International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID:1174

THE DESIGN OF AC/DC HYBRID EXPERIMENTAL SYSTEM CONSIDERING NEW ENERGY ACCESS

Author Zhensheng WU, Author Huiyuan ZHANG*

Beijing Jiaotong University, Beijing, China

ABSTRACT

The global energy Internet is one of the effective ways to solve the global energy crisis and environmental problems. The AC/DC hybrid power distribution network can accommodate a variety of new energy sources, providing conditions for the wide access of distributed power sources and new loads. The important development direction of the power grid form, and the wide-area interconnection of power systems with different voltage levels and different regional networks can be realized, which is the basis for building a global energy Internet. Based on the grid-connected characteristics of new energy sources, this paper proposes a design of AC/DC hybrid experimental system considering new energy access, studies the key equipment requirements of AC/DC hybrid test system, and designs the topology of each key device and its control strategy. Relying on the constructed AC/DC hybrid experimental system, this paper was verified.

Keywords: AC and DC, new energy, flexible ring network device, distributed power supply, islanding

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
Symbols	
n	Year

1. INTRODUCTION

With the development of intelligent micro-grid and renewable energy power generation, AC-DC hybrid test has become one of the hot topics of research.

Many European countries, the United States, Japan and China have built corresponding physical and experimental platforms for AC and DC hybrids. Several countries in the European Union, such as Greece, Germany, France, Spain, Italy, etc., have established test platforms based on AC/DC hybrids. The test system of German Demotec laboratory includes several small distribution networks. The system (single-phase photovoltaic-battery system, three-phase photovoltaic-battery-diesel system), can test various situations and can realize the reconstruction of the entire network, through the upper controller scheduling.

The AC-DC hybrid micro-network experimental platform has been established by the United States in several universities and multiple states. The typical reference is the DUIT experimental platform, which is the first commercial micro-network project in the United States, focusing on the multi-distributed power's penetration for distribution networks. The core issue of DUIT research is to analyze the impact of different types and quantities of distributed power supplies on the distribution network under different conditions.

In recent years, China's national key research and development plans such as "863" and "973" have been initiated to encourage and support research on the AC and DC interconnection technologies of various universities and research institutes. At the same time, with the large-scale integration of new energy sources, the access of distributed power supplies has a great impact on the power grid. In particular, the islanding effect has been brought by new energy sources. The island effect, that is, the large power grid trips due to power failure maintenance or human factors, and the new energy grid-connected power supply fails to detect the power-off state and cuts itself away from the main system. Eventually, the phenomenon of supplying power to the surrounding load forms a self-sufficient island. The existence of the islanding effect will cause many harms to the AC and DC power grid. Not only will the voltage and its frequency be out of control, but also the reclosing phenomenon will occur. More seriously, it will cause certain confusion and bring about a series of faults.

Therefore, combining with the characteristics of new energy grid-connected, this paper proposes a design of AC/DC hybrid experimental system considering new energy access, which studies the key equipment requirements of AC/DC hybrid test system, designs the topology of each key device and its control strategy. Relying on it, the constructed AC/DC hybrid experimental system was verified.

2. PAPER STRUCTURE

2.1 The design of hybrid experimental system

In the design process of the AC-DC hybrid experimental system, VSC plays an important role as the core unit. Among them, there are four main control methods of VSC in the AC-DC hybrid experimental system: ① set Ps, set Qs; ② set Ps, set Us; ③ set Udc, set Qs; ④ set Udc, set Us. In the power flow calculation, the VSC using the ① and ② control modes can be regarded as the PQ node, and the ③, ④ control mode is the PV node. That is to say, the dividing boundary of the AC and DC subsystems in the alternating iterative method of the distribution network is set at the common connection point. That is, the commutating reactor and the equivalent resistance are also divided into the DC subsystem side. In the calculation of the power flow of the AC subsystem, according to the control strategy of the VSC, the common connection point is equivalent to the PQ or PV node. Thereby, existing AC power flow calculation method can be directly used.

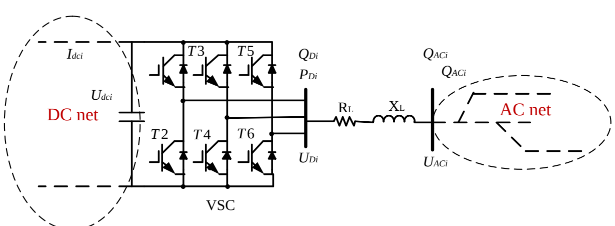

Fig 1 Grid-connected device model

The power flow calculation model of VSC is shown in the figure above. In the figure, X_L and R_L are the equivalent inductance and equivalent resistance of the commutating reactor respectively. U_{ACi}, P_{ACi}, Q_{ACi} are the commutator's common connection point *i's* voltage of AC side, active power and reactive power of respectively; U_{Di}, P_{Di}, Q_{Di} are the converter *i's* voltage of AC side, the injected active power, and the injected reactive power respectively. U_{dc} and I_{dc} are the inverter *i*'s the DC voltage of the DC side and current respectively. The VSC node variables are as follows:

$$\begin{cases} U_{Di} = \dfrac{M_i}{\sqrt{2}} U_{dci} \\ P_{Di} = U_{dci} I_{dci} \\ P_{ACi} = \dfrac{R U_{ACi}(U_{ACi} - U_{Di}\cos\theta_i) + X_L U_{ACi} U_{Di} \sin\theta_i}{R_L^2 + X_L^2} \\ Q_{ACi} = \dfrac{X_L U_{ACi}(U_{ACi} - U_{Di}\cos\theta_i) - R_L U_{ACi} U_{Di} \sin\theta_i}{R_L^2 + X_L^2} \end{cases} \tag{1}$$

Therefore, the control parameter variable of each VSC is:

$$X_{VSCi} = [U_{dci}, I_{dci}, \theta_i, M_i] \tag{2}$$

The value of X_{VSC} needs to be solved in the power flow calculation.

2.1.1 Key devices

The design of AC/DC hybrid experimental system includes: AC voltage simulation experimental zone, system grid experimental zone, load simulation experimental zone, and test equipment experimental zone. Each part is allocated corresponding according to the implemented functions and requirements.

AC voltage simulation experimental area simulate laboratory's four-way power supply, which include a 10MVA MMC-based AC voltage regulator, three 8000kVA (self-cooling) isolation transformer, and 23 supporting 10kVKYN28 switchgear.

The system grid experimental area establish 20 sets of 10kV switchgear, 40 ring network cabinets, simulating 4 substation 10kV busbars and 8 cable junction rooms. By changing the cable connection or operating the ring network cabinet switch, we can flexibly construct single ring network, double ring network, and other typical AC-DC hybrid physical test network.

Two sets of AC load groups and one set of plant load group were constructed in the load simulation experimental area. Among of which, 1 set of AC load regulation device and 2 sets of photovoltaic power generation system (500kW) are conneted to the low voltage side of the AC load group.

The distributed power supply, which are used to simulate new energy access, includes: 4 sets of 1kW wind power generation system; 2 sets of 250kW photovoltaic power generation system and 5 sets of 20kW photovoltaic power generation system, totaling 600kW. The above devices are all connected to the AC, among of which, 5 sets of 20kW photovoltaic power generation systems are equipped with DC interfaces connected to the DC load switching cabinets, which can realize free switching of AC grid-connected and DC grid-connected.

2.1.2 System circuit topology

The voltage level of the experimental system AC system is 10kV, and single-ended power supply capacity is 10MVA. According to IEC standard and DC traction system voltage standard, DC system voltage level is selected as 750V, and each port capacity is 500kW.

The main circuit topology used in the experimental system is shown in the figure below.

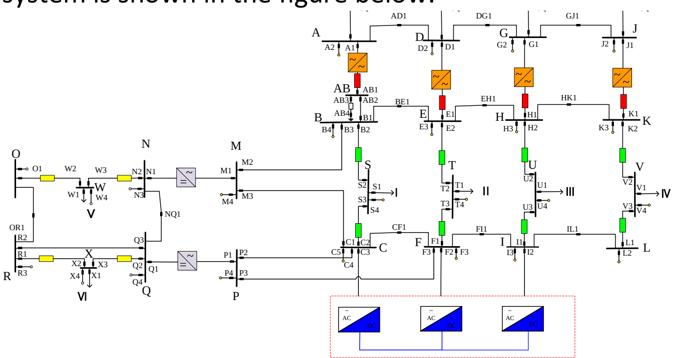

Fig 2 Magnetization AC voltage simulation and AC / DC grid test area

AC/DC hybrid experimental system can realize four kinds of AC/DC hybrid distribution network topology (AC and DC lines without contact, AC and DC lines with contact, AC line with DC load through flexible DC device, AC line interconnecting DC line through flexible DC device). The four distribution network topologies are shown below:

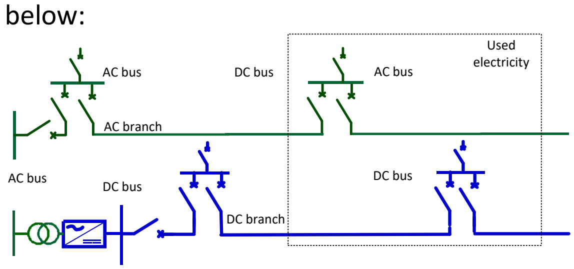

Fig 3 Typical connection mode for AC and DC lines without contact

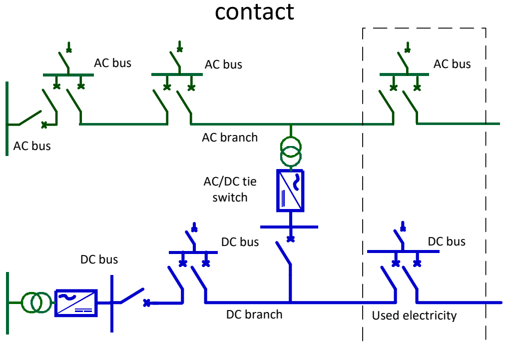

Fig 4 Typical connection patterns of AC and DC lines with contact

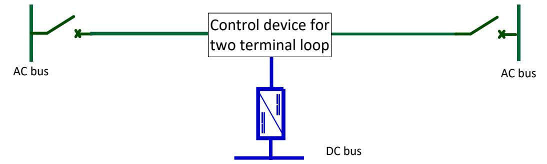

Fig 5 AC line with DC load through flexible DC device

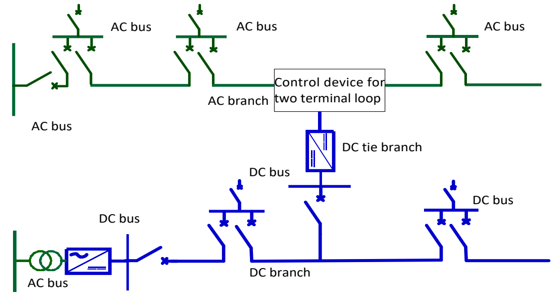

Fig 6 AC line interconnecting DC line through flexible DC device

2.1.3 Experimental system function

The AC/DC hybrid experimental system is equipped with voltage measuring devices at all busbar nodes, and all incoming and outgoing line switch nodes are equipped with current measuring devices. The AC voltage simulation experimental area is used to simulate the real grid power supply; the system grid experimental area can realize four or more distribution network grid structures through different switch combinations; the power feedback area is used for the power feedback type analog load with power Provides feedback to the grid, powering local loads, and residual power to the Internet; simulation of new energy access in the load simulation experimental area.

Considering the problems caused by new energy access, the AC/DC system uses digital simulation to simulate various processes of the power system and access the actual physical devices for the test project. The software module of the hybrid test system can also generate various custom waveforms. These voltage and current signals are sent to the actual device through the power amplifier device interface for system failure analysis and harmonic analysis.

The test system can test the operation and fault conditions that the new grid-connected device of AC/DC hybrid distribution network may encounter in the real distribution network.

(1) Normal start and stop experiments

(2) Power quality testing

(3) Control mode smooth switching experiment

(4) Active and reactive control experiments

(5)Emergency shutdown experiment

(6) Loss experiment

(7)Experiments on grid-connected control strategies for suppressing negative sequence currents

(8) Grid low voltage ride through and high voltage ride through experiments

(9) Islanding conversion experiment

2.2 AC-DC multi-source collaboration strategy

This paper, considering the new energy access, design the load link to simulate the characteristics of wind power and photovoltaic output, simulate the external characteristics of the energy storage device, simulate the typical electrical load characteristics, and simulate the disturbance of the load to the power grid, in order to realize the AC and DC hybrid experimental system design. The following figure shows the simulated load design:

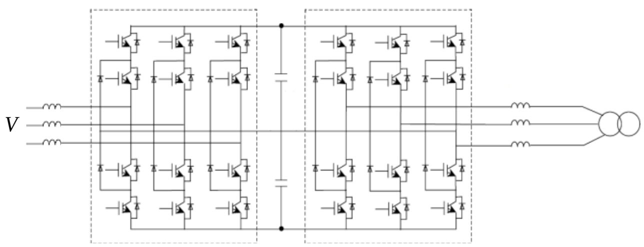

Fig 7 Simulated load design

Considering the many effects of new energy access to AC/DC hybrid power grid, the AC/DC multi-source synergy strategy is studied. And the control strategy verification is carried out through the AC/DC multi-source collaborative optimization scheduling strategy experiment and the mutual support experiment of DC and AC network.

2.2.1 AC/DC multi-source coordinated scheduling experiment

Because of the new energy access, AC/DC hybrid distribution network is with different distributed power supply ratio and different grid structure. Therefore, we design the AC/DC multi-source coordinated scheduling experiment, in order to test the multi-source coordinated scheduling strategy. The experiment can achieve many optimization goals which include the lowest system network loss, the highest utilization rate of renewable energy and minimum load-to-valley difference, which also can compare the economics of various scheduling strategies.

2.2.2 AC/DC hybrid distribution network support experiment

Considering the access of new energy, when AC side load or distributed power supply has large fluctuations (such as step change of active and reactive load), AC/DC hybrid distribution network supports experimental can test the DC side control strategy, and suppresses voltage fluctuations of AC side by playing the DC side support role.

2.3 Experimental scheme verification and simulation analysis

Considering the problems caused by the integration of new energy sources, this paper builds a photovoltaic power generation simulation module through simulation platform, and simulates the performance of AC/DC hybrid experimental system after accessing photovoltaic power generation, so as to realize the simulation verification of AC/DC multi-source synergy strategy. Photovoltaic power generation consists of a DC-DC booster circuit and a three-phase grid-connected converter. The DC-DC booster circuit keeps the output voltage constant, and the three-phase grid-connected converter realizes grid connection and control output power.

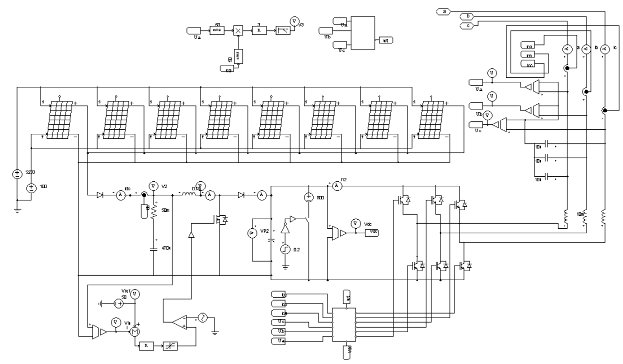

Fig 8 Photovoltaic power plant simulation module

By constructing a photovoltaic power generation module simulation module as a new energy access system, ensure that the photovoltaic power generation simulation module can simulate the photovoltaic grid-connected characteristics, which can be used as an auxiliary for AC/DC multi-source collaborative strategy verification.

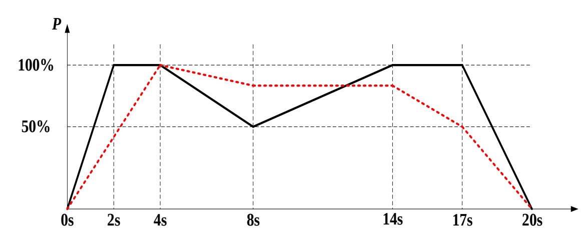

Fig 9 Given three-phase unbalanced load curve

At the same time, the test load simulation function of the hybrid experimental system was tested, and the test results are shown in the figure above. It can be seen that the simulation of a given load curve is completed, including the simulation of three-phase unbalanced loads.

Next, for the simulated load device of new energy access, we simulated the constant power load and the constant impedance load. The experimental results are shown in the following table.

TABLE 1
Simulation of constant power load

Number	Given value(kW)	Actual value(kW)	Error(kW)	Error rate
1	160	162.8	2.8	1.75%
2	200	203	3	1.75%
3	300	305	5	1.7%
4	400	407	7	1.75%
5	500	509	9	1.8%

TABLE 2
Simulation of constant impedance load

Number	Given value(Ω)	Actual value(Ω)	Error(Ω)	Error rate
1	Z=0.75	Z=0.73	0.02	1.8%
2	Z=1.5	Z=1.47	0.03	1.8%

It can be seen from Table 1 and Table 2 that the device can better simulate the constant impedance and constant power load, and the steady state error does not exceed 1.8%.

Using the test load simulation device, the load condition can be quickly adjusted, and the dynamic response test of the load simulation is completed, and the dynamic adjustment time does not exceed 17 ms.

Then, the AC-DC hybrid experimental system is going to power-on test and AC charging, which is divided into three stages: uncontrolled charging with resistance, uncontrolled charging with resistance bypass, and active charging with AC. The figure below shows the charging waveform.

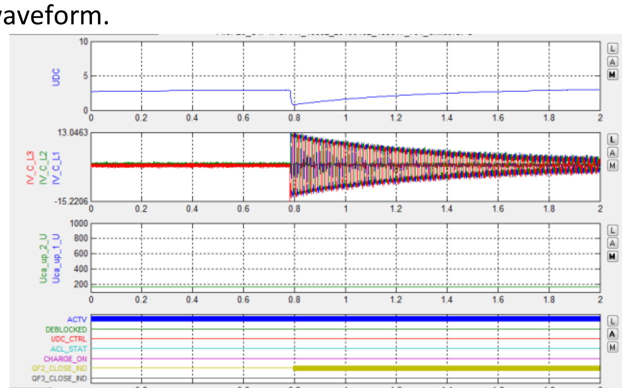

Fig 10 Charging waveform

It can be seen from the charging waveform that the AC-DC hybrid experimental system is successfully charged and can be started, paving the way for subsequent verification of the multi-source synergy strategy.

Next, considering the islanding problem brought by the new energy access to the AC/DC hybrid system, the new energy such as photovoltaics are connected to the system to simulate the islanding effect. And the multi-source synergy strategy of the AC/DC hybrid experimental system is verified to realize the islanding-to-reciprocal dynamic performance.

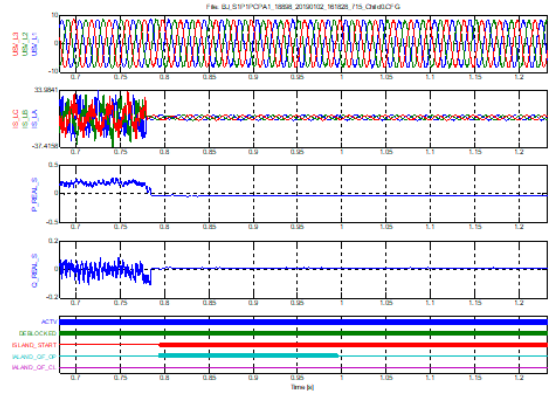

Fig 11 Networking to islanding waveform

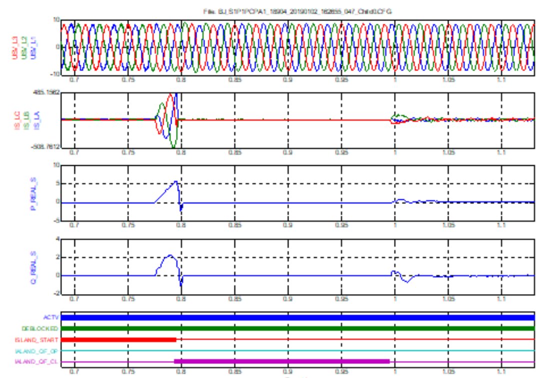

Fig 12 Islanding to networking waveform

The test results show that when the multi-source synergy strategy realizes the interconnection of islanding, the harmonic voltage does not appear in the AC voltage, and the conversion process is stable.

2.4 Discussion

In this paper, we propose a design of AC/DC hybrid experimental system considering new energy access, studie the key equipment requirements of AC/DC hybrid test system, design the topology of each key device and its control strategy. Although there are important discoveries revealed by these studies, there are also limitations due to the complexity of AC/DC hybrid experimental system. Thus, future research should focus on more meaningful exploration, relying on the constructed AC/DC hybrid experimental system.

3. CONCLUSIONS

According to the characteristics of AC/DC hybrid distribution network, this paper designs AC/DC hybrid experimental system, refines the key equipment requirements of AC/DC hybrid experimental system, designs the topology structure and control strategy of key equipment, and builds the simulation model of DC grid test for simulation analysis. Design experimental projects for the operation and fault conditions that the new grid-connected devices may encounter in the real distribution network, test the functions of the tested devices and verify their performance, which can ensure that the tested devices can be connected to the grid safely after the experiment. At the same time, combines AC/DC hybrid distribution network topology (AC and DC lines without contact, AC and DC lines with contact, AC line with DC load through flexible DC device, AC line interconnecting DC line through flexible DC device), key devices and multi-source synergy strategy of new energy access, in order to verify the AC-DC hybrid experimental system. The research results can provide a demonstration means and platform for the subsequent construction of AC-DC interconnection projects. The established experimental system has certain applicability and can provide a basis for steady state calculation and related research of AC/DC hybrid systems.

REFERENCE

[1]CHI Yongning, YAO Liangzhong, ZHUANG Jun, et al. Research on Renewables-based DC Grid Demonstration System and Experimental Strategy [J]. Smart Grid, 2016, 4(8):811-823.（in Chinese）

[2]CHENG lin, TIAN liting, GE xianjun, et al. Multi-voltage grade AC-DC hybrid power supply test system with distributed power supply [J]. Electrical and electrical technology, 2019(2).(in Chinese)

[3]ZHANG yan. Islanding Detection technology Research DGs[D]. 2018.（in Chinese）

[4]Van Hertem D, Ghandhari M. Multi-terminal VSC HVDC for the European supergrid: Obstacles[J]. Renewable and sustainable energy reviews, 2010, 14(9): 3156-3163.

[5]Dodds S, Railing B, Akman K, et al. HVDC VSC (HVDC light) transmission–operating experiences[J]. Proc. CIGRE Session, Paris, France, 2010: 1-9.

[6]Marquardt R, Lesnicar A. New Concept for High Voltage-Modular Multilevel Converter PESC 2004 Conference[J]. Aachen, Germany.

[7]Knaak H J. Modular multilevel converters and HVDC/FACTS: A success story[C]//Power Electronics and Applications (EPE 2011), Proceedings of the 2011-14th European Conference on. IEEE, 2011: 1-6.

[8]CIGRE B4-37 Working Group. DC transmission using voltage sourced converters[J]. Paris, France: International Council on Large Electric Systems, 2004.

[9]CIGRE B4-39 Working Group. Integration of large scale wind generation using HVDC and power electronics[R]. Paris: Cigre, 2007.

[10]ZHOU hao, SHEN yang, LI min, et al. Research on Insulation Coordination for Converter Stations of Zhoushan Multi-Terminal VSC-HVDC Transmission Project [J]. Power System Technology,2013,37(4): 879-890.(in Chinese)

[11]Yuefeng Y, Jie Y, Zhiyuan H, et al. Research on control and protection system for Shanghai Nanhui MMC VSC-HVDC demonstration project[J]. 2012,4:1-6.

[12]SONG qiang, ZHAO biao, LIU wenhua. An Overview of Research on Smart DC Distribution Power Network [J]. Proceedings of The Chinese Society for Electrical Engineering, 2013, 33(25): 9-19.(in Chinese)

[13]Ito Y, Zhongqing Y, Akagi H. DC microgrid based distribution power generation system[C]//Power Electronics and Motion Control Conference, 2004. IPEMC 2004. The 4th International. IEEE, 2004, 3: 1740-1745.

[14]Lin C E, Tsai M T, Tsai W I, et al. Consumption power feedback unit for power electronics burn-in test[J]. IEEE Transactions on Industrial Electronics, 1997, 44(2): 157-166.

[15]Tsai M T, Tsai C. Energy recycling for electrical AC power source burn-in test[J]. IEEE Transactions on Industrial Electronics, 2000, 47(4): 974-976.