A Novel AC-DC Hybrid Microgrid Control Strategy Based on VSM

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Abstract. It is an important goal of the microgrid control system to realize the rational allocation of power between the AC and DC microgrid by using the power electronic converter to integrate the renewable energy into the power distribution system. This paper introduces the Virtual Synchronous Generator (VSM) control strategy of hybrid microgrid, which solves the above problems by mimicking the characteristics of traditional Synchronous Machine (SM). In order to better optimize the performance of AC/DC hybrid microgrid, a novel VSM-based bidirectional converter (BC) control strategy is proposed, which also ensures the capability of BC independent power allocation. Finally, in the PSCAD environment, two types are used. The hybrid microgrid with different BC control structures was studied and compared.

1. Introduction
With the development of microgrid technology, AC / DC hybrid microgrid has attracted people's attention [1]. The operation of AC / DC hybrid microgrid (hybrid microgrid) combines the advantages of AC microgrid and DC microgrid. Hybrid microgrid is composed of AC and DC subsystems interconnected by voltage source converters. Hybrid microgrid has two different operation modes: grid-connected mode and island mode. Maintaining the frequency of AC subnet and the voltage of DC subnet in an acceptable standard range is the most important issue. At first, power electronic interface is an important part of integrating different types of distributed energy into different microgrid operation modes. Due to many advantages of power electronic interface and its superior performance, power converter has become a practical renewable energy interface. In reference [2, 3], a voltage controlled virtual synchronous generator with external characteristics of voltage source is proposed. Its essence mainly considers the relationship between active power and frequency, reactive power and voltage, and provides stable frequency and voltage support for the system. It is widely used in high permeability power grid environment. However, unlike synchronous motors, the RES interface power converter is ineffective to improve system stability due to the lack of inertia required to support AC system frequency and voltage control. Therefore, VSC with high penetration level will also lead to stability problems and affect the dynamic stability of the system [4] the independent microgrid is considered to be a weak system because there is no frequency support on the AC side and no DC voltage support on the DC side. Therefore, the reasonable distribution of power between AC and DC sub-microgrids is crucial to the stability of microgrid. The change of power generation or load conditions will lead to large frequency deviation and may lead to system instability [5].
This paper solves these problems by applying the concept of virtual synchronous machine controller combined with VSC and SM characteristics. This algorithm introduces virtual inertia and virtual damping into the loop controller of the interface converter, and in the actual operation of SM, VSC has no physical inertia quality. The main innovation of this paper is to propose a new control algorithm, which makes the bidirectional converter as a synchronous motor to support AC subnet voltage and frequency and DC subnet power supply in isolated island mode. This paper also takes the independent power allocation of bidirectional converter based on VSM as the second innovation point. The proposed controller is composed of two controllers, the inner-loop current controller and the outer-loop voltage controller. The advantage of the current control loop is to protect the converter from the influence of overcurrent.

2. Configuration and Control Structure of AC / DC Hybrid System

The AC / DC hybrid microgrid configuration used in this paper is shown in Fig. 1.

![Fig. 1 AC/DC hybrid microgrid structure](image)

The AC side is powered by wind power and diesel power. The current is filtered through the rectifier, and then the power is supplied to the AC load by the inverter. There is a battery plate for the AC side backup power. The DC side is powered by photovoltaic array and battery plate, and the current is directly distributed to the DC load after filtering through the rectifier. The AC sub-microgrid and the DC sub-microgrid are connected by bidirectional converters. The control structure of AC subsystem and bidirectional converter is based on the synchronous reference synchronous reference frame of the current and voltage controllers, as shown in Fig. 2.

![Fig. 2 Control block with virtual impedance cascade voltage and current controller](image)
The control structure of the inverter of the DC subsystem is based on the cascade voltage and current control, as shown in Fig. 3.

![Fig. 3 Cascaded voltage and current control of](image)

The BC controller only includes the current loop and the droop controller[6]. The reference data are shown in Tab.1.

**Tab. 1 Parameter Configuration of AC / DC Hybrid Microgrid**

| type                  | name                          | numerical value |
|-----------------------|-------------------------------|-----------------|
| DC DG units AC Microgrid | Converter rated power         | 1MVA            |
|                       | AC side voltage               | 690V            |
|                       | AC Resistance Measurement     | 0.01Ω           |
|                       | active current side inductor  | 1mH             |
|                       | AC side capacitance           | 50uF            |
|                       | system frequency              | 50HZ            |
| Bidirectional converter | virtual inertia               | 0.005Kg/m²      |
|                       | Virtual damping coefficient   | 16000N.s/min    |
|                       | AC Resistance Measurement     | 0.1Ω            |
|                       | active current side inductor  | 2mH             |
|                       | AC side capacitance           | 50uF            |
|                       | Converter rated power         | 1MVA            |
|                       | DC link pd                    | 2500V           |
|                       | DC Resistance Measurement     | 0.05Ω           |
|                       | DC side inductance            | 1mH             |

2.1. **AC Microgrid**

The distributed generation (DG) unit in AC microgrid is composed of three-phase voltage source converter (VSC) powered by DC power supply. Whether the adjustable DG or non-adjustable DG represented by DC voltage source is controlled by the traditional droop scheme, and each DG unit provides load according to the predetermined droop gain. Therefore, when the system parameters are symmetric, in order to make all DG units have the same power distribution, the droop gain should also be the same. In addition, equal power sharing between DG units provides system stability margin [7]. The DG unit must meet the power supply requirements of the active power supply of the AC subnet. The sum of the total power injected by each DG must be equal to the sum of the common AC load power, as shown in Equation (1).

\[
P_{AC_{load}} = \sum_{i=1}^{n} P_{AC_{DG}(i)}
\]

Where \( P_{AC_{load}} \) represents the total AC load power, \( P_{AC_{DG}(i)} \) represents the power injected by each DG unit in the AC microgrid, and the operating system frequency is calculated according to its droop coefficient \( m_{p}^{ac} \). Variable n represents the number of DG units connected to the AC microgrid.

2.2. **DC Microgrid**

Each DG unit is composed of a half-bridge DC-DC converter from DC power supply in the DC subnet. The DC bus voltage in the DC subnet is based on the droop control of the DG unit. The droop control is similar to the AC subnet, and each DG unit provides load according to the predefined droop gain. The
sum of total power injected by each DG unit must be equal to the sum of common DC load power, as shown in Equation 2.

\[ P_{\text{DCloud}} = \sum_{i=1}^{n} P_{\text{DC,DC}(i)} \]  

Where \( P_{\text{DC,DC}(i)} \) represents the power injected by DG, which is calculated according to the droop coefficient \( m_p \) under the DC system voltage.

### 2.3. Autonomous Control of Hybrid Microgrid

The autonomous operation of AC sub-microgrid is mainly based on droop control. Whether the power supply power is active or reactive depends on the frequency of the system and the AC voltage at the point common coupling (PCC) \[8\]. Increasing AC load reduces the frequency of the system and makes DGS provide more active power, and vice versa. On the other hand, reducing the AC voltage at PCC is a sign that DGS provides reactive power. Therefore, vector control can realize independent active and reactive power control.

The autonomous operation of DC sub-microgrid is similar to that of AC sub-microgrid. However, the DC voltage level determines the required injection power. The change of DC voltage is the main signal for DGS to maintain DC voltage by injecting active power. Moreover, due to the resistance line voltage drop, all DGSs with the same droop coefficient in DC microgrid cannot allocate the same power. Compared with AC and DC microgrids, the autonomous operation of bidirectional converter based on droop control is very different. BC can be autonomously controlled based on droop control, which is determined by measuring the sum of AC subnet frequency and DC subnet voltage level of its AC and DC terminals. Therefore, the control benchmark is composed of AC droop related to the frequency of AC microgrid and DC droop related to the DC voltage of DC microgrid. The mathematical expressions of AC / DC combined droop characteristics of BC are as follows:

\[
\begin{align*}
P_{\text{BC}}^{\text{ref}} &= \begin{cases} 
0 & \omega < \omega_{\text{min}} \& V_{\text{dc}} < V_{\text{dc}}^{\text{min}} \\
P_{\text{BC}}^{\text{dc}} - P_{\text{BC}}^{\text{dc}} & \text{other}
\end{cases} \\
\end{align*}
\]

\[
\begin{align*}
P_{\text{BC}}^{\text{dc}} &= \begin{cases} 
V_{\text{dc}}^{\text{min}} - V_{\text{dc}}^{\text{min}} \\
m_p \omega_{\text{min}} - \omega & \text{if } V_{\text{dc}} < V_{\text{dc}}^{\text{min}} \\
0 & \text{other}
\end{cases}
\end{align*}
\]

\[
\begin{align*}
P_{\text{BC}}^{\omega} &= \begin{cases} 
\omega_{\text{min}} - \omega \\
m_p \omega_{\text{min}} & \text{if } \omega < \omega_{\text{min}} \\
0 & \text{other}
\end{cases}
\end{align*}
\]

When the BC power reference is determined by equation 3, the current reference of the input current controller can be found by dividing the power reference by the voltage when only the current controller circuit is used.

### 3. Simulation results and analysis

The system model used in this study is composed of the average VSC model constructed in PSCAD / EMTDC. The research in this paper mainly focuses on two important factors, namely, the power exchange from DC to AC and from AC to DC. In addition, this paper also compares and analyzes the hybrid microgrid based on the new VSM controller and the traditional current controller circuit.

#### 3.1. Dynamic characteristics of power variation of AC / DC subnet under underload condition

In this case, the two hybrid microgrids have the same operating conditions, and the simulation of the load power variation characteristics of the two subsystems under under-load conditions is shown in Fig.
4. Initially, AC subsystem provides 1MW power for AC load, while DC subsystem provides 0.8MW power. When $t=5$ seconds, AC load power increases to 1.5MW.

![Fig. 4 Load power variation of AC microgrid under underload conditions](image)

As shown in Fig. 5, it may be preferable to supply power during slow-reaction transitions, better provided by controls, and BC based solely on current controllers does not display this feature. As shown in Figures 4 and 5, the VSM-based control improves the start-up transient of DGS in AC subsystem and reduces overshoot.

![Fig. 5 BC power exchange under underload conditions](image)

Due to the existence of VSM in BC controller, the converter power is affected by inertia. As shown in Fig.6, DC load power increases from 0.4 MW to 0.8 MW at $t=3$ seconds; therefore, it has no influence on the communication subsystem. In this case, the two subsystems work under the condition of underload, so the DGS unit of the two subsystems can still provide more additional power, equivalent to 0.2 MW of each DG unit.

![Fig. 6 Load power variation of DC microgrid under underload conditions](image)

Inertia refers to the power provided by the bidirectional converter in a short period of time, which represents the rotation quality in the process of frequency change. As shown in Figures 5 and 6, when $t=5$ seconds, due to the droop control characteristics of DC subnet, DC voltage follows the VSM action and converts power from DC microgrid to AC microgrid in a very short time. In addition, the DGS unit in the DC subsystem is powered under transient disturbance, so the DC DGS unit also follows the VSM action. Fig. 7 shows the influence of virtual inertia in the DC voltage subsystem.
3.2. Power Exchange from DC to AC Microgrid under Overload Condition of AC Power Grid

In the case of insufficient power of AC subsystem, these two types of hybrid microgrid are studied. As shown in Fig. 8, when $t=5s$, the AC load of the AC subsystem increases from 1MW to 2.3MW, which means that the AC subsystem overloads 0.3MW.

In addition, in this case, as shown in Fig. 9, the DC subsystem is under- to provide 1.6 MW power for its DC load. Therefore, the bidirectional converter provides power from DC microgrid to AC microgrid to compensate for the power shortage of AC microgrid. As shown in Fig. 10, the power from DC subsystem to AC subsystem is 0.3 MW.

It is clear that the power supply from the DC subsystem to the AC subsystem keeps both sub-grids within their rated power limits and prevents all DGS units in the AC / DC hybrid microgrid from being overloaded.
The power generated by the DGS of the AC subsystem is shown in Fig. 11. Due to the dependence of the load voltage, the power of the AC power supply is less than the rated power, which is 1 MVA. Considering that the VSM control of BC makes all DGS units follow SM behavior only when power exchange or transient disturbance from DC to AC or from AC to DC subsystems, this advantage of VSM is reflected in this case.

3.3. Power exchange from AC to DC microgrid under DC grid overload

In this case, the AC voltage at the common coupling point (PCC) is affected by the power exchange between AC and DC, resulting in the decrease of AC load voltage. Therefore, the proposed VSM control of BC supply AC voltage is helpful to improve the performance of hybrid microgrid. In this case, both subsystems work under low load conditions. As shown in Figures 12 and 13, the AC subsystem load power is equal to 1 MW, while the DC subsystem load power is equal to 1.5 MW.

When \( t=5 \) seconds, the DC load increases from 1.5 MW to 2.3 MW, which indicates the overload of DC DGS unit. In order to maintain a better operation of DC microgrid, the BC supplies power from AC microgrid Fig. 14 shows the power exchange from AC to DC subsystems through BC.
Fig. 14 Power exchange of BC under AC microgrid overload condition

Reference Fig. 12, due to the load voltage dependence of AC load, the power exchange between AC and DC microgrid has an impact on AC microgrid and the lack of inertia causes PCC voltage fluctuations. Therefore, the proposed VSM control of BC provides an effective control to solve this problem, thus reducing the PCC voltage drop in the process of AC to DC microgrid power exchange. In addition, the proposed controller is integrated into BC to improve the power quality of hybrid microgrid. In fact, when only the current controller circuit is used, the total power transfer fluctuates due to the sensitivity of the droop controller. This fluctuation may reach the stable boundary or violate the demand standard. Therefore, as shown in Fig. 15, the proposed BC controller can eliminate this fluctuation due to the inertia of the BC controller loop.

Fig. 15 AC voltage on PCC

4. Conclusion
This paper introduces the integrated circuit control based on VSM in AC/DC hybrid microgrid. VSM control strategy ensures accurate bidirectional power flow between AC and DC subnets under different loads. In this paper, two different control structures of hybrid microgrid based on BC are studied and compared. The experimental results show that under different load conditions, the VSM algorithm is more effective than the current control loop due to the reduction of AC voltage load. The simulation results show that the proposed control strategy improves the performance of the whole hybrid microgrid. Through the simulation test system in PSCAD/EMTDC environment, the influence of VSM control algorithm on hybrid microgrid is verified.

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