Distributed Generation System Development Based on Various Renewable Energy Resources

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Abstract: In promotion of the new energy policy, the large-scale expansion of constructions of the wind and solar power is developing in China, whose random high-power electric energy fluctuation causes huge shock to the power grid. Confronting this important problem of the power system safe operation, it is really top urgent to build a feasible solution to develop the large-scale new energy. Therefore, this paper raises a distributed generation system based on various renewable energy resources, adopting a small-sized combined generation equipments of unit capacity 100kW max with wind, solar and biogas energies, and super capacitor and battery storage devices, which builds and installs near to the local loads center to supply it optimally in stable and safe, high reliability and less feeder loss mode. The operation performance of the demonstration project shows: the distributed generation system based on various renewable energy resources is an effective and feasible approach for its large-scale and efficient utilization purpose because of its particular distribution characteristics, direct power supply to the local loads and its little influence to the grid.

Key Words: Power Grid, Renewable Energy Resources, Distributed Generation System, Local Loads, Power Supply

1 Introduction

Distributed generation system (DGS) based on various re-newable energy resources is the important approach to the development of clean energy, improving the reliability of power supply and enlargement of the power system capacity. Compared to the traditional centralized power supply sys-tem, DGS has many advantages: easy start-stop, good peak shaving, beneficial to load balance and less investment, yield faster result, and satisfying power supply demand in the special occasion and less transmission loss, improving disas-ter level. Some literature introduces a wind-solar generation system with battery storage or flywheel energy storage [1-3]. And some introduces a wind-solar-water combined generation system that utilizes both wind and solar complementary resources to generate, and then uses a pumped-storage power station and battery storage to store energy [4, 5]. However, the pumped-storage power station is constrained by the geographical condition to cause less suitable area, and also affected by its large cost and longer lead time. After a fur-ther study and analysis of the contemporary DGS situation, aim at the different workloads and rich and scattered renew-able energy resources, this paper proposes a new DGS design based on wind, solar and biomass combination energy.

The system, to link all available distributed power generation devices of solar, wind and biomass renewable en-ergy resources, and other optional self-supply power gener-ation facilities or the backup generators, can supply the lo-cal consumer straightly or to operate grid-connection with power grid. The essence is to integrate all closely related distributed energies, loads, storages and control devices into a micro-grid(MG) to operate and manage systematically and optimally. DGS is an autonomous work cell to the power company, and it can provide effective power distribution, new power expansion and safe power backup for the power grid and improved reliability of the local power supply, less feeder loss and improved power quality for the local loads. Concurrently, it can continue the power supply by switch-off the main power grid (autonomy mode) during the power fault or special need, so it is the great safeguard to the lo-cal power supply special in any emergency. This paper de-scribes its control strategy clear and proves its feasibility in the demonstration project.

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2 Structure of DGS

Based on various renewable resources, this DGS consists of solar PV, wind and biomass biogas power generations, storage devices, power electronic converter devices, energy monitor and management system, loads and transmission lines, etc. See Fig1. Each distributed generation unit goes through inverter; filtering and transmission lines into micro-grid central control(MGCC) to manage and allocate the to-tal energy to supply for the local loads directly or into the point of common coupling(PCC) to connect the power grid. Multiple DGSs should go through the distribution manage-ment system(DMS) to cooperate and interact together to the whole system for safety and control. Its grid-connection will bring big influence on the power system operating charac-teristics, power network structure and relay protection and so on. For the purpose of research on their operating char-acteristics of each generation cell and storage cell, control strategy and the mutual influences with the power system in the grid-connection mode, firstly it will build a detailed sta-ble and transient mathematical model of a DGS to analyze and study. At present, there are many studies of the differ-ent distributed generation and power storage modeling at the home and abroad [6-9].

2.1 Wind power generation(WPG) cell

Output power P_W [10] formulation per wind speed v of wind turbines:

$$P_w(v) = \begin{cases} P_R \cdot \dfrac{v - v_{ci}}{v_R - v_{ci}} & (v_{ci} \le v \le v_R) \\ P_R & (v_R \le v \le v_{c0}) \\ 0 & (v \le v_{ci} \text{ or } v \ge v_{c0}) \end{cases} \quad (1)$$

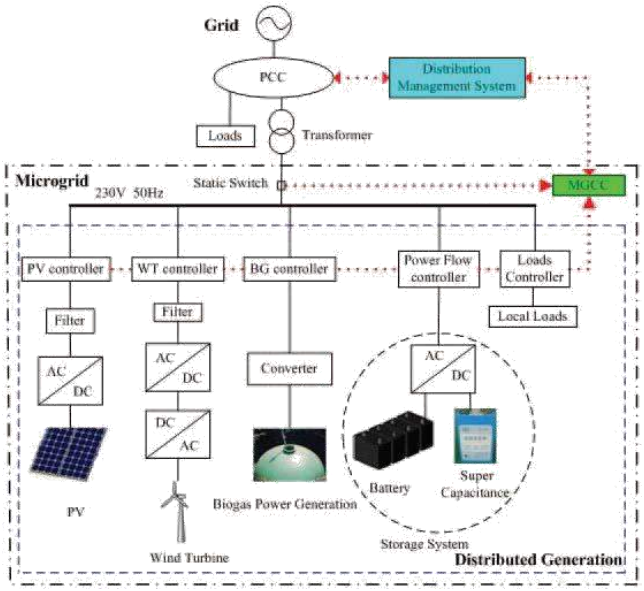

Fig. 1: Structure of DGS

In (1), P_R is the rated output power, v_{ci} is cut-in speed, v_R is rated speed and v_{c0} is cut-out speed.

It adopts 100kW wind turbines (work principle shows in Fig2) that can work in switch-off or switch-on mode with the power grid, work in a way of direct-coupling with the wind wheel and electric motor (three-phase permanent magnetism AC synchronous generators), automatic yawing toward wind and cast loose, cut-in wind speed 3m/s, cut-out wind speed 25m/s, rated wind speed 12m/s, max designed wind speed 50m/s, wind power utilization ratio over 42%, normal output rating 100kW, max output 118kW, and normal voltage rating AC690/380V. The power diagram shows in Fig3.

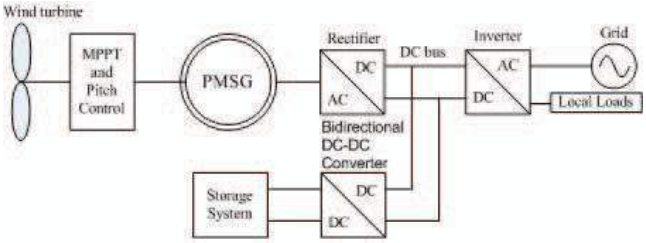

Fig. 2: Structure of WPG

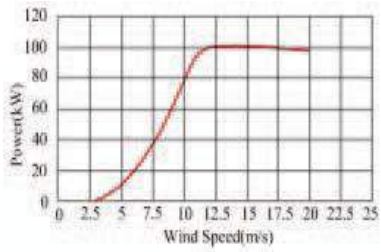

Fig. 3: Power curve of WPG

2.2 PV generation cell

Solar PV generation system is an autonomous distributed power generation and supply system, consisting of PV battery array, PV converter, system controller, storage and local loads. Show in Fig 4.

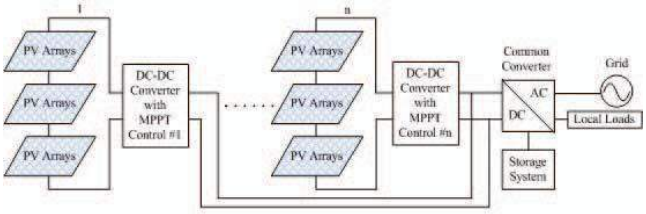

Fig. 4: Control structure of PV system

Its rated output power is calculated under the standard condition(illumination intensity1000w/m^2 and temperature 25$^\circ C$), and its real output power is influenced by many factors. This paper mainly considers two key factors of illumination intensity and temperature, and its output power [11] formulation shows in formula (2).

$$P_{PV} = \begin{cases} P_{STC}\dfrac{G_{ING}}{G_{STC}}(1 + k(T_C - T_r)) & (G_{ING} > C) \\ 0 & (G_{ING} \le C) \end{cases} \quad (2)$$

In (2), P_{PV} is the real output power in illumination intensity G_{ING}, P_{STC} is max output power under standard status, G_{ING} is real-time illumination intensity, G_{STC} is standard illumination intensity(1000w/m^2), k is the correlation coefficient between temperature and output power, T_C is real-time temperature of PV battery, T_r is standard temperature 25$^\circ C$, C is constant as base threshold of illumination intensity.

It mainly utilizes the PV generation and storage device in an autonomous way or connects with the external distribu-tion network to supply the local loads. PV generation system is a good choice to supply autonomously, special suitable for the work loads not request high quality power and the remote area with high cost of power.

2.3 Biogas power generation

Biogas is a type of combustible gas produced from the anaerobic fermentation of a large number of organic wastes like lees liquid, animal manure, municipal refuse and sewage, coming from industry, agriculture and urban life. Biogas burning generation is a specialized application technology along with the gradual development of the large bio-gas pool construction and comprehensive utilization, and it loads the biogas into the engine and integrated generation fa-cility to produce electric and heat energy that is good for the biogas production. Biogas power generation structure shows in Fig 5. It is widespread and cheap distributed resources with the favorite features of energy-saving, safety and envi-ronmental protection.

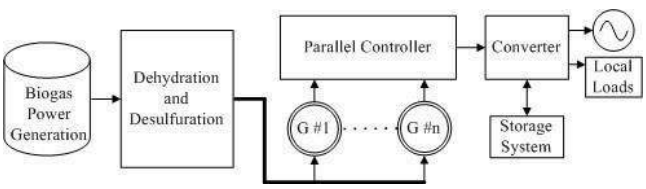

Fig. 5: Structure of biomass energy generation

2.4 Energy storage system

Recently the new energy generation development goes up fast, especially the large-scale development of wind and so-lar power generation inevitably brings remarkable influence upon the power grid peaking and system safe operation be-cause of their inherent random, intermittent characteristics. In a large extent, the energy storage technology can resolve these random and fluctuant problems of new energy gener-ation. On the one hand, it can flat the output power of the new energy generation, improve power quality, maintain sta-ble system, and on the other hand, it can adjust the changes of grid voltage, frequency and phrase caused by new energy generation, and enable the large-scale wind turbine and solar power generation, etc distributed generation units to oper-ate as the schedulable units to achieve good grid-connected operation with the grid. Concurrently an amount of stor-ages available can act as transitional function when some distributed generation units are abnormal [12,13].

2.4.1 Super capacitor energy storage

The basic principle of super capacitor energy storage is to convert 3-phase AC into DC through converter, and then to convert DC into the controllable 3-phase AC through in-verter. Normally, it utilizes multiple cells to store that DC energy through converter, while any emergency of losing power or load's power waving sharply, it will release the stored energy through inverter to compensate the requested active and reactive power of the system quickly to achieve the power balance and stable control. It is more flexible and prompt response.

Suppose the super capacitor group consists of $m \times n$ cells, so its total energy is calculated as:

$$E = mnC_F (U_{SC2} - U_{SC1}) \quad (3)$$

In (3), m is the series numbers of super capacitors, n is the parallel line numbers of super capacitors, C_F is the equiva-lent capacitor of unit super capacitor and its voltage range: $U_{SC2} - U_{SC1}$ during discharge.

Super capacitor storage has many good advantages of long recycling life-span, big power density, high effective storage, simple and accuracy energy management and no-need main-tenance, etc, and it can take effect of the instantaneous power compensation to the DGS, and also act as the standby in case of generation interruption to improve the stability and relia-bility of power supply.

2.4.2 Lead-acid battery storage

Lead-acid battery storage has low-cost, mature-technique and higher energy capacity (MW level), etc advantages, mainly apply to the backup capacity and frequency control of power system and uninterruptible power supply (UPS) func-tion. However, its disadvantages are low storage energy den-sity, less time of charge-discharge and a certain amount of pollution produced during production.

The battery storage and super capacitor have strong func-tional and technical compensation. The battery storage has bigger energy density and smaller power density, lower ef-fectiveness of and very sensitive to charge-discharge, shorter life-span, and not good adaptability for big power and high frequent charge-discharge work. On the contrary, the super capacitor has smaller energy density and bigger power den-sity, higher effectiveness of charge-discharge, longer recy-cling life-span and very suitable for big power and recycling charge-discharge workplace. To combine them both together to perform their advantages and reduce their disadvantages to improve the output power capacity, less inner loss, relia-bility and economy.

The demonstration project in this paper is a multiple en-ergy storage system of huge capacitor energy storage and lead-acid battery energy storage that works in reasonable controllable multiple integrated storage system to achieve the optimum operation of the wind-solar-biogases combined generation system. In conditions of adequate sun light, fa-vorable wind and huge capacity of mash gas, the system not only supplies the local loads, and also transport the surplus energy to the storage system or the grid; in a case of suc-cessive cloudy day and no wind weather, the field genera-tion power lacks not to guarantee the normal operation of the loads, at that moment, the power storage system will release energy or the grid will switch-on to supply immediately.

2.5 PWM Converter

The distributed generation unit and storage unit should use power electronic converter devices to link local loads or the grid, and its PWM converter can make the bidirectional en-ergy flow. When PWM converter absorbs power from grid, it works as AC/DC situation; when PWM converters outputs power into the power network, it works as DC/AC status and its line side current and power factors are all controllable [14-17]. PWM converter structure shows in Fig6.

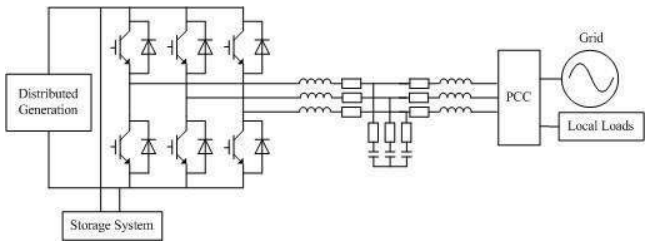

Fig. 6: PWM converter

3 MAS control strategy of DGS

Compared to the traditional centralized power supply with coal and petrochemical industrial resources, the DGS based on various renewable resources has some major characteris-tics as following:(a)It is a multiple link, inter-coupling and nonlinear system, and it integrates wind, solar light and bio-gases etc resources to have various and different character-istics, and also easy to affect by outside various factors to present the obvious nonlinear group. (b)It is dynamic and random because the various resources of DGS show the large scatter in space, the uncontrollable and random feature in time and difficult to predict accurately because it is con-strained to external conditions of wind and solar light. (c)It is an integrated generation, storage, distribution and trans-mission into an autonomous micro-grid system, and whose generation sources, storages, control methods and operation modes, etc are all different and diverse. Based on the char-

acteristics of DGS and agent modeling theory [18,19], this paper adopts Multi-agent system (MAS) and the federated architecture to study, and appoints each device or sub-system as an individual agent and define their mutual work relations for the mutual cooperation and coordination to maintain the safe and stable operation of the whole system.

3.1 MAS theory

MAS are a control system to organize multiple agents in a certain structure, and each agent could run independently and also communicate in its language and co-operate each other to ensure them working in an optimal way. Its aim is to divide the large and complex system into some small sub-systems according to each agent characteristic and func-tion, so that they can communicate, coordinate mutually and manage easily. Its key role is to define the functions for each agent and create the mechanism of their mutual com-munication, cooperation and coordination. Its virtues have: (a)each agent has its independence and autonomy, and its own goal and behavior is not constrained by other agents, (b)MAS supports the distributed applications, so it has good module, easy extensibility and flexible and simple design, (c)each agent communicate and coordinate mutually to solve complex problem.

3.2 MAS control strategy

The most important key contents of MAS modeling is how to build its work architecture and coordination mechanism for the optimum effect. The MAS architecture should de-velop per reliability, expansibility, reconfiguration and dy-namic adaptability, etc, so this paper raises a 3-levels sys-tematic architecture of MAS to study the DGS, and accord-ing to its structural property, builds a bidirectional flow oper-ation mechanism of feedback report flow from bottom to top direction and systematic decision flow from top to bottom direction, which guarantees the whole systematic optimal-ity, but also give consideration to each agent to ensure its respective autonomy and max effectiveness. Based on MAS technology, the good solution for DGS is to build a hierar-chical systematical control structure, and here it is the fed-eral control architecture with 3 levels of micro-power/load agent (control level 1), MGCC agent (control level 2) and grid agent (control level 3). See in Fig7. On the bottom, the micro-grid agents of WPG, PV, biomass biogases power generations and storage devices and load agent are the base of the control structure. Each micro-grid agent should take its own specific control technique to implement the contin-uous operation according to its special characteristics such as max power capture for WPG, max power tracking for PV, voltage frequency control of biogas power generation and charge-discharge control of storage systems. The load agent should setup in local load side easy for its shorter-time forecast and receiving order from its higher level to optimize. The bottom agent groups can exchange the in-formation to cooperate and implement the work order from its higher level. The MGCC agent gets the request informa-tion from micro-grid agent or local load agent, firstly relies on itself of the database, knowledge base, learning and re-action ability, and meets the conditions of DGS systematical energy balance, every micro-grid start-stop constrains, relia-bility and stability, etc, and then coordinate the energy man-agement of each micro-agent to optimize and calculate the optimum solution, and finally issue the detailed and specific task breakdown to each bottom agent to execute together. In grid-connection status, MGCC agent should upload informa-tion to grid agent, and then get the order of real-time control and scheduling from grid agent to implement their double-flow.

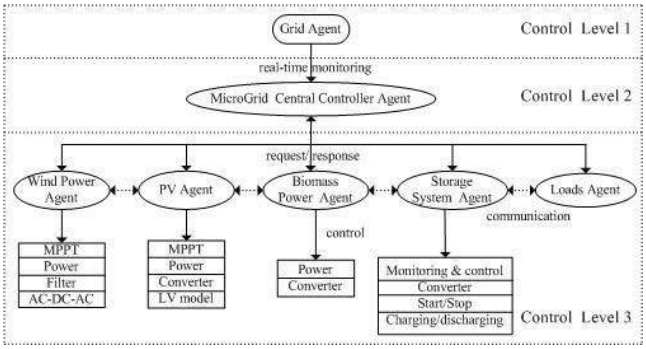

Fig. 7: MAS structure of DGS

That wind power and solar energy is intermittent ran-domness and uncontrolled energy results in its autonomous operation not to provide continuous stability power output. Biomass biogases can store effectively in tangible ways, and its generated power has good quality of no volatility and in-termittent, high reliability and non-clearance output power. Its power-generation controllable and network characteris-tics are same as the thermal power, and much better than WEC and PV generation. The researched DGS emphasizes voltage stability for the system's security and stability, and its optimum operation ways is to put WPG and PV units working in MPPT mode as the main supply resource and to let biogases generation work as necessary assistant energy. The control flow of DGS based on MAS shows in Fig.8.

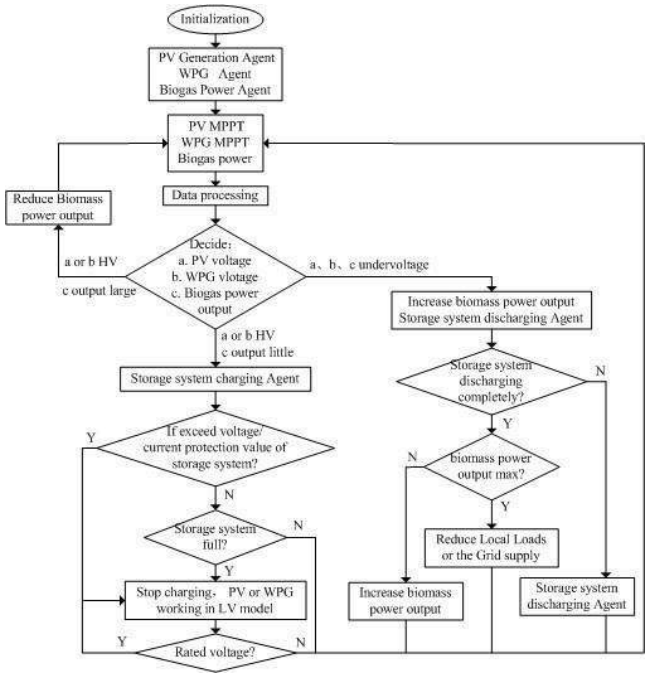

Fig. 8: Control flow of DGS

4 Demonstration projects of DGS

The experimental demonstration system developed in this paper shown in Fig9, supplies the power for personal com-puter and daily lighting's operations well. Its operation re-sult shows: the DGS based on various renewable resources is an effective way of the large-scale development and uti-lization of various renewable resources because it can uti-lize the renewable resources efficiently to supply the local loads straightly and its optimized distribution characteristics help reduce the impact to the grid greatly for its good grid-connection.

Fig. 9: Distributed generation experiments

5 Conclusion and Prospect

The distributed energy system developed oriented to various renewable resources, combines the each DGS with the scattered energy storages to construct and install a new terminal micro-grid near to load center to supply, stable and safe power. Its key role and function are: a necessary supple-ment of grid to resolve scattered power need and improving the reliability of power supply; to reduce the cost of build-ing new power station or upgrading transmission and dis-tribution network; to supply more energy and backup ser-vice to big grid to improve its operation stability; to reduce transmission loss and improve the power supply reliability and quality. At present in policy and technology aspects, DGS based on various renewable resources and multiple in-tegrated energy storage is still immature and imperfect, so the research should take deeply from following aspects: to take scientific demonstration and reasonable planning in the whole system of the power generation and supply, and to consummate and implement authentication and access sys-tem of DGS facility and micro-grid access standard specifi-cations; the key core technologies of DGS of the power out-put forecast technology of the high-precision DGS, power quality and control technology, and the integrated operation control technology of multiple renewable energy generation system, inverter standard design, interconnection interface technology and storage technology; the economy of the re-newable energy generation, improvement of the stabilization and reliability of renewable energy generation with the grid, and influence on the power market.

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