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The no-deviating control of frequency and voltage in AC/DC mixed micro-grid

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Abstract

Combining with both the advantages of AC micro-grid and DC micro-grid, AC/DC hybrid micro-grid is gaining more and more extensive researches and applications, and the core component is the interlinking converter. The alternating current frequency of existing AC/DC hybrid micro-gird and DC bus voltage are deviating regulated, and in terms of this, this paper raised another virtual synchronous generator control strategy about interlinking converter. This strategy can not only make mixed micro-grid responded more smoothly in the process of load handoff process, but also can maintain the alternating current frequency of the mixed micro-grid and ensure DC bus voltage operate in rated value. Moreover, this paper has verified the correctness and practicability of the proposed control strategy through the model built by PSCAD simulation software.

Keywords: *AC/ DC hybrid micro-grid, Interlinking converter; Virtual synchronous generator, Deviating regulation*

1. INTRODUCTION

Micro-grid can be divided into AC and DC micro-grid in terms of structure.[1-2] Combining with both advantages of AC and DC micro-grid, AC/DC mixed micro-grid has gotten more and more attention.

There are some obvious advantages of the AC/DC hybrid micro-grid [3-4] : (1) Includes AC micro-grid and DC micro-grid, as well as interlinking converter (ILC), which connects the AC and DC micro-grid.[5-6].

The ILC control strategy in the AC/DC hybrid micro-grid is of great importance to maintain the power balance and stable operation in the hybrid micro-grid [7].

However, most of the proposed control methods are based on troop control, which inevitably leads to the deviation between DC bus voltage and AC bus frequency when the AC/DC hybrid micro grid

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stable operated in island mode. At the same time, the mixed micro-grid in island mode is a weak grid system, which means the voltage and frequency are sensitive to DG output and load fluctuation, and in turn the voltage and frequency fluctuation of the system would influence the stable operation of DG and load in the mixed micro-grid.

In terms of the above problems, this paper proposed a ILC control strategy based on control VSG, which can not only enhance the stability of AC/DC hybrid micro grid system, but also can realize no-deviating control of DC bus voltage and AC frequency. The control system proposed in the paper can realize the mixed grid switch between the grid mode and island mode of the AC/DC micro-grid smoothly, and what’ s more, its correctness and practicability has been verified through Simulation Verification.

2. STRUCTURE OF AC/DC HYBIRD MICROGRID

Figure 1 shows the typical structure of AC/DC hybrid micro-grid, which is composed of AC micro-grid, DC micro grid and ILC. In each subnet, the photovoltaic and wind power and other renewable energy sources are connected to the corresponding bus lines through their respective transformation devices, and directly supply the local load. At the same time, static transfer switch (STS) is installed on the AC bus line, through which the AC/DC micro-grid can switch between grid and island grid mode.

3. OPERATION MODES OF AC/DC HYBIRD MICROGRID

The AC/DC hybrid micro has two modes: grid and island mode according to whether the static switch STS are closed or not.

3.1 grid mode

In the grid mode, for the AC micro-grid connected to the Large power grid, the frequency and voltage of the AC micro-grid are supported by the large power grid. For the DC micro-grid, it also connects to the Large power grid through ILC. At this time, any power imbalances within AC/DC micro-grid are adjusted by the bulk power grid, and the role of ILC is to maintain the power balance of DC bus voltage stability and power frequency. When there are surplus frequency in DC hybrid micro-grid, ILC works in contravariant mode, transmitting the surplus power from DC micro-grid to AC micro-grid. When the power of DC micro-grid is in short supply, ILC works in rectification mode, transferring the power to DC micro-grid from AC micro-grid

If the power loss of ILC is ignored, the watt level and flow direction of the DC hybrid micro-grid can be expressed as follows:

DC micro-grid:

$$P_{ILC}=\sum_i P^i{}_{dc-load}+P_{dc}{}^{loss}-\sum_i P^i{}_{dc} \tag{1}$$

AC micro-grid:

$$P_{grid}=\sum_i P^i{}_{ac-load}+P_{ac}{}^{loss}-P_{ILC}-\sum_i P^i{}_{ac} \tag{2}$$

In the formula, P_{ILC} represents the transmission power of ILC. And we make the power flow from DC hybrid micro-grid positive power. The P_{grid} represents the power transmitted by the bulk power grid, and the positive power represents the output power. $P^{\mathrm{i}}_{\mathrm{dc\text{-}load}}$ and $P^{\mathrm{i}}_{\mathrm{ac\text{-}load}}$ respectively represents the load of AC and DC hybrid

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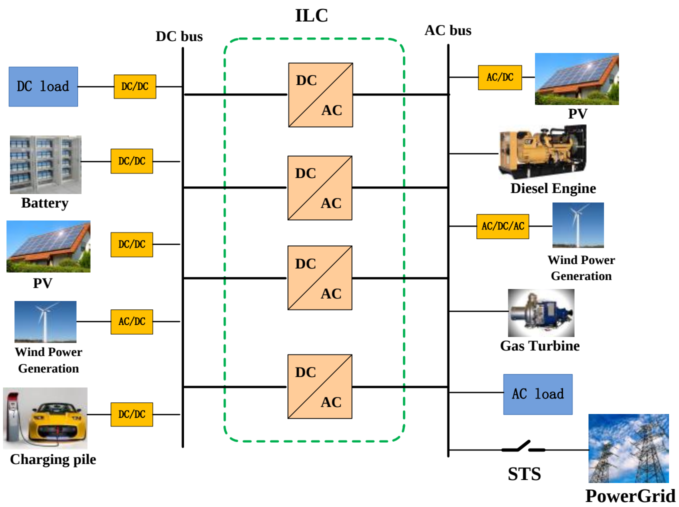

Fig. 1 Structure of AC/DC Hybird Microgrid

micro-grid. P^{dc}_{loss} and P^{ac}_{loss} represents the power loss within DC and AC micro-grid. P^{i}_{dc} and P^{i}_{ac} respectively represents the generated power of distributed generation of DC and AC hybrid micro-grid.

3.2 Island mode

In island mode, the power is supplied by the DG in the mixed micro-grid. To maintain the stable operation of the grid, ILC should adjust the working mode of itself according to the operation state and energy requirement.

Mode 1: Both the DC and AC micro-grid are operated with light load, and the power output from DG in each grid can meet the load requirements. At this time, ILC is in standby mode and does not need to transmit power.

$$P_{grid} = P_{ILC} = 0 \tag{3}$$

$$\text{DC micro-grid:} \sum_i P^i{}_{dc-load} \le \sum_i P^i{}_{dc} \tag{4}$$

$$\text{AC micro-grid:} \sum_i P^i{}_{ac-load} \le \sum_i P^i{}_{ac} \tag{5}$$

Mode 2:DC micro-grid operated in light load,but AC micro-grid in heavy load.At this time,ILC should work in converter mode,transmiting power from DC micro-grid to AC micro-grid to replenish the needed power.

$$P_{grid} = 0, P_{ILC} = \sum_i P^i{}_{ac-load} + P_{ac}{}^{loss} - \sum_i P^i{}_{ac} \tag{6}$$

$$\text{DC micro-grid:} \sum_i P^i{}_{dc-load} < \sum_i P^i{}_{dc} \tag{7}$$

$$\text{AC micro-grid:} \sum_i P^i{}_{ac-load} > \sum_i P^i{}_{ac} \tag{8}$$

Mode 3:DC micro-grid is in heavy load,and AC micro-grid is in light load,so ILC works in rectification mode,and the power needed of the DC micro-grid was supplied by the AC micro-grid.

$$P_{grid} = 0, P_{ILC} = \sum_i P^i{}_{dc-load} + P_{dc}{}^{loss} - \sum_i P^i{}_{dc} \tag{9}$$

$$\text{DC micro-grid:} \sum_i P^i{}_{dc-load} > \sum_i P^i{}_{dc} \tag{10}$$

$$\text{AC micro-grid:} \sum_i P^i{}_{ac-load} < \sum_i P^i{}_{ac} \tag{11}$$

4. THE ILC CONTROL STRATEGY OF AC/DC MIXED HYBRID MICRO-GRID

4.1 The ILC control strategy on the basis of VSG

To make up for the disadvantages of traditional troop control strategy,this paper put forward a kind of ILC control strategy based on VSG.It can improve inertia of the grid without taking normalization to the DC bus voltage and AC micro-gird frequency,because it can generate the reference value of ILC output power by collecting the DC bus voltage and AC frequency after a certain process directly.

The p-f mathematical expression of VSG is as follows.

$$\begin{cases} J\dfrac{d\Delta w}{dt} = P_m - P_{ILC} - D\Delta w \\ \Delta w = w - w_N \end{cases} \tag{12}$$

In the formula,J is the moment of inertia of VSG,w_N and w are the grid rated angular frequency and VSG angular frequency respectively.The P_m and P_{ILC} are respectively the mechanical power and transmission power of VSG,and D is the damping coefficient.

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In order to eliminate the deviation between DC voltage and AC frequency caused by droop control,VSG's mechanical power P_m consists of two parts.

$$P_m = P^*_{dc} + P^*_{ac} \tag{13}$$

$$P^*_{dc} = (k_{dc} + \frac{k_{idc}}{s})(U^*_{dc} - U_{dc}) \tag{14}$$

$$P^*_{ac} = (k_{ac} + \frac{k_{iac}}{s})(w_N - w) \tag{15}$$

In the formula,P^*_{dc} and P^*_{ac} are required power to eliminate deviation between DC voltage and AC frequency.K_{DC},k_{idc} and k_{ac},k_{iac} respectively corresponds to PI ratio coefficients and integral coefficients.

In steady state,because of the PI regulator,the DC voltage U_{dc} and AC frequency f would keep stable to rated value,we can get $d\Delta w/dt=0$,and from formula(12),we can get:

$$P_m = P^*_{dc} + P^*_{ac} = P_{ILC} \tag{16}$$

That means the watt level and direction are co directed by the operation state of DC micro-grid and AC micro-grid.

The reactive voltage regulation equation of VSG is as follows:

$$E = (K_v(Q_N - Q) + U_N - U_m)(k_p + \frac{k_i}{s}) \tag{17}$$

In equation (17), Q_N is the VSG reactive power setting value, the actual output reactive power of VSG is Q, K_v is the voltage adjustment coefficient, U_N is the rated effective value of the VSG terminal voltage, and Um is the actual terminal voltage RMS. The voltage regulation of the VSG mainly adjusts the VSG output voltage by the deviation of the output reactive power and the amplitude of the output voltage, and obtains the amplitude E of the VSG excitation electromotive force after passing through the PI regulator. After adjustment, the VSG can keep the output voltage of the terminal stable at a relatively reasonable value. The block diagram for the entire control strategy is shown F.ig 2.

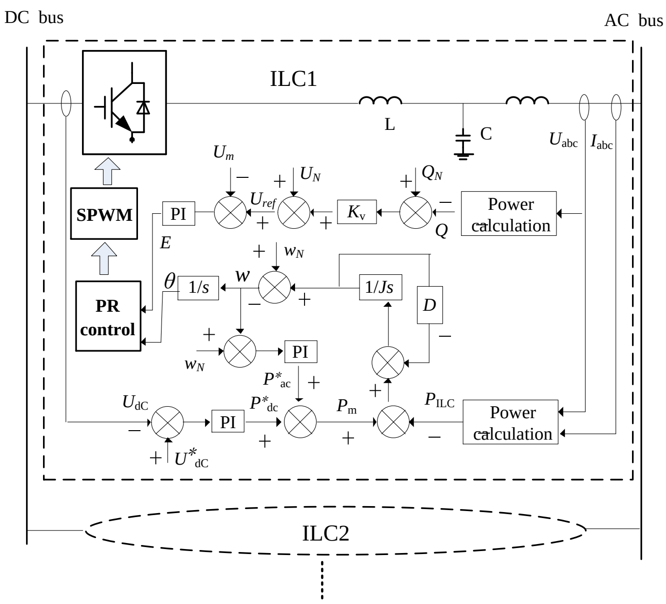

Fig. 2 Control strategy of ILC based on VSG

5. THE SIMULATION ANALYSIS

In order to verify the effectiveness of the ILC control strategy based on VSG proposed in this paper, the simulation model of the AC and DC hybrid micro grid is built in the PSCAD environment as shown in Fig.3.

The rated voltage of DC micro grid bus is 800V, AC micro grid rated frequency is 50Hz, AC and DC bus are connected by an ILC. Simulation parameters are shown in the following table.

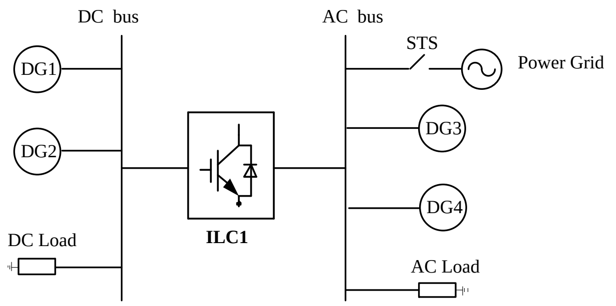

Fig. 3 Simulation model of the tested AC/DC hybrid microgrid

Tab. 1

Simulation parameters of hybrid AC/DC microgrid

Rated capacity of DC power P_{dc}/kW	40

Rated capacity of AC power P_{ac}/kW	50
The moment of inertia $J/Kg/m^2$	2
Damping coefficient $D/_{N\cdot m\cdot s/rad}$	10
PI ratio of DC voltage K_{dc}	20
PI integral coefficient of DC voltage K_{idc}	0.5
PI ratio of AC frequency K_{ac}	5
PI integral coefficient of AC frequency K_{iac}	0.3

5.1 grid mode

At beginning, DC micro-gird was loaded 40kW, while AC 60kW. Because it was connected to the bulk power grid, the frequency of AC bus is always 50Hz, as shown in Fig.4 (b). In order to make full use of DG, the DC and AC power sources are running at the maximum power, as shown in Fig.4(d)(g), P_{ac}= 50kW ,P_{dc}= 40kW.The required power of the AC micro grid is supplemented by the large power grid, so the P_{grid}= 10kW, and the power output from the DC power supply can meet the load requirements, so the voltage of DC bus voltage is stable at the rated value of 800V, as shown in Fig.4 (a).At this point, ILC does not need to transmit power and is in standby mode, that is, P_{ILC}= 0kW, as shown in Fig4(c)

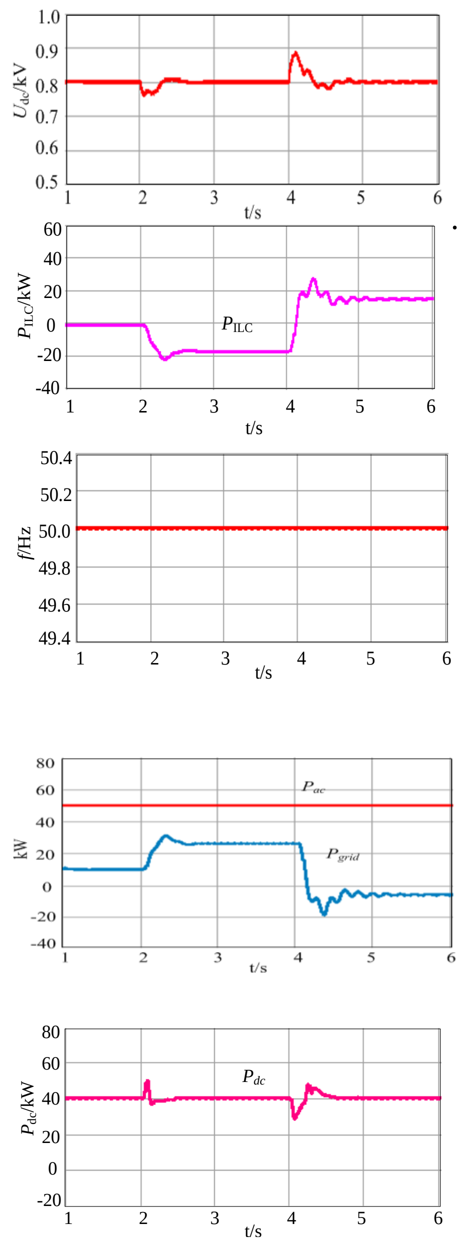

Fig. 4 AC/DC hybrid microgrid operate in grid mode

In the 2 second,16 kw load was increased to the DC micro-grid side, surpassing its maximum power output, and the DC bus voltage drop, so the ILC switched from standby mode to the rectifier mode, supplying power to DC side from the bulk power grid, and then the DC bus voltage began to rebound to the rated value. The stable value are: P_{ILC} =-16 kw, P_{grid} = 26kw.During the whole process, the AC power supply will always operate at the maximum power. The output power of DC power supply will

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appear some fluctuation when the DC bus voltage changes, but it became stable in no time. In the 2 second, 32 loads was decreased from the DC micro-grid side, and the changing process may be similar to the process when the load increased, the difference was that ILC work on the converter mode, transmitting surplus power to the bulk power grid from DC micro-grid, and the values in stable state are: P_{ILC} = 16 kw,Pgrid = - 6 kw.

5.2 grid mode

5.2.1 DC micro-grid overload, AC micro-grid light load

At beginning, DC micro-grid loaded 40 kw, AC loaded 30 kw load. Both power supply output power can meet the required load, so the AC bus frequency and DC bus voltages are at the rated power, as shown in fig.5 (d), P_{ILC}=0kW, AC power output P_{ac}= 30kW, as shown in fig.5 (c).

In the 2 second, 16kw was increased to the DC micro-grid, surpassing the maximum power output of the DC micro-grid, so the DC bus voltage drop. After the

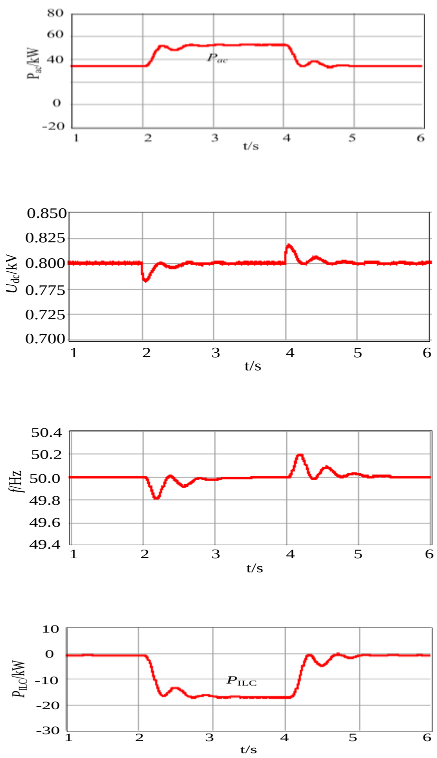
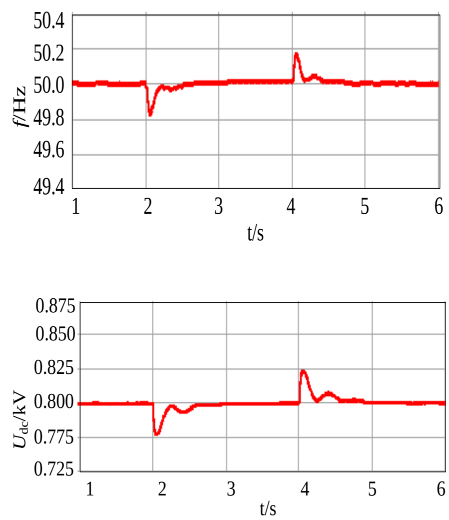


Fig. 5 AC/DC hybrid microgrid operate in island mode

ILC detect the drop, it began to switch from standby mode to rectifier mode.In contrast to the grid mode, the power was supplied by AC micro-grid. In terms of AC micro-grid. It equivalent to that the load was suddenly increased in this side, since ILC is controlled by VSG, it can provide a certain inertial support for the frequency of AC micro-grid, so the frequency of it decreased slowly. However, the AC frequency and the DC bus voltage would recover to the rated value as the power within the AC and DC micro-grid reach the balanced state.At stable state, P_{ILC}= -16kw, P_{ac}= 46kW. In the 4 second, 16 kw was decreased from the DC micro-grid, and this changing process may be similar to that process when the load increased, the different point was that due to DC power supply can satisfy the requirement of its requirement, ILC work in standby mode, and values at stable state are: P_{ILC} = 0 kw, P_{ac} = 30 kw.

5.2.2 DC micro-grid is light load, AC micro-grid is overload

At the initial moment, the DC micro-grid loaded 15kW, AC micro-grid loaded 50kW, and ILC worked in standby mode, P_{ILC}= 0kW, P_{dc}= 15kW, and the simulation waveform is shown in fig 6 .



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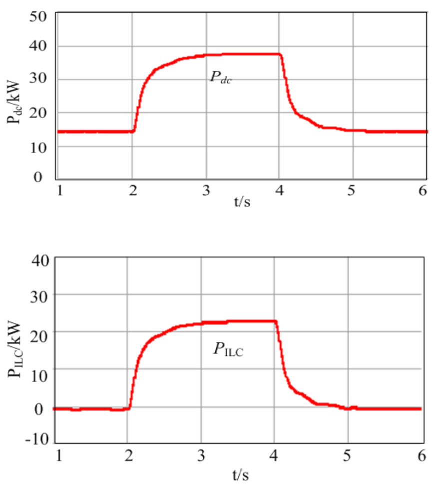

Fig. 6 AC/DC hybrid microgrid operate in island mode

In the 2 second, 22 kw was increased to the AC micro-grid, making the AC micro-grid overload. The process is similar to the previous process when the DC micro-grid overload, but the difference was that the ILC worked on the converter mode, the power AC micro-grid needed was supplied by the DC micro-grid. In the stable state, the AC frequency and the DC bus voltage recover to the rated value: P_{ILC} = 22 kw, P_{dc} = 37 kw. In the 4 second, the loaded power decreased 22 kw, and this changing process was similar to the process when the load increased in the 2 second. Due to the AC power can meet the its requirement, ILC worked in standby mode, the values in the stable state are: P_{ILC} = 0 kw, P_{dc} = 15 kw.

CONCLUSION

This paper put forward a ILC control strategy based on VSG, and verified the effectiveness of the proposed control strategy through the model built by PSCAD simulation software. The conclusions are as follows:

1) In the grid mode, any imbalance within the AC and DC hybrid micro-grid are adjusted by the bulk power grid, and each AC and DC power source is operated at their maximum power, thus increasing the use ratio of distributed energy.

2) In island mode, the ILC can switch operating mode automatically and make power regulation quickly by accessing the operating state of the mixed micro-grid according to the characteristic signal change of the mixed micro-grid kneck (DC bus voltage and AC micro-grid frequency), ensuring the stable operation of the mixed micro-grid.

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