Research on STATCOM for Reactive Power Flow Control and Voltage Stability in Microgrid

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***Abstract*—Static Synchronous Compensator (STATCOM) is a kind of parallel reactive power compensation equipment in FACTS system. To study the reactive power regulation of STATCOM in microgrid, the relationship between reactive power flow and voltage in microgrid is analyzed theoretically in this paper. The direct current control is used to control the reactive power exchange between the microgrid and distribution network based on a given reference voltage. Then the simulation research on reactive power flow control of a microgrid system connected STATCOM is carried out. The simulation results show that the voltage at PCC point will be unstable under the two conditions. STATCOM can effectively maintain the voltage balance of PCC point in the microgrid access to the grid and meet the requirements of flexible regulation and stable operation of microgrid.**

***Key Words*—Microgrid; STATCOM; Reactive Power Flow control; Voltage Stability**

I. INTRODUCTION

The centralized traditional large power supply mode has some defects such as low reliability, environmental pollution and poor flexibility. In order to solve the above problems, the distributed generation installed near the users becomes an alternative choice [1-3].However, due to the shortcomings of DG, such as randomness and intermittency, DGs will have a great impact on the large power grid when transmitted to the grid directly. Therefore, the concept of microgrid is proposed[4].The microgrid can make full use of these new energy sources and interconnect the DGs with the loads, which can work independently as a reliable and stable power supply and also used as a generation transmitting power to the large power grid [5-6].

STATCOM is a shunt reactive compensation device based on inverter technology. It is equivalent to an adjustable voltage or current source that can be controlled by its amplitude and phase to change the reactive power delivered to the grid[7].A STATCOM positive and negative sequence voltage coordinated control strategy for cage wind farm with voltage unbalance is proposed in paper[8], so as to reduce the three-phase voltage imbalance of PCC point of grid-connected wind farm. Reference[9] introduced the optimization of reactive power flow based on droop control to improve the voltage stability of the microgrid system. References [10-11] studied the application of UPFC to a distribution network with a wind power generation system, which can reduce the reactive power exchange between the wind power generation system and the distribution network. Due to this, low voltage ride through capability of wind power system is improved. Reference[12] studied that STATCOM can control the reactive power exchange between wind farm and grid to improve the dynamic voltage stability of wind farm. Aiming at voltage unbalances in microgrid, the virtual admittance control method is proposed in paper[13] to control STATCOM connected to the microgrid, which improves the three-phase imbalance of the microgrid. At present, the power control of

The project is supported by National Nature Science Foundation of China (61671338), and Wuhan University of Science and Technology students' science and technology innovation fund project (16ZRC131).

978-1-5386-3758-6/18/$31.00

microgrid is mainly within the microgrid. In this paper, the microgrid system is regarded as a whole. Power flow control is implemented from the outside of the system.

In this paper, the relationship between reactive power flow and voltage in the microgrid is analyzed theoretically firstly. Then the operating principle of STATCOM access in the microgrid connected to the grid is explained. Based on this, the direct current control strategy is proposed. Finally, the microgrid model in the grid-connecting mode with STATCOM is established in Matlab/Simulink. The simulation results indicate that STATCOM can control the reactive power exchange between the microgrid and the distribution network at sudden load change operation. Moreover, it also can stabilize the voltage and reactive power balance at the PCC point.

II. THE RELATIONSHIP BETWEEN REACTIVE POWER FLOW AND VOLTAGE IN MICROGRID

There are mainly two factors that cause the voltage fluctuation in microgrid. One is the change of reactive power flow in the system. The other is the change of loads connected to the system. Therefore, the voltage is closely related to the reactive power flow. Under any operating conditions, it is required that the reactive power output by the power generation terminal is equal to the reactive power required by the power supply terminal, that is, the reactive power balance need be satisfied. Regarding the microgrid system as an inverter, the distribution network as an ideal source, the grid-connected microgrid equivalent circuit is shown in Fig.1, in which transmission lines are represented by inductance and resistance.

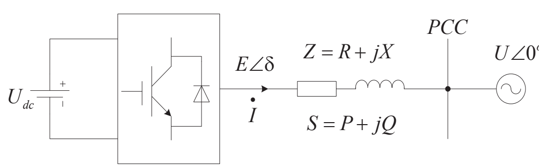

Fig.1.Equivalent circuit diagram of grid microgrid

According to Fig. 1, the power delivered by the microgrid system is obtained:

$$P = UI\cos\varphi = \frac{EU}{X}\sin\delta \tag{1}$$

$$Q = UI\sin\varphi = \frac{EU}{X}\cos\delta - \frac{U^2}{X} \tag{2}$$

When the load is fixed in the microgrid system, the output active power is certain. At this point simultaneous (1) and (2) were:

$$Q = \sqrt{\left(\frac{EU}{X}\right)^2 - P^2} - \frac{U^2}{X} \tag{3}$$

The relationship between reactive power and voltage required by the load is:

$$Q = \frac{U^2}{X} \tag{4}$$

If the reactive power output from the system power supply does not increase with the increase of reactive load, the balance between the reactive power at the power supply terminal and the load terminal at the rated voltage cannot be guaranteed. To achieve reactive power balance at lower voltage levels, the system voltage need to be reduced. Otherwise, if the reactive power is greater than the reactive load demand, the system will operate at a higher voltage level.

III. ANANLYSIS OF REACTIVE POWER FLOW CONTROL IN MICROGRID BY STATCOM

A. The Basic Working Principle of STATCOM

In order to analyze the control effect of STATCOM on the reactive power flow of microgrid, the working principle of STATCOM is introduced by the voltage bridge circuit. The microgrid is equivalent to a voltage source $\dot{U}_M$. And STATCOM is equivalent to a controlled voltage source $\dot{U}_C$ .The circuit equivalent diagram is shown in Fig. 2.

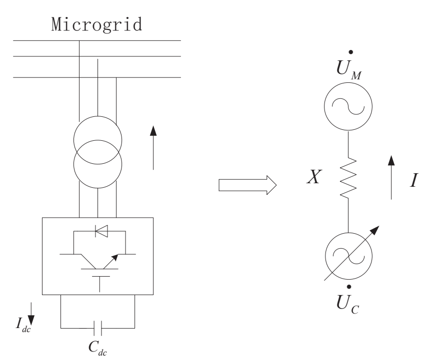

Fig.2.circuit equivalent diagram of STATCOM

The current absorbed by STATCOM in Fig. 2 is expressed as [14]:

$$I = \frac{\dot{U}_M - \dot{U}_C}{jX} \tag{5}$$

Regardless of the loss of the STATCOM and its effect on the active power, $\dot{U}_M$ and $\dot{U}_C$ are almost the same phase. The reactive power absorbed by the device can be expressed as:

$$Q = \mathrm{Im}(\dot{U}_M \frac{\dot{U}_M - \dot{U}_C}{-jX}) = \frac{U_M - U_C}{X} U_M \tag{6}$$

From the formula (6), it is can be seen that in the ideal case, the two phases are identical. Controlling the magnitude of $\dot{U}_C$ can indirectly control the phase and magnitude of the current absorbed by STATCOM from the system. When the STATCOM output voltage is smaller than the microgrid voltage, the current phase from the system to STATCOM lags the microgrid voltage by90^o, which is equivalent to the inductance and provides capacitive reactive power support to the grid. When the STATCOM output voltage is greater than the microgrid voltage, the current phase from the system to STATCOM leads the microgrid voltage by 90^o, which is equivalent to the capacitance and provides inductive reactive power support to the grid, as shown in Fig. 3.

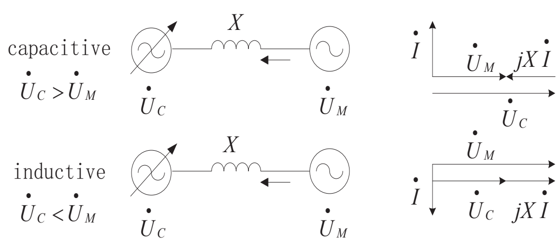

Fig.3.the simplified working principle of STATCOM

When the voltage is reduced or raised to a certain value, the STATCOM is limited by the capacity of the available switch devices. So the output current will remain unchanged. Due to the continuous adjustment of the magnitude and phase of $\dot{U}_C$, the reactive power of the STATCOM output can be controlled.

B. Control Strategy of STATCOM

The main control target of STATCOM is to adjust the voltage and reactive power of PCC point. The control methods can be divided into open loop control, closed loop control, etc[15]. In this paper, direct current control is applied to control reactive power and voltage of STATCOM. The control chart is as follows:

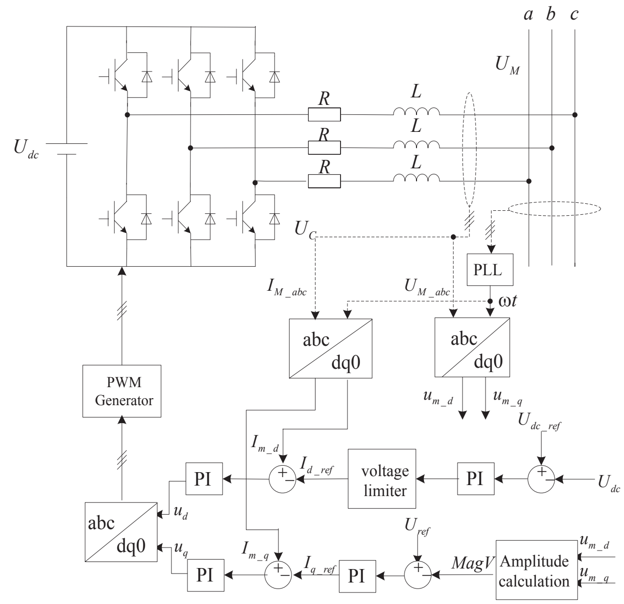

Fig.4.system schematic diagram of STATCOM control

As is shown in Fig. 4, the system voltage maintains at the reference voltage by the method, moreover, it can keep voltage at dc side of STATCOM to be stable. For keeping system voltage at the reference value depends on reactive power compensation, to stabilize system voltage is realized by controlling reactive current in the control block diagram, and to stabilize voltage at dc side is realized by controlling active current. Three-phase compensation voltage is obtained by dq inverse transform, which is delivered to converter as trigger signal after PWM modulation, and generate a voltage whose phase has a certain gap with synchronous system voltage, so that appropriate reactive power at the parallel side is compensated to maintain the stability of the system voltage, and assimilate appropriate active power to stabilize voltage at dc side.

IV. SIMULATION ANALYSIS

To verify the effect of STATCOM on reactive power flow control and voltage stabilization in the microgrid, a grid-connected microgrid system is established by MATLAB, which is shown in Fig. 5.

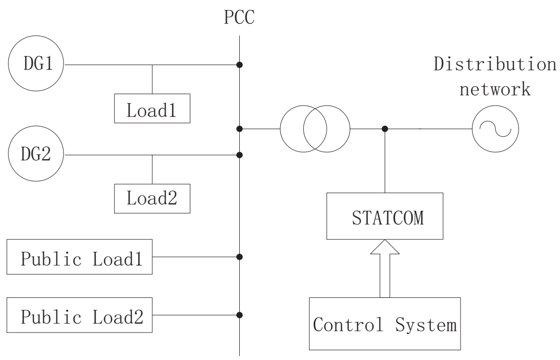

Fig.5. the simulation system diagram

The microgrid system consists of two distributed power supplies and four loads, which are converged to a common bus PCC point and connected to the distribution network via a transformer, STATCOM is connected to public connection bus. STATCOM regulating reactive power to stabilize voltage at PCC point under voltage fluctuation at the distribution network side and the load fluctuation at microgrid side is verified by the simulation, and the condition of reactive power and voltage fluctuation at the PCC point is compared without adding the STATCOM device. The basic simulation parameters are shown in TABLE I.

TABLE I. SIMULATION PARAMETERS OF THE SYSTEM

	Physical Quantity	Value
microgrid	rated voltage/V	380
	rated frequency/Hz	50
	load 1/kW	50
	load 2/kW	40
	public load1/kW	60
	public load2/kW	30
Distribution network	rated voltage/kV	25

A. The operating condition I: load is suddenly increased or decreased in power distribution network

When load is suddenly increased or decreased at the distribution network side, voltage will fluctuate, which causes voltage fluctuation at PCC point and influences power quality of microgrid, by the time STATCOM can regulate reactive power of microgrid according to reference voltage and maintain the voltage balance at the PCC point. the simulation result is shown in Fig. 6.

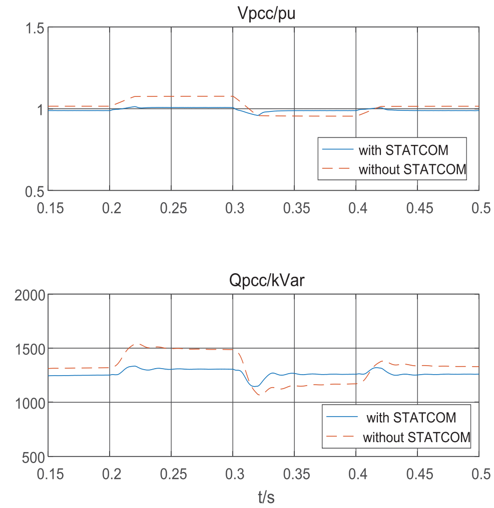

Fig. 6.the simulation result(operating condition I)

There is a brief period of fluctuation for the system before simulation, and voltage and reactive power maintain stable. At 0.2s, for the load is suddenly decreased at grid side, a 6% step occurs to voltage, which causes voltage fluctuation at PCC point, reactive power becomes larger; at 0.3s, for the load is suddenly increased at grid side, a 6% decline occurs to voltage, which causes voltage decline at PCC point, reactive power becomes smaller; the voltage at grid side is restored to normal after 0.4s. When STATCOM is accessed to system, at 0.2s, STATCOM detects a rise of reactive power and assimilates part of the reactive power, reactive power of microgrid is assimilated by grid, voltage drops to normal; at 0.3s, reactive power at PCC point drops, STATCOM deliver part of reactive power to system, reactive power of grid is assimilated by microgrid, voltage rises to normal.

B. The operating condition II: load is suddenly increased in microgrid

When load is suddenly added into microgrid, it is not enough for power of microgrid to satisfy power required for the load, the voltage at PCC point suddenly drops, reliability of system decreases. STATCOM can compensate reactive power at PCC point and stabilize voltage. The simulation result is shown in Fig.7.

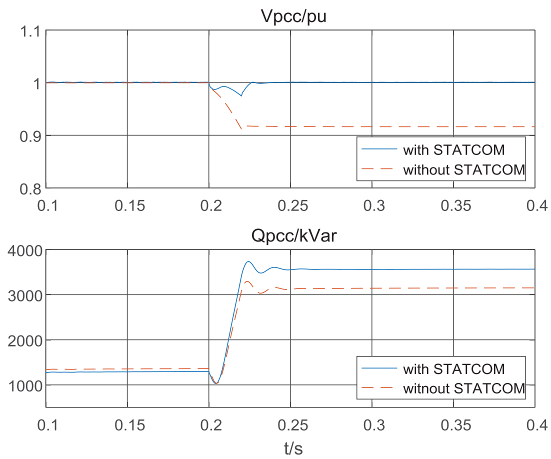

Fig.7. the simulation result(operating condition II)

Voltage and reactive power are stable before simulation, at 0.2s, for load is suddenly added into load side of microgrid, voltage at PCC point drops approximately 10%, in order to keep stable reactive power of microgrid system, reactive power is delivered to microgrid from grid side, reactive power at PCC point rises, but it can't completely compensate reactive power, the voltage keeps at 0.9pu. When STATCOM is accessed, for the reactive power compensation effect of STATCOM, delivered reactive power from grid side to microgrid increases, the voltage at PCC point rises, comparing with the condition without accessing STATCOM, there is almost no change for voltage, voltage almost keeps stable.

As is known form operating condition Ⅰ and operating condition II, STATCOM can control reactive power exchange between power distribution network and microgrid, stabilize voltage of PCC point, stability and reliability are improved.

V. CONCLUSION

The relationship between reactive flow and voltage in microgrid is analyzed, the basic principle for STATCOM controlling reactive flow in microgrid is researched, according to steady mathematical model, a control strategy based on direct current control is presented in this paper. The simulation is carried out by Matlab/Simulink, the simulation under two operating condition is finished. The results show that, when grid-side voltage fluctuates, STATCOM can control reactive power of microgrid and power distribution network and stabilize voltage at PCC; when voltage at load side fluctuates in microgrid, STATCOM can effectively compensate reactive power, restrain voltage reduction, improve stability and reliability of system.

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