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Impacts of Distributed Renewable Energy Generations on Smart Grid Operation and Dispatch

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Abstract—Distributed generations and renewable energy generations have been widely installed in the distribution systems all over the world. The intermittence of distributed renewable energy generations and their special characteristics have various impacts on power system operation and dispatch. In this paper, the impacts of distributed generations on dispatch modes of power systems are discussed based on the Guangdong power grid in China. We introduce the situations of Guangdong power system, and its installation of distributed generations. The impacts of various distributed renewable energy generations on the system dispatch from the system operator’s view point have been discussed. Based on the Guangdong existing generation resources and potential distributed generation grid integration, we provide suggestions to smooth the future integration of large amount of distributed renewable energy generations.

Index Terms—Distributed generation, distributed renewable energy generation, power system dispatch.

I. INTRODUCTION

DISTRIBUTED generations (DGs) have been widely installed in distribution networks worldwide due to the fast development of distributed generation technologies. The DG technologies using renewable energy sources for power generation become emerging technologies due to their utilization of dispersed renewable energy and the policy support from the government. Installation of DGs close to customers in the distribution network could relieve the long distance transmission congestion and lower the capacity investments in transmission lines and distribution substations, although the reverse power flow caused by DGs could affect the operation of traditional power systems. The latest renovation and development of smart grid technologies provide technical platform to integrate a large amount of distributed generation to power grid. Distributed renewable energy (DRE) generation is encouraged and pushed in developed countries and several large carbon-emitting developing countries through various renewable energy policies and carbon reduction policies. DRE generation is financially supported as well in most countries through pricing mechanisms like feed-in tariffs and emission trading schemes, etc. With the new DG technologies and policy supports, distributed renewable energy generations have been well-developed in most countries, and the penetration level of DRE generations has been increasing at a high speed. The most commonly used DRE generations include micro hydro power, wind power, solar energy, biomass generation, combined cooling heating and power (CCHP) and geothermal generations, etc.

Guangdong is one of the most economic developed provinces in China. It is one of the five provinces within the terrain of China Southern Power Grid (CSG). Guangdong province is the load center of southern China power grid. About 65% percent of total demand of CSG is located in Guangdong province. High voltage AC/DC lines are built to transmit power from the large hydro stations and thermal power plants in western provinces to Guangdong. The energy resources in Guangdong are limited. The major generation sources are thermal power plants including some low efficiency coal-fired small power plants. In recent several years, due to the carbon reduction requirements, the government has issued policies to force to close up low energy efficiency coal-fired generating units. Since 2007, China has started to push energy saving and carbon reduction dispatch to lower the CO₂ emissions from power industries. Guangdong has been selected as a pioneer province to demonstrate the energy saving dispatch. The basic principle of energy saving dispatch is to dispatch generating units according to their energy/carbon consumptions and carbon emissions [1]. Renewable energy generations have the highest priority to be dispatched, and the fossil fuel fired generating units are dispatched according to their coal/carbon consumptions. The energy saving dispatch policies have significantly changed the dispatch patterns of power system operation in Guangdong, as well as their future generation planning and investment. Distributed renewable energy generations, like small hydro, wind power and biomass generation, and the issues of them have been raised to system operators for the consideration in real-time power generation dispatch. In this paper, we will introduce the situations of distributed renewable energy generations in Guangdong power grid, and discuss the impacts of the generations on power system dispatch and operation modes.
The paper is organized as follows, Section II will introduce the distributed generations in Guangdong power grid. Section III will discuss the impacts of distributed generations on power system operation. Section IV will provide suggestions to Guangdong for future DG integrations. Section V concludes.

II. DISTRIBUTED GENERATIONS IN GUANGDONG POWER GRID

By October 2011, the total installed capacity in Guangdong power grid is 74.477 GW. The dispatch of China Southern Power Grid is a three-level dispatch paradigm. From up to bottom, it is CSG dispatch center, provincial dispatch center and local-area dispatch center. Guangdong power dispatch center is one of the five provincial dispatch centers. Guangdong power dispatch center follows the dispatch instructions sent from CSG control center, while distributes dispatch instructions to local-area dispatch centers [2].

Within the total installed capacities in Guangdong, 84.02% of the capacities are dispatched directly by the provincial dispatch centers, while the 15.98% are dispatched by the local-area dispatch centers, which control 110 kV and lower voltage networks and substations.

Distributed generations including wind farms are generally installed and connected in the 110 kV and lower voltage distribution grids, which are dispatched and controlled by the local-area dispatch centers. The capacity of 11.904 GW (15.98% of total capacity in Guangdong), which are connected in 110 kV and lower voltage distribution network include, 3.11 GW of thermal units (26.42%), 7.45 GW of small hydro power (62.58%), and 1.31 GW of wind and biomass power (11%), respectively.

A. Small Hydro

Hydro power is a traditional renewable energy generation. The generation technology is mature and the cost is low compared to most other types of power generations. In China, the hydro power installed capacity is about 19% of the total installed generation capacity. Besides the large hydro power stations, China is abundant in small hydro / run-of-river hydro generation resources, especially in countryside. By 2010, the small hydro installed capacity in China has reached 55 GW. The development of small hydro will play an important role in energy saving and carbon reduction to achieve the target of reducing the rate of carbon emission / GDP by 40% of 2005 level before 2020.

Guangdong as a coastal region, is abundant of small hydro resources. Within the 34 provinces and regions of the country, 15% of the small hydro installed capacity is located in Guangdong, and generates around 20% of the small hydro power generation. The generation capacity could reach 4000 MW in wet seasons; and 1,000 MW in dry seasons. Most small hydro in Guangdong is run-of-river hydro power generations. There are no reservoirs and the outputs are not controllable.

In Guangdong, most small hydro power generations are installed in the distribution network. The small hydro power outputs are connected to the 110 kV (or 35 kV and 10 kV) distribution substations, which are also connected with loads. As the power generation of small hydro is hard to forecast and not controllable; and small hydro and loads are connected to the same bus-bar, it is very hard for the system operator to tell exactly the reasons of load changes (load variations or changes of small hydro generations) on the bus-bar due to the lack of output measurements of small hydro. The random and uncontrollable hydro power generations have affected the results of load forecasting of those bus-bars from the system operators’ view points. This has become one of the problems in power generation dispatch in Guangdong due to its large amount of small hydro generations installed in the distribution levels.

B. Wind Power

Wind power generation as an emerging renewable energy generation has been increased exponentially in China since 2006 as a result of the Renewable Energy Act and related pricing policies issued by National Development and Reform Commission (NDRC). The policies of feed-in-tariff for wind power generation have provided significant incentives to investment in wind power plants. The energy saving dispatch has provided the dispatch priority to the wind power generation, although the price of wind power generation is higher than thermal power generation.

By 2010, 24 wind farms have been built on the coastal areas of the province. The total installed capacity is about 783 MW. The annual increase rate of wind power capacity is about 41.3% since 2008. Annual wind power generation is 11.08 billion kWh, which is 0.27% of the total power consumption [3].

The investments of the wind farms in Guangdong are diversified with different generation investment companies. The feed-in-tariffs of the wind farms vary from CNY 0.5013 / kWh to CNY 0.74295 / KWh base on their project bidding procedures. The annual generation hours vary from 1,500 hours to 2,900 hours. The average number of annual wind farm generation hours is around 2,000 hours.

Among the wind farms, for those with installed capacity lower than 20 MW, they are connected in the 10 kV distribution systems. The wind farms larger than 20 MW are connected in the 110 kV network, and the longest transmission distance is 83 km. For the similar reasons as small hydro, the intermittent wind power generation will affect the load forecasting results from the system operator’s view points.
In Fig. 1, we have studied the capacity factor of a wind farm in Guangdong. It shows that wind power generation in Guangdong is high in the winter and relatively low in the summer. This is different from the Guangdong load pattern, which has summer peaking load. The studied wind farm shows that the wind power is higher in the day time than in the evening, which is different from the usual practices in most wind farms.

Although wind power is stronger in the winter, we notice that the wind power fluctuation / sudden changes in winter are higher than in summer, as shown in Fig. 2. By studying the 2010 wind power output data of a wind farm in Guangdong, it is found that in most of the time (87% of the time), the sudden change of wind power output (within 1 hour) is less than 10%. The wind power output sudden decrease is more frequent than output sudden increase.

From the system operator’s view point, the wind power forecasting is important. And the wind power generation planning may affect the dispatch mode once the wind power capacity has reached a certain level. System reserve capacities, ramp rates and power exchanges with other areas all may need to be re-considered if the wind power penetration level is high. To maintain a stable dispatch mode, the generation mix and planning issues need to be considered in advance to mitigate the potential impact of high wind power penetration on power system dispatch.

C. Biomass Generation

Biomass is considered as a kind of carbon-neutral energy resource. In biomass generation, three major methods are applied, direct-burn biomass generation, co-firing generation, and biogas generation. Wood, agriculture crop residue, landfill gas and biogas / methane are the common used resources for biomass generation.

By 2010, the generation capacity of biomass generation in Guangdong has reached 289 MW, which are all landfill gas and biogas generating units located close to big cities. The landfill gas and biogas units are mostly small units from 6 MW to 12 MW, except Likeng landfill gas generating unit is 22 MW. The units are connected to nearby 10 kV or 110 kV substations. The power transmission distances are not longer than 10 km [3].

On the other hand, Guangdong has the resources of building up crop-residue burned generating units. The agriculture products in Guangdong include sugar cane, grain, sweet potato and corn, etc. Among those, 82.2% is sugar cane and grain, which are the best resources of direct-burn biomass generation. It is planned to install 1.21 GW of direct-burn biomass generating units in the near future. The biomass generation capacity will save a large amount of coal.

To system operators, the outputs of biogas and biomass generating units are controllable, which is better in system operation’s view points than the intermittent renewable energy generations.

D. Combined Cooling Heat and Power

Combined cooling heat and power (CCHP) has a very high energy efficiency, which could reach 70-90% due to the utilization of residue heat of power generation. The efficiency of traditional centralized power generation can only be around 30-45%. CCHP has diversified generation technologies and generating turbines.

Guangdong has setup several CCHP projects in Guangzhou University town and a couple of large manufacturing factories. Guangdong Power Grid Co. considers CCHP as one of the important distributed generations that will be developed in the near future because of the weather conditions of the province. Guangdong is located mostly in the tropical area. The air-conditioner (AC) load lasts for more than half of the year from end of March to middle October. The AC load could be about 30-40% of the summer peaking demand. It is not economic to build up new generating capacities just for air-conditioner load. CCHP will be an alternative method for solving the problem. For system operators, the installation of CCHPs will change load pattern of summer AC demand. In a system with a large amount of CCHPs, the load forecasting needs to be adjusted considering the heat, cooling and power outputs of CCHPs.

E. Solar Power Generation

By 2010, the solar photovoltaic (PV) generation capacity has reached 11.4 MW in Guangdong. Besides the standalone PV power generation in islands, the grid-connected PV power generation capacity is 10.4 MW, all connected to the 380 V low-voltage distribution grid. The annual generation hour is around 1,000 hours [3]. Most of the capacities are installed in the economic developed pearl-river delta (PRD) area. The latest project is the 3 MW solar PV generation system installed in the campus of a local university. Based on the government tariff policies of solar generation, the PV generations are basically consumed by local customers of the 380 V secondary service lines. Surplus PV generations of
large-scale PV projects could be sold to the power grid at the cap electricity price for de-sulfur coal-fired generating units. Obviously, the tariff is not attractive to selling PV generations to the power grid. As a result of the tariff policy, most PV generations in Guangdong are grid-connected, but not actually selling electricity to the grid. Similar as CCHP, the intermittent PV generation supplying customers directly will affect the total load seen by the system operator. From operator’s viewpoints, the forecasting of PV generations needs to be considered in load forecasting results once a large amount of PV panels are installed in the low voltage distribution network.

F. Energy Storage

Energy storage technologies and distributed energy storage (DES) is another issue that must be raised to facilitate the increasing amount of intermittent distributed renewable energy generations. Electric vehicle (EV) and EV to grid (V2G) are widely discussed as a supplement technology of energy storage. In Guangdong, pump-storage stations are strategically developed to accommodate the large amount of hydro power transmitted from western provinces. By June 2011, the capacity of Guangdong pump-storage stations has reached 4.2 GW, which is almost the largest one in the country. The newly built pump-storage station in Huizhou in June 2011 has the capacity of 2.4 GW, which is the largest pump-storage station in the world. The capacity of Guangzhou pump-storage station is 1.8 GW. The pump-storage capacity in Guangdong is a special feature of Guangdong power grid. It provides a very good way in quick response to load/generation variations.

The pump-storage capacity in Guangdong power grid could be utilized as a very good mean to accommodate intermittent renewable energy generations and the deviations of load forecasting caused by distributed generations.

Among all units dispatched by the Guangdong power dispatch center (provincial dispatch level), 56.15% is coal-fired power plants, 11.1% is gas-turbine, 5.57% is oil-fired units, 7.32% is nuclear power generation, and 4.45% is pump-storage [4]. From the generation mix, we can see that coal-fired thermal generating units still dominate the power generation. Their ramp rates limit the capability of load following and frequency regulation. Although hydro power and gas turbines can response quickly to the load changes, however, the capacities of controllable hydro power and gas turbines are small, and their capabilities of frequency regulations are restricted by seasonal water resources and gas resources, respectively. In Guangdong, most gas turbines are used for base load.

III. IMPACTS OF DRE GENERATIONS ON DISPATCH MODE

The daily load pattern in Guangdong has three peaking load periods: morning peak, afternoon peak and evening peak. The working day daily peak load usually occurs around 11AM. However, it abruptly reduces in a short term, as shown by the upper red line in Fig. 3. The afternoon peak lasts for a longer time. Compared with the morning peak, afternoon and evening peaks reduce not so abruptly. The difference between peak and valley loads could reach 28.5 GW in a short period, as shown in Fig. 3. On the other hand, the load pattern in the holiday is usually flat. And the energy consumptions in holidays are much lower than in working days. This is clearly showed by the lower green line in Fig. 3.

From dispatch viewpoint, DGs can be classified as output controllable DGs and output uncontrollable DGs. Controllable DGs are mainly biomass generation, micro turbines, and other generating units using traditional generation technologies. Uncontrollable DGs include wind power, small hydro, PV generation, and CCHP etc. Controllable DGs could be considered as traditional generations with less impact on traditional dispatch method. Uncontrollable DGs require generation forecasting which may be very complicated due to their relations to the weather and other unpredictable conditions. For those uncontrollable DGs connected to the same substations as loads, their intermittent generations will affect the accuracy of load forecasting as well.

For distributed renewable energy generations, in case that their outputs are not in line with the load pattern, more reserves are needed to mitigate the fluctuations caused by the renewable generations in addition to load fluctuations. Energy storage is an alternative way to solve the problem.

Another issue caused by distributed generations is the voltage problem. The voltages of the distribution feeders will be pushed up due to the DGs installed at the downstream of the feeders. The problem is especially important in the wet season if a cascade hydro power is installed in the distribution system.
IV. DRE GENERATION INTEGRATIONS TO POWER GRID - SUGGESTIONS

Compared with most provincial power grids in China, Guangdong power grid has a higher percentage of nuclear power generation, gas turbine, and pump-storage station. The large amount of hydro power transmitted from western provinces to Guangdong is also a feature of Guangdong grid. The pump-storage capacity and western hydro power capacity will play a very important role in the future integration of large amount of distributed renewable energy generations to Guangdong power grid. The development of quick response energy storage technologies, like fly wheel and large capacity battery will further facilitate the capability of frequency regulations.

Within the DG technologies, development of CCHP could be a suitable way for Guangdong to lower the air-conditioner demand in the summer, hence reduce the investment of peak units.

Due to the pushing of energy saving dispatch and other carbon reduction policies, increasing renewable energy generations will be installed in the power grid. The growth could be exponentially increased once the policies provide strong incentives to renewable energy grid integration. The Guangdong power company should be prepared in advance from long-term generation planning and adjustment of structure of generation sources. On the other hand, power dispatch center should well-utilize the frequency regulation capability of existing pump-storage, gas turbines, and hydro power. The last is to build up renovated smart control center utilizing the latest smart grid technologies.

V. CONCLUSIONS

In this paper, based on the situation of Guangdong power grid, we introduced various distributed generations and their impacts on power system operation and dispatch. It is concluded that controllable DGs have less impacts on traditional system dispatch, while uncontrollable DRE generations could affect the dispatch mode if their penetration levels are high, and they may affect the load forecasting results as well if they are connected to the substations with loads.

The capability of frequency regulation and capacity of spinning reserves are very important for a power grid to accommodate large amount of DRE generations. Pump-storage and other quick response energy storage devices will play an important role in DRE generation grid integrations.

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VII. REFERENCES