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Operation Principle of Multiple DC Smart Grids

Chitralekha Vangala[1], Kavita Mhaskar[2]

Department of Electrical Engineering, Mumbai University

Abstract— *Smart grid has been having great attention from the view point of introducing more renewable energy sources. However, due to fluctuating power output of energy sources, the DC bus voltage fluctuation of DC grid occurs frequently. It has become a major issue at the time of islanding. This paper represents coordinated operation of few multiple DC smart grids. The power system in this paper consists of three smart DC grids. Each smart DC grid has wind generators, PV generations and also controllable loads. The DC bus voltage has been maintained within acceptable range by applying the control of power consumption in controllable loads, the power control by grid connected converter and also the power control by the renewable sources.*

***Keywords*— controllable loads, dc distribution, droop characteristic, islanding operation, multiple DC source, renewable energy source, smart grid.**

I. INTRODUCTION

Power demand in islands has been increasing rapidly. Diesel generators which are fueled by fossil fuels mostly supply the required power for this demand. For green house gas reduction and also oil substitution, introduction of renewable energy sources such as photo voltaic, wind etc. are important. Renewable energy resources giving power are safe, clean and in extinct in nature. However, due to the less power or power fluctuation of renewable energy source, voltage and frequency deviate in isolated power systems. Because of this, the ability to maintain stable supply and demand balance becomes low. Therefore, it is very necessary to control the frequency and voltage of the system at the supply-side.

At supply-side, storage equipment installation and pitch angle control of the wind generator has been proposed to control power of distribution system. However, the installation of storage equipment that requires large storage capacity and maintenance cost for battery degradation cannot be expected. Hence, in case of using the renewable energy source plants connected to the power system, the supply side control has certain limitations. Therefore, mutual cooperation control with the demand side controllers is required because it becomes difficult to maintain good power quality by only the supply side controllers. From this point of view, a smart grid which maintains stable supply and demand balance by observing and correcting the power information of the demand side is very much necessary.

II. DC SMART GRID CONFIGURATION AND CONTROL SYSTEM

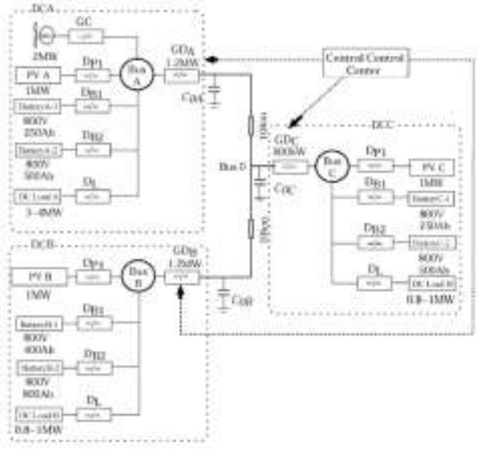


FIG. 1 Power System Model

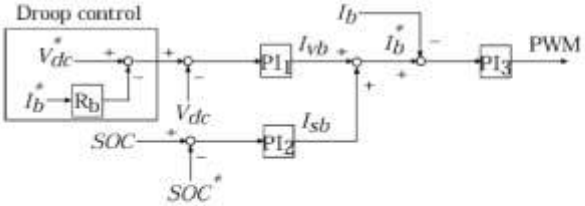


FIG. 2 Model and Control System of Battery

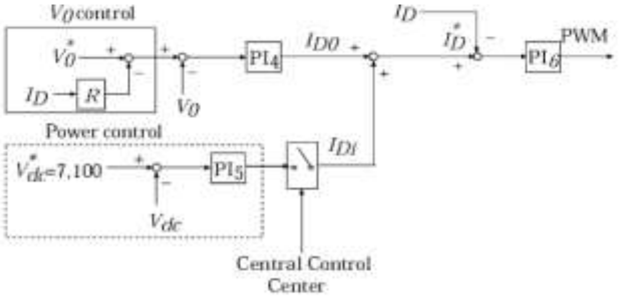


FIG. 3 Control System of Grid connected Converter

The alignment of the power system is shown in Fig. 1. Three DC smart grids (DCSG) with different capacities are connected through grid connected converters (GD A, GDB, GDe,) as shown. The DC smart grid A (DCA) has one wind turbine generator along with PV generators, a generator side converter, controllable loads i.e. batteries, etc., and variable loads. The wind turbine generator is gearless with 2MW permanent magnet synchronous generator (PMSG). Permanent magnet synchronous generator has a very simple structure and has high efficiency which is expected to be installed in the next generation WTG systems. Wind energy power obtained from the windmill is sent to the permanent magnet synchronous generator. In order to generate max power, the rotational speed of the PMSG is controlled by using PWM converter. Its output power and photovoltaic output power are then supplied to the DC load through DC distribution line. The remaining power of the PMSG and PVs are then supplied to the other DC smart grid through grid connected converters. The grid connected converters control its power output to maintain DC bus voltage of Bus O in acceptable range. The operation of grid connected converter is then determined by using center of central control which manages the information of all DC smart grids as shown in Fig. 1.

2.1 Controllable load control system

In this paper, the DC bus voltage is been controlled by using voltage control of controllable loads. Here, battery is used as controllable loads. Although the battery is available in DC smart houses, electric vehicle (EV) can be used as battery in the future. The electric vehicle is very important due to depletion of available energy sources and it is also available as a backup power in the residential homes. The storage systems are also modeled as a current source device and state of charge (SOC) is calculated by using feedback control with an integral control of the discharge and also charge power consumptions.

The control system of the given model is illustrated in Fig. 2. In this type of control system, by using droop control the fluctuation of DC bus voltage of each DC smart grid is suppressed. The power consumption command I_B is decided by droop coefficient $R_{\mathbf{B}}$ and control variable I_{EB} is produced by PIB controller of SOC.

2.2 Control system of grid connected converter

The grid connected converter is a bidirectional buck boost chopper and is modeled by using IGBTs as a power device. The grid connected converter is used to implement DC bus voltage control along with power transfer operation of Bus O. The control system of the model is shown in Fig. 3. In the case of power transfer between different DC smart grids, when remaining power is available in DC smart grid, the DC bus voltage V_{de} of the DC smart grid is then controlled by transferring all the remaining power to other DC smart grids available. When the power transfer is not available between DC smart grids, the grid connected converter is shut and the DC smart grid operates in the isolated mode. Therefore, the DC bus voltage of the DC smart grids is controlled by using power control of controllable loads and also the renewable plants.

In the control system, droop control is applied to suppress DC bus voltage fluctuation Vo of Bus O. When power transfer is available between DC smart grids, power control which is used to suppress DC bus voltage fluctuation is implemented by the grid connected converter.

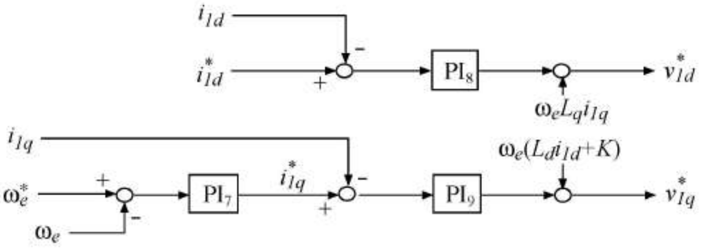


FIG. 4 Generator side converter system model

III. BUS O DC TRANSMISSION VOLTAGE CONTROL BY DROOP CHARACTERISTICS

This section gives the idea to control the decentralized control loads according to droop characteristic. By using the droop control characteristics, the DC network requires no central control and no communication is available between the different elements of the network.

In the DC smart grid, the fluctuations of DC transmission voltage occur due to the fluctuation in the output produced by transmitting the remaining power to other available DC smart grids. The reduction of this fluctuation is achieved by grid connected converter. Determination of the power consumption command is required for each grid connected converter which is of different capacity. Therefore, the grid side converters are then controlled according to the droop characteristics and the load is shared according to the available capacities of grid connected converters. The droop characteristics for the grid connected converter are shown in Fig. 5. The droop characteristics for the grid connected converters for DC transmission voltage is also shown in Fig. 5. When the DC transmission voltage increases, the droop characteristics are obtained such that the higher the capacity of grid connected converter is, the more the power consumptions of grid connected converter are. Additionally, when the DC transmission voltage droops, the droop characteristics are configured such that the bigger the capacity of grid connected converter is, the more output power of grid connected converter is obtained.

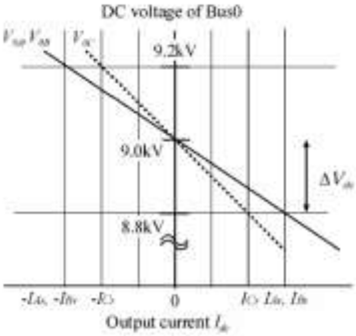


FIG. 5 Droop characteristics of grid connected converter

IV. SIMULATION RESULTS

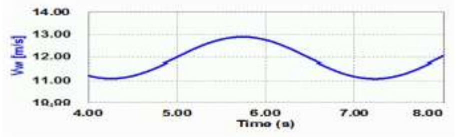
In this paper, the effectiveness of operation for multiple DC smart grids is tested by using simulations with the system model shown in Fig. 1.

4.1 Case of no power interchange

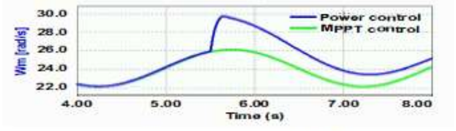
Fig. 6 shows simulation results of Bus A in case of no power interchange between all the DC smart grids for isolated operation. For wind speed shown in Fig. 6(a), output of permanent magnet synchronous generator and electrical speed of permanent magnet synchronous generator are shown in Figs. 6(b), 6(c), respectively. It can be seen that electrical speed of permanent magnet synchronous generator changes according to DC bus voltage fluctuation. Therefore, the power coefficient is decreased and the output power of the wind power generation reduces. Fig. 6(d) shows the output power of photovoltaic. It can be seen that the output power of photovoltaic is reduced according to the DC bus voltage fluctuation like permanent magnet synchronous generator. The output of batteries is shown in Fig. 6(e). It can be seen that, the power consumption of batteries are changing with respect to the capacity of each battery, due to the designed control system based on the droop characteristics. The state of charge (SOC) of batteries are raised up to 100% (=50C*) as shown in Fig. 6(g). From these obtained simulation results, the DC bus voltage of Bus A is kept within acceptable range by allowing to control the power of the permanent magnet synchronous generator, the photovoltaic generator, and the controllable loads. The power consumption of the variable loads is set to randomly consume.

4.2 Case of power interchange

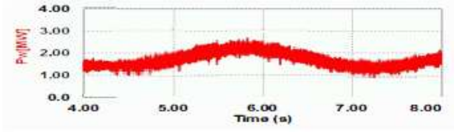
Fig. 6 shows simulation results of Bus A in case of power interchange operation. Here, the remaining power of DCA is transferred to other DC smart grids (Bus B, Bus C) by the power control of the grid connected converter. From these simulation results, it can be claimed that the DC bus voltage can be maintained within the acceptable power range by using the power control of the converter and the controllable loads. The power consumption of the variable loads is set to randomly consume power.



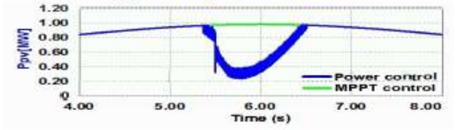
(a) Wind speed.



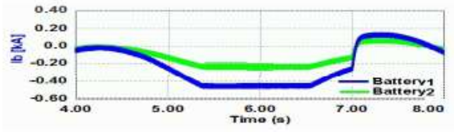
(b) Electrical speed of PMSG.



(c) Active power of PMSG.

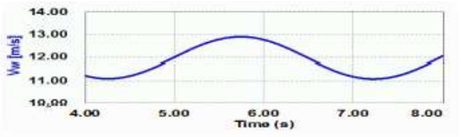


(d) Active power of PV.

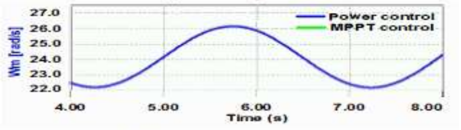


(e) Output of batteries.

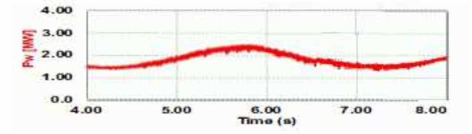
FIG. 6. Simulation results for no power transfer of operation A



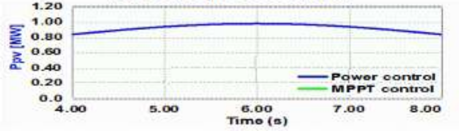
(a) Wind speed.



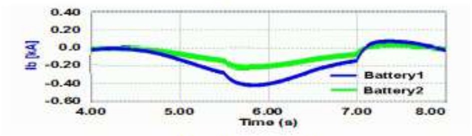
(b) Electrical speed of PMSG.



(c) Active power of PMSG.



(d) Active power of PV.



(e) Output of batteries.

FIG. 7. Simulation results for power transfer of operation A

V. CONCLUSION

This paper gives us a brief idea of coordinated operation for multiple DC smart grids. The fluctuations of DC bus voltage due to the renewable energy sources (WTG and PV) and loads are suppressed by applying the control of power consumption of the controllable loads, the power control with grid connected converter and also the power control of the renewable energy sources. The proposed method provides us with the renewable power plants that are able to operate at maximum power point with benefits of the reduction in cost by reduction in the storage equipment of renewable power plants and by increasing the controllability for DC bus voltage.

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