopt single group of MTs connected

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### Table 1: Load Forecasting Results

<table>
<thead>
<tr>
<th>Building</th>
<th>Testing Building</th>
<th>Office Building</th>
<th>Dispatching Building</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum cooling loads (kW)</td>
<td>545</td>
<td>1239</td>
<td>1485</td>
<td>3269</td>
</tr>
<tr>
<td>Maximum air conditioner electric load (kW)</td>
<td>114</td>
<td>538</td>
<td>646</td>
<td>1297</td>
</tr>
<tr>
<td>Maximum electrical load (kW)</td>
<td>85</td>
<td>331</td>
<td>303</td>
<td>719</td>
</tr>
</tbody>
</table>

(3) Table 1 shows the load forecasting results of testing building, office building and dispatching building. Especially, the electrical loads just include common lighting, elevator, computers and water heaters, and do not include fire safety loads, high level facilities and air conditioner which needs larger power supply requirement. Based on the practical power consumption of unit fresh air and cooling capacity of the air conditioners, the maximum air conditioner electrical load of three buildings (office building and dispatching building adopt central air conditioners, testing building adopts split air conditioners, takes the cooling to power ratio of central air conditioner as 2.3, and split air conditioner as 4.8) is calculated. The total maximum electrical load exceeds 2000kW.

**CCP system scheme**

Since the electrical loads are mainly office loads, which have stronger real time performance. There is great power demand between 8:00 and 18:00, less power demand from 7:00–8:00 and 18:00–20:00, and in other time there is little power demand.
in the same side. Scheme 3 and 4 adopt grouped MT scheme, which takes two groups of MT connected to two buses respectively. In all these schemes MTs are connected with 0.4kV bus through a grid-connected switch, while MTs is connected through a booster transformer with 10kV bus in scheme 5. As figure 3(a) shows, scheme 1 and 3 adopt single grid-connected switch. There is just one switch 1DL in the connection between MicroGrid and public grid, and the MicroGrid is composed of 1DL, prime loads and MT. Scheme 2 and 4 adopt double grid-connected switch as figure 3(b) shows, which cancel switch 1DL. The low voltage bus LM1, loads and MT consist of MicroGrid, which has two grid-connected switches A1 and A3 in the connection with external grid.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>MT combination</th>
<th>Grid-connected manner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600/800kW</td>
<td>Single grid-connected switch</td>
</tr>
<tr>
<td>2</td>
<td>600/800kW</td>
<td>Double grid-connected switch</td>
</tr>
<tr>
<td>3</td>
<td>400kW+200kW</td>
<td>Single grid-connected switch</td>
</tr>
<tr>
<td>4</td>
<td>400kW+200kW</td>
<td>Single grid-connected switch</td>
</tr>
<tr>
<td>5</td>
<td>600/800kW</td>
<td>Booster transformer</td>
</tr>
</tbody>
</table>

COMPARISONS OF SCHEMES

The selecting of voltage level of turbine accessed will have effect on the area of MicroGrid and protection setting of system. As shown in figure 1, no matter to which 10kV bus the MT and transformer are accessed, MicroGrid involves all the loads of 10kV bus. When fault occurs to the transformer T1, all loads connected T1 loss power until the transformer is restored. Secondly, if the turbine and 10kV transformer are accessed to M1 or M2 10kV bus, Load-shedding devices should be installed while MicroGrid runs at SA mode, as the maximum loads of T1 and T2 exceed 800kW according to the results of load forecasting.

Scheme 1 and Scheme 3 adopt single grid-connecting switch; while Scheme 2 and Scheme 4 adopt double grid-connecting switch. Taking Scheme 1 as example, mode controller takes voltage of bus LM1 as criterion of whether external fault exists or not and to control MT’s mode conversion. In double switches schemes, there is no appropriate bus voltage to be conversion criterion. Taking Scheme 2 as example, assumed that voltage of LM1 bus is taken, when 10kV fault of Chandiaojia line occurs, if backup automatic switch is failure, mode controller should make sure A1 and A3 switches open simultaneously before MT begins to transform from GC to SA mode. After MicroGrid has been at SA mode, mode controller couldn’t judge whether external grid is resumed because bus LM1 voltage is always normal. If taking voltage at low-voltage side of T1 transformer to be judgment criterion, when T1 fault happens, breaker at high-voltage side will be opened. After the criterion checked, mode controller sends conversion order to MT to turn into SA mode supplying loads. Operator could not shut down A3 switch once MT runs at SA mode.

In Scheme 2, the protection range doesn’t increase. In single switch scheme, a grade of protection is added because of grid-connecting switch 1DL used, which makes the protection setting much harder. There are two methods to solve this problem. One is to cancel protection coordination between 1DL and testing building load, 1DL and turbine, and to allow protection mismatching of 1DL. The other way is to broaden protection setting range properly, such as protection time of 10kV line of Foshan and Shiwang substations is prolonged to 1.0s, to facilitate protection cooperation.

In scheme 1, the Type I MT with capability of 800kW can serve the largest electric loads smoothly. In most time, due to the low cooling and power loads, most of power flows back into 10kV line (or into other 10kV lines), when it works at full capability. Besides, 800kW MT exceeds 60% of transformer with 1250kVA capacity. To start and pause of MT does large impulsion to system voltage and loads. As the power factor of MT approaches 1 during grid connecting, reactive power of MicroGrid loads can only be provided via transformer or local reactive power compensation devices. The transformer runs at much time of transferring reactive power. In Scheme 3, capacity of each MT group becomes small, as well as loads in MicroGrid. For two sets of mode controller and superior control system are applied, it is difficult to realize optimization control of cooling and power of the whole system.

All considered, scheme 1 with 600kW MT is recommended.

MICROGRID ENERGY MANAGEMENT SYSTEM

The secondary equipment in the system are mainly MT controller, cooling units controller, protection and monitoring device, MicroGrid mode controller and public
measurement and control device. Based on the location, these controllers can be divided to local control, local central control and remote dispatching control. Device local control is set in the equipment level, which is provided by manufacturer; local central control is set in the control house (MT control house and switch house); remote dispatching control is carried out by remote action. MEMS uses Ethernet, adopts layered, distributed and network control principle, to monitor and control the system devices above.

As figure 6 shows, a set of two-layer control system in CCP system above.

As in different times of day, or in different periods of year, cooling and electricity load requirements are constantly changing. In order to achieve the high efficiency of CCP system in system operation, it is needed to control cooling and electrical power output of the system real-timely through the MT communication interface devices.

As figure 6 shows, a set of two-layer control system in MEMS is proposed to satisfy cooling, electricity load requirements and realize the optimal control objectives. (1) Coordinated control in system level. This function is accomplished by MEMS host computer. Based on the information from the dispersed collecting system (DCS), following the scheduled operation mode (such as cooling determined power operation mode, optimized economy operation mode or grid-connected with power supply operation mode), MEMS calculates the system-level control settings (the active power of MT and the cooling power of chiller), and sends to the cooling and power coordinated controller.

(2) Coordinated control in equipment level. The function is accomplished by cold and power coordinated controller, which is provided by the manufacturer. Through the coordinated controller the power can be dispatched in MT group, and optimized operation between MT and chiller can be achieved.

**CONCLUSION**

According to the requirements of the national 863 demonstration project, several selective design schemes of CCP MicroGrid are proposed. After considering the basic design principle of MicroGrid, system reliability, design feasibility and economics, the paper recommends the feasible scheme, determines the MicroGrid structure, capacity of MT, and system operation mode.

In order to ensure operation efficiency of CCP system, the MEMS is presented, including the system construction, real time cooling and power optimization function, system status monitoring function, etc.

**REFERENCES**


