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Advances on Distributed Generation Technology

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Abstract

At present distributed generation is becoming a hot research. In this paper, the major distributed generation technologies and the development trend are introduced. The key technology of grid-connected distributed generation system: micro-grid technology, is described. The proposed micro-grid technologies mainly include operation control such as the control problems between various **micro-sources,** switching process **in micro-grid connection/isolation** operating state, load classification principles and methods in islanding, and advanced energy management and optimal operation of micro-grid. Further, the development trend of grid-connected distributed generation technology is proposed, which is the distributed hybrid energy system and smart micro-grid in the framework of smart grid. DC-AC dual bus architecture of distributed hybrid energy system will be presented, which achieves the two-way flow and control of electric energy between large electricity network and distributed generation system. The power infrastructure and the information infrastructure of smart micro-grid will be given, and the key technical problems are pointed out.

Keywords: distributed *generation (DG); micro-grid; distributed hybrid energy system (DHES); smart micro- grid*

1. Introduction

In the context of increasing tensions in the traditional fossil energy sources and energy conservation, the world's growing energy demand and the growing shortage of traditional fossil energy resources and the consequent environmental pollution seems to pose irreconcilable conflicts. Along with the rapid development of micro-energy power generation technology, distributed generation technology and storage energy technology as the representative of new energy and renewable energy, distributed generation technology based on new energy is becoming a hot research.

New energy and renewable energy will eventually replace the role of traditional energy in the electricity market based on the international development trends of energy use, and the grid-connected power generation will be the only way as the new energy and renewable energy into the electricity market.

In this paper, the major distributed generation technologies based on new energy and the main development trend are introduced briefly. The paper focuses on key technologies of grid-connected distributed generation system, such as micro-grid technology. Finally, the development trend of grid-connected distributed generation system will be proposed, which is the distributed hybrid energy system (DHES) and smart micro-grid in the framework of strong and smart grid. DC-AC dual bus architecture of

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distributed hybrid energy system will be presented, which achieves the two-way flow and control of electric energy between large electricity network and distributed generation system. The power infrastructure and the information infrastructure of intelligent micro-grid will be given, which achieves two-way power flow and multi-stakeholder interactions, and the technical problems are discussed.

2. The main distributed generation technologies and development trend

Distributed generation generally means small power generation unit based on the new energy and renewable energy, which is arranged near the load [1].

New energy and renewable energy includes hydropower, wind energy, solar energy, biological energy, geothermal energy and ocean energy. From the use and development of new energy, wind power generation, solar photovoltaic generation and fuel cell technology is the current major research area and development trends in electrical engineering.

*1) Wind power generation technology:*Wind power technology is one of the most important emerging renewable technologies. It started in the 1980s with a few tens of kilowatt production power to today with multi-megawatt-size wind turbines that are being installed. The wind power generation technology is used to convert wind energy into electrical energy power generation. It can be divided into two broad categories: constant speed constant frequency (CSCF) and variable speed constant frequency (VSCF).

Because VSCF power generation technology has merits of capturing the maximum limit wind power, the wide rotational speed movement scope, flexible adjustment of the system active power and reactive power, as well as the advanced PWM control, it has gradually became the mainstream technology of the current wind power generation.

Reviewing the fast development route of global wind power generation in recent years**,** the latest development trend and research progress are as follows [2]: larger rated power, variable blade pitch, variable speed constant frequency (VSCF), no gearbox driven (direct driven), grid-connected full power converter, low voltage ride through (LVRT), intelligent control for wind power generation**,** remote wireless network wind farm monitoring system, and so on.

2) Solar photovoltaic technology: The solar photovoltaic technology directly converts solar energy into electrical energy by photovoltaic effect of semiconductor material. Photovoltaic generation system is divided into separate photovoltaic systems and grid-connected photovoltaic system.

Photovoltaic generation system typically uses two power converters. The first one is the DC / DC converter, using Boost step-up circuit to achieve the transformation of solar output voltage and photovoltaic arrays maximum power point tracking (MPPT) control. The second one is used to convert the direct current into alternating current by voltage source inverter to the utility grid, and the inverter controls the DC constant voltage and inputs reactive power of the utility grid.

At present the biggest hurdle of photovoltaic generation is the high price of solar cells, which accounts for over 60% the price of the whole solar photovoltaic generation system, so the solar cells research such features as cheap price, high efficiency, high reliability, high stability, long lifetime has become the world's focus. In addition, the focus of photovoltaic generation is shifted gradually to components research and system development for grid-connected photovoltaic generation system, such as grid-connected inverter, BIPV, large-scale grid-connected photovoltaic station and the automatic tracking systems of photovoltaic arrays .

3) Fuel cell technology: Fuel cell is a generation facility which can directly convert the chemical energy stored in the fuel and oxidizer into electricity power efficiently. The FC converts fuel and air directly to electricity, heat, and water in an electrochemical process. It also has some merits in the fuel diversification, clean exhaust, low noise, low pollution, high reliability and good maintainability. It is considered as one of power generations with high efficiency, energy saving, environmental protection in the 21st century.

Different technological challenges considering the FC generation have been presented. The main research objective is cost reduction and performance improvement in all aspects of FC production, materials, systems, and applications, together with those of related components. To reach these objectives,

many points still have to be studied: water management issues, cold start-up, efficient and real-time control, online diagnosis, real and large-scale experimental tests and evaluation, and power electronics topologies.

3. Key technologies of grid-connected distributed generation system

In recent years, the distributed generation system of photovoltaic, wind power and fuel cell has studied further, and a number of technical issues are presented and discussed. The key technical issues include (but not limited to) micro-grid operation control and energy management system.

A. Micro-grid concept and basic structure

Micro-grid is a small distribution network which is composed of distributed generation (DG), load, distributed storage (DS), power conversion equipment and control system, and can realize flexible energy management. A typical micro-grid model is shown in Fig. 1.

Distributed generation (DS) in micro-grid involves a variety of energy forms, such as photovoltaic, wind power, micro gas turbines and CCHP (combined cold heat and power). Distributed generation in micro-grid can be connected to the utility grid directly, or through power electronic converter device. It can supply electric power to the local load and feedback surplus electric power to the utility grid. Through energy management, it can adjust the output heat or cold
energy of distributed generation to meet user hot and cold demands.

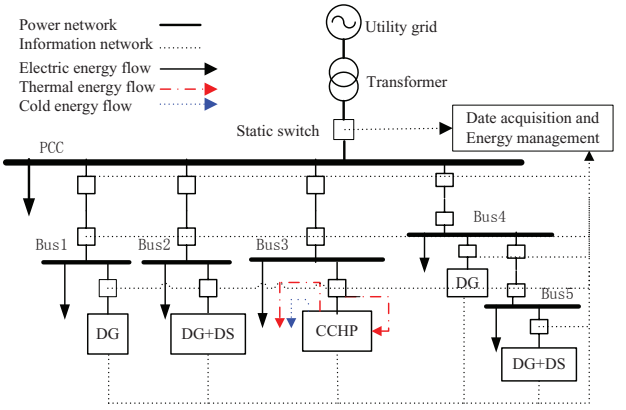

Figure 1. Typical micro-grid model.

Micro-grid is connected to the higher bus of the utility grid by the static switch at the point of common coupling (PCC) [3], where the voltage and current transformer is usually placed for detecting the micro-grid running state. For some of the micro-grid control methods, such as the master-slave control mode, decentralized control mode, the communications equipment is put to transfer control signals. In addition, the micro-grid can also configure the information collection and energy management central control unit to flexible control for micro-grid and distributed generation.

B. Operation control of micro-grid

The ability to withstand disturbances of micro-grid system is correspondingly weak, especially in islanding operation mode. Considered the randomness of wind energy and solar energy, the security of the system may face a higher risk, so effective operation control for micro-grid is one of key technology.

1)The control problems between various micro-sources in the micro-grid: There are various micro-powers in the micro-grid system, which can be the same type of micro-source or heterogeneous type of micro-source. The external characteristics, time constants and composition of these micro-sources are different, and the energy in the power system is balanced. Therefore, how to maintain the voltage stability, the system steadiness, reliability under micro-grid operation, and reduce impact of the micro-grid to large grid, should be further discussed and studied.

*2)Switching process in micro-grid connection/isolation operating state:*The difference between micro-grid and distributed generation is that micro-grid can run connected to the bulk power grid, or run independently disconnected with a large grid in the case of a large grid fault. The switching process of two operating state is a disturbance and impacts stable operation of bulk power system, and these influences can not be completely eliminated. In order to eliminate the impact for the large power grids, it is needed to improve the micro-grid structure, configuration parameters and the control strategy.

3)Load classification principles and methods in islanding: Micro-grid isolation operation increases the micro- grid detection and control complexity. Therefore, load is required to be carefully classified and refined, ultimately forming the pyramid's load structure. Low power supply reliability and power quality-demanding load is put at the bottom of the pyramid, and high power supply reliability and power quality requirements load is put at the top of the pyramid. Detailed classification of the load reflects the individual characteristics of micro-grid. It is very necessary to design micro-grid to achieve the complex hierarchical structure.

C. Advanced energy management and optimal operation of micro-grid

Advanced energy management is a core component of micro-grid, which can do rapid decision-making according to energy demand, market information, constricted operation conditions, and realize the system optimal operation through flexible scheduling for the distributed device and load [4,5].

The key differences between micro-grid EMS and traditional EMS are that micro-grid EMS ①needs to match heat energy and power energy; ②exchanges energy with the utility grid freely; ③can provide differentiated services, and sacrifice non-critical load or delay response to their demand under special circumstances, in order to supply high quality power for critical load.

4. Development of grid-connected distributed generation

A. The distributed hybrid energy system

Most renewable energy source such as photovoltaic and wind turbine heavily rely on the ambient environmental conditions therefore produce unpredictable output characteristics. The other renewable energy source such as a micro turbine and fuel cell system doesn't have ambient dependency but their out response characteristics are so slow that they can't hardly meet the dynamic load conditions. Therefore renewable energy sourced generation systems are weak in stable and sustainable power supply since the sources are mostly dependent on weather conditions. However, some of them, like solar irradiance and wind speed, have complementary profiles. Therefore, the distributed hybrid energy system composed of several new energy power generations is the future development direction in new energy grid-connected power generation system. DHES is a new power supply system combining distributed energy and distributed energy storage technology.

The characteristics of hybrid energy system is to overcome the instability of a single energy supply, and achieve the complementary advantage and efficiency improvement of different energy by using different characteristics of various micro-sources, the rational allocation of micro-sources and energy storage systems; meantime, enhance electricity supply reliability and power quality at connection/isolation operating state by the load levelling control strategy and the power electronic devices.

In distributed hybrid energy systems, the theoretical and technical problems are the topology, design and modeling of key components and control strategy.

1) Selection of the structure and key components in distributed hybrid energy system: The HES structure chooses a DC-AC dual bus, which uses the DC bus in the nearby supply area to reduce the AC-DC rectifier of the power device and improve efficiency of electric power. In the selection of key components, the capacity and structure of the storage system are selected and configured correctly, and topology characteristics based on grid-connected converter, the grid-connected converter achieves the composite functions of grid-connected power generation combined with the regulatory of power quality.

2) Main circuit design and various components modeling in distributed hybrid energy system: In the DHES, the design parameters of the main circuit and the model of various components are researched. Based on the characteristics of the micro-sources and energy storage devices, the equivalent circuit model,

hot model, performance evaluation, and mechanical and electrical equations are set up. Meantime, the power electronic interface circuits for micro-sources and energy storage devices are discussed, and the control model of the grid-connected converter is analyzed. The rationality and validity of the proposed models are validated by the simulation analysis, and the main circuit design of the DHES is completed.

3) The coordinated control problems of between various micro-sources in distributed hybrid energy system: The DHES have different micro-sources, which are connected to the DC bus or AC bus of the DHES through advanced power electronic devices, and most of them are flexible and controllable, each of them has different characteristics of voltage-current and frequency-power, and the different time constants. Therefore better coordinated control strategy can guarantee the stable operation and power quality of *the utility* grid, and give full play to the new energy power generation efficiency.

Figure 2 is a block diagram of proposed grid-connected distributed hybrid energy system. This hybrid system includes a wind turbine and a photovoltaic as energy sources, battery and fuel cell/electrolyzer combination as an energy buffer, a common dc bus, power electronic converters through appropriate power electronic interfacing circuits, and a grid-connected inverter to AC grid. The system can be easily expanded; i.e., other energy sources can be integrated into the system when they are available. DHES is DC-AC dual bus architecture, which achieves the two-way flow and control of electric energy between large electricity network and distributed generation system.

When excess wind and/or solar energy is available, the battery charging and/or the electrolyzer is turned on. The

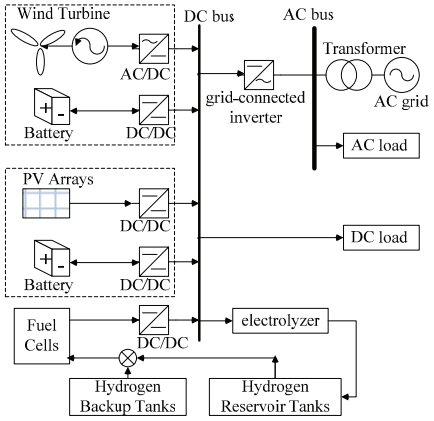

Figure 2. Block diagram of distributed hybrid energy system

electrolyzer produces hydrogen (H2), which is delivered to the hydrogen storage tanks. The control strategy optimizes how the spare energy is used. When there is a deficit in power generation, the fuel cell stack begins to produce energy using hydrogen from the reservoir tanks, or in case they are empty, from the backup H2 tanks. A battery bank is used to supply power to fast load transients, ripple and spikes in stand-alone applications [6].

B. Smart Micro-Grid

The concept of smart micro-grid has already emerged [7, 8]. The smart micro-grid is a new organization form of smart distribution network. A typical smart micro-grid model is shown in Fig. 3.

The key components to a smart micro-grid are the integration following four components into a centrally managed, campus-based energy infrastructure:

- Supply: storage and distributed generation (renewable and non-renewable sources).
- Demand: energy consumption devices across entire organization including but not limited to lighting, HVAC, and IT equipment.
- IT Management platform: intelligent system to optimize supply and demand based on management objectives and conditioning factors.

- Environmental factors: variables external to the management system that will influence energy use such as weather, pricing, and comfort.

Intelligent energy and building management software is the brains and nerve system of a smart micro-grid. The lack of this critical component has kept facilities managers from broadly and efficiently implementing smart micro-grids. This software platform must cover four critical management tasks:

- Collect and analyze data.
- Identify opportunities for managers and administrators to take action on information, or automatically executes actions.
- Provide powerful communication tools on objectives and progress through real-time dashboards.
- Provide optimization tools and interface with different automation management systems to increase personnel and asset productivity.

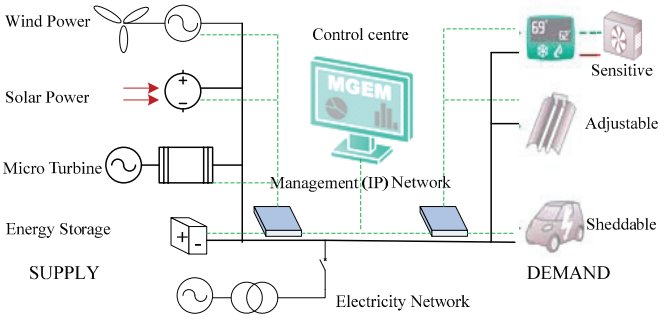

Figure 3. Smart micro-grid model.

Smart micro-grid is involved in multitudinous range of technology, and key technology includes advanced power electronics technology, measurement and communication technology, information management systems, advanced energy management and advanced analysis techniques. Within the framework of the advanced distribution operation of strong and smart distribution network, the characteristics of distributed generation systems are combined to achieve self-healing control of smart micro-grid, distributed generation coordination and adaptive control, optimal energy management, information integration. Smart micro-grid will be eventually intelligent, information, digitalization and automation.

5. Conclusion

In summary, distributed generation based on new energy and renewable energy power generation technology has been made a breakthrough. However, most of the renewable energy power generation systems are unpredictable and intermittent, such as wind power and photovoltaic power generation. The stable operation of the utility grid will be serious influenced if that power inputs grid directly, therefore, the use connected-grid of renewable energy and further development will be restricted. Hence, it is urgent for some solutions to improve the economy and reliability of the new energy and renewable energy connected-grid power generation technology. New energy and renewable energy distributed generation should be as an important distributed power, to be included in the overall research framework of the strong and smart distribution network in the future study.

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