American Journal of Electrical and Electronic Engineering, 2020, Vol. 8, No. 2, 60-67
Available online at http://pubs.sciepub.com/ajeee/8/2/3
Published by Science and Education Publishing
DOI:10.12691/ajeee-8-2-3

Coordinated Control Method for AC/DC Distribution Network Based on Four-port Energy Router

Yongan Wang*, Junshuo Huang

Nanjing Normal University, Nanjing, Jiangsu China
*Corresponding author: 544906768@email

Received April 23, 2020; Revised May 25, 2020; Accepted June 01, 2020

Abstract With the large increase in DC load penetration rate of renewable energy and electric vehicles, the traditional AC distribution network has been unable to meet the requirements of load transfer and reliability, and the research on AC/DC distribution network has developed rapidly. This paper proposes a new coordinated control method for AC/DC distribution network, which aims to solve the coordination problem in various states of AC/DC distribution network. Based on the analysis of AC/DC distribution network characteristics, based on the characteristics of four-port energy router, an AC/DC distribution network model based on four-port energy router is established. Taking full advantage of the convenient operation and high reliability of the four-port energy router, the coordinated control method of the AC/DC distribution network in the normal working mode, operation mode switching and key equipment operation is proposed respectively, which can realize flexible access to the distribution network of renewable energy and DC load, comprehensively improve regional stability, and has high application value.

Keywords: *four-port energy router, AC/DC distribution network, coordinated control, renewable energy*

Cite This Article: Yongan Wang, and Junshuo Huang, "Coordinated Control Method for AC/DC Distribution Network Based on Four-port Energy Router." *American Journal of Electrical and Electronic Engineering*, vol. 8, no. 2 (2020): 60-67. doi: 10.12691/ajeee-8-2-3.

1. Introduction

In recent years, environmental pollution and energy crisis are threatening the rapid economic and social development of the country. For this reason, many countries are vigorously developing renewable energy to replace traditional fossil energy. Among many renewable energy sources, such as photovoltaic power generation, fuel cells, and electric vehicles, DC loads need to be connected to the grid through DC / AC inverters; and the power generated by wind turbine generators needs to be converted through AC / DC / AC conversion. Access to the traditional AC distribution network [1,2]. The problems of harmonics, resonance, and voltage fluctuations caused by the access of a large number of power electronic equipment to the distribution have brought great challenges to the comprehensive management capacity of the traditional AC distribution network [3]. Compared with the traditional AC distribution network, the line loss of the DC distribution network is only 15% to 50% of the AC network, and it does not involve phase, frequency control, reactive power, and AC charging current. It is convenient for distributed power supply, Energy storage devices, etc. [4,5,6,7,8]. However, because the current AC distribution network infrastructure is complete and AC loads exist in large numbers, it is difficult to replace the AC distribution network. Therefore, the AC-DC distribution network is an important development trend of the power grid, which can effectively improve the power quality, reliability and operation efficiency of the urban distribution system.

At present, there is still insufficient research on the coordinated control technology of the AC / DC hybrid distribution network. The existing control technologies are from the control method of the power electronic transformer between the AC and DC, and the layered scheduling coordinated control of the AC / DC hybrid distribution network. The research and construction of distribution network automation and distribution network terminals for AC and DC distribution networks are relatively few, and they still cannot meet the requirements of safety, reliability and economy of AC and DC distribution networks.

Therefore, based on the comprehensive analysis of the morphological characteristics of the AC and DC distribution network, a model of the AC and DC distribution network based on the four-port energy router is proposed. When the key equipment is in operation, the corresponding coordinated control methods are proposed respectively, which can achieve flexible access to distributed power and DC loads, and comprehensively improve the stability of the area.

2. Analysis of Network Shape Characteristics of AC / DC Distribution Network

The AC-DC hybrid distribution network with DC network is mainly divided into three forms: one is that the AC subnet and the DC subnet are independent of each other, and there is no contact; the second is that the AC subnet lines are connected to the DC load through a flexible DC device; Subnet lines are interconnected with DC subnet lines through flexible DC devices [9].

It can be seen that in such traditional networking, a large number of converter devices are required, and the overall operation control of the AC / DC distribution network depends on various power electronic converters, including DC / AC interconnection converters that undertake power flow control between AC and DC systems Stations, and DC / DC converters that complete the conversion of different DC voltage levels. In the AC-DC distribution network formed by this type of sectional connection wiring, corresponding converter devices must be installed in each converter line, and corresponding protection devices must be equipped. The monotonous two-port energy router increases the cost of all aspects of the network, and cannot solve the problems of bus synchronization at both ends. The safety and reliability of the system power supply are poor [10,11,12,13].

Therefore, using energy routers to upgrade and transform the AC and DC distribution network, multi-port energy routers can gather multiple feeders to achieve interconnection between different AC and DC lines.

3. Model of AC / DC Distribution Network Based on Four-port Energy Router

3.1. Four-port Energy Router Model

The physical essence of the energy router is a multi-level power electronic converter, and its core module is a power electronic transformer, which is a combination of power electronic conversion technology and electromagnetic induction technology to realize the conversion of one power feature into another power feature Power electronic equipment [14]. Traditional energy routers are divided into two categories based on whether their topology contains DC isolation links: back-to-back secondary structure and tertiary structure. Due to its capabilities of AC and DC flexible interconnection, distributed power and plug-and-play functions of energy storage units, fault isolation, etc., it is currently widely used in the construction of AC and DC distribution networks.

The topology diagram of the four-port energy router proposed in this paper is shown in Figure 3. The multiport structure is an important advantage of the energy router. The four-port router connects the common voltage level busbars of the medium and low voltage distribution network. Among them, the medium-voltage AC port is mainly used as a port connected to the 10KV AC distribution network; the low-voltage AC port is mainly used as a power source for various 380V AC loads; of the two low-voltage DC ports, the ± 750V DC port is mainly used as an energy storage device, distributed The connection ports of DC devices such as power supplies and electric vehicle charging devices. The ± 375V DC port is mainly used as a connection port for energy storage and electronic highways.

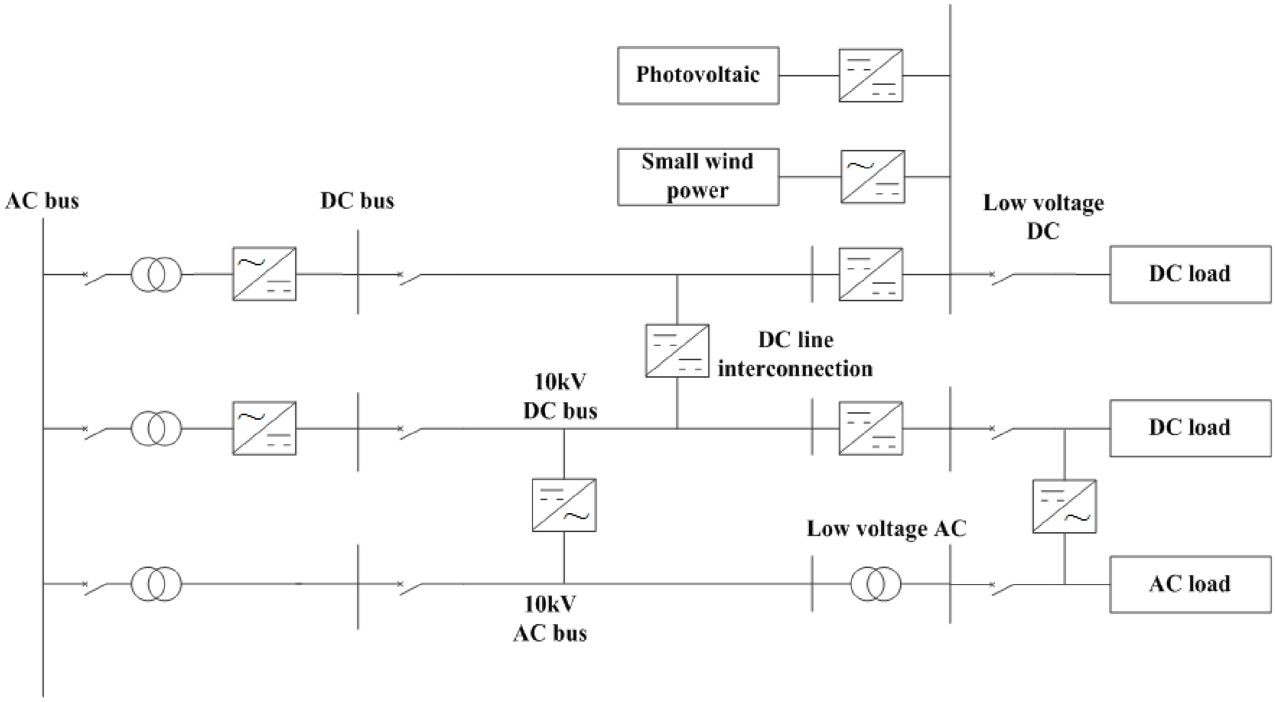

Figure 1. Typical Network Form of Medium Voltage AC/DC Distribution Network with DC Network

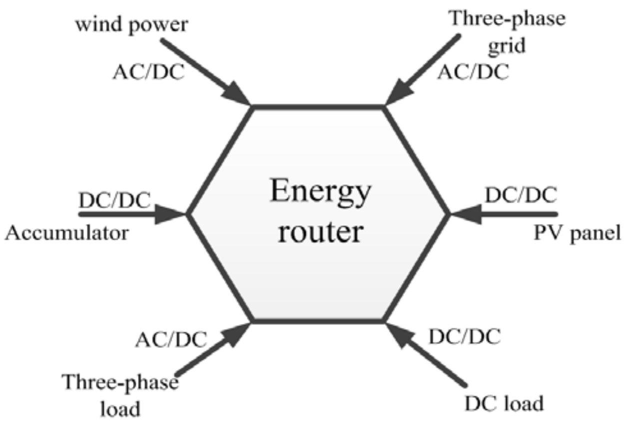

Figure 2. Conceptual graph of energy router

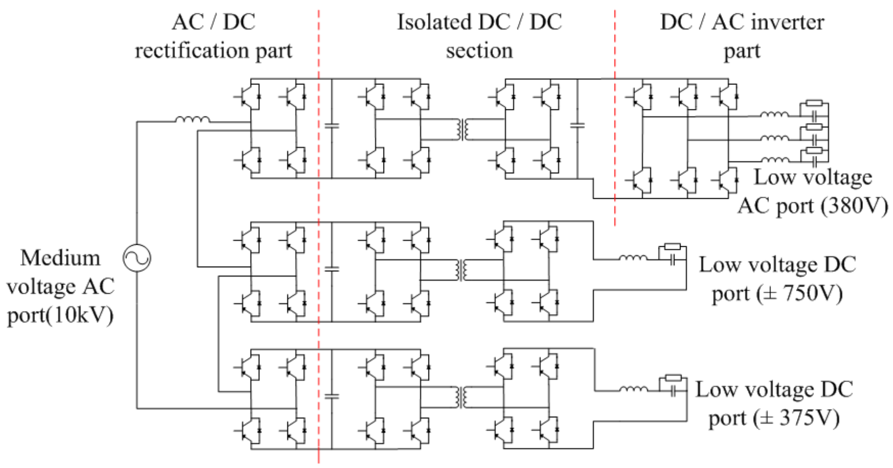

Figure 3. Topology of four-port energy router

As can be seen from Figure 3, the energy router, as a network power flow hub for various system adjustment and protection functions, has the following functions: (1) The power flow on each feeder can be flexibly controlled in two directions, and real-time adjustment can be achieved [15]; (2) The voltage of each bus can be controlled independently, so as to achieve the optimized operation of the system [16]; (3) to achieve the plug-and-play coordinated operation of multiple modes of new energy and energy storage devices; (4) Cooperate with the energy storage device to smooth the peak-to-valley difference of energy supply.

The energy router in the AC / DC distribution network proposed in this paper can provide a communication interface to support the monitoring and operation control of the upper-level system; provide a fast communication interface to support process-level networking with external stability control devices for switching and control commands Interactive, and can receive external naming to perform corresponding control; in the voltage source working mode, it has the ability to operate with other voltage source devices in a short-term loop.

3.2. AC / DC Distribution Network Model

The regional AC-DC distribution network model proposed in this paper is shown in Figure 4. Coordinate and control the four-port energy router, distributed power supply, energy storage, PCS, and tie switches of various voltage levels, switches of branches and tie lines in the area. The main functions include: microgrid normal operation control, tie line power control, microgrid parallel off grid switching, distributed generation unit coordination control, operation mode switching, load transfer, fault self-healing and other functions, and coordinate control of each of the four-port routers The port operation mode and output power realize the flexible access of distributed power supply and DC load, reduce the blackout area and blackout time, and comprehensively improve the stability of the area. The AC 380V port of the energy router has voltage frequency control mode and power control mode; the DC ± 750V and DC ± 375V port of the energy router and the PCS have voltage control mode and power control mode. To ensure the safe and stable operation of microgrids at all levels, the power router ports of different voltage levels, PCS and other power supplies must provide voltage (or voltage / frequency) frequency support to the power supply load; When multiple power supplies are connected to the grid, only one device can be used as the main power supply to operate in voltage (or voltage / frequency) operation mode, and other power supplies in parallel operation are operated in power control mode. In order to prevent the impact on the energy router and the PCS during the switching of the operating mode, it is necessary to perform sequence control on the operation of the switch and the switching of the PCS operating mode to ensure consistency.

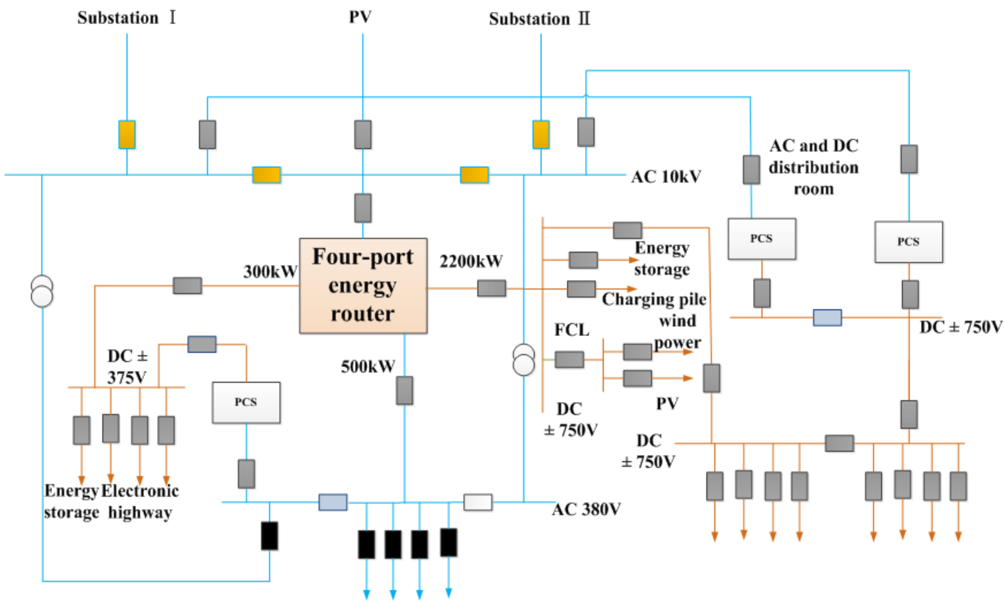

Figure 4. AC/DC distribution network system model

When a microgrid of DC ± 750V or DC ± 375V fails, the DC port of the energy router will block the output within 300us. A 0.3MW PCS has similar transient characteristics, and a 2.5MW PCS has a current limiting function. In addition, the topology structure of the DC load side energy storage system, DC fan power generation, and DC photovoltaic power generation system contains capacitors, which will quickly discharge electricity when a fault occurs, showing a short circuit state. Therefore, in addition to the need to quickly remove the fault when the fault occurs, It is also necessary to control to cut off or shut down the DC power generation equipment, and then control the energy router DC side port to remove the pulse blockade or control the PCS to switch to voltage control mode according to different fault points. In order to shorten the gap of power loss, a quick communication mechanism such as GOOSE must be adopted Achieve self-healing of failure.

4. Coordinated Control Method Under Three Modes

The coordinated control scheme proposed in this paper is the overall control scheme for the operation of energy routers, PCS and microgrids at all levels, including the start and stop control of each port of the microgrid energy router and the control of the operation mode of each port; the start and stop control and operation mode control of PCS; power supply Power control of the tie line. According to the scheduling instructions, it can realize the switching function of microgrid operation modes such as AC 10KV, AC 380V, DC ± 750V, DC ± 375V, etc., and realize the switch of PCS from joint operation with energy router to off-grid operation control, and PCS from off-grid operation to control the operation of the grid connection with the energy router. Taking full advantage of the above characteristics of the four-port energy router, this paper proposes an overall control plan for the operation of the energy router, PCS and microgrids at all three aspects of the AC / DC distribution network under normal working mode, operating mode switching and key equipment operation. It can achieve flexible access to distributed power and DC load, comprehensively improve regional stability, and has high application value.

4.1. Normal Working Mode

As shown in Figure 4, with a four-port energy router as the center, the main power points are four ports of 10KV, ± 375V, 380V, and ± 750V.

In the normal working mode, the 10KV incoming port works in the power source working mode, powered by substation I and photovoltaic, and substation II is used as a backup power source. The 10KV bus of the two-incoming line central station adopts single bus section operation mode. The power supply of incoming line 1 is substation I, the power supply of incoming line 2 is substation II. 10KV / 0.38KV transformer, 1 # PCS, the feeder line of the section II bus is connected to 2 # 10KV / 0.38KV transformer, 2 # PCS. The 10KV I and II busbars operate in open loop under normal conditions and are used as backups for each other. The 10KV port of the energy router works in the power source working mode, and the rated power of the port is 3MW.

The DC ± 375V port works in the voltage source working mode. The 0.3MW PCS is powered by the AC 380V power supply, set to the hot standby state, and works in the power source working mode. The central station DC ± 375V is a single bus structure, with 2 power supplies, 1 channel is the energy router DC ± 375V port, and 1 channel is a 0.3MW PCS. Under normal circumstances, the energy router DC ± 375V port is the main power supply and works in the voltage source working mode. The 0.3MW PCS is electrically interconnected with the energy router DC ± 375V port as a backup working in the power source working mode. The DC ± 375V port of the energy router and the PCS have a true bipolar topology. Each DC + 375V contact switch is equipped with a positive and negative switch. The positive and negative power supplies can operate independently.

The AC 380V port works in the voltage source working mode, the two switches on the AC 380V bus are in a separated state, and the two AC power supplies connected to it are used as backup power supplies. The 380V bus of the central station adopts a single bus and double section structure. Under normal circumstances, the two section switches are disconnected. The section I bus is powered by a 1 # 10KV / 0.38KV transformer and is passed to a direct current ± 375V through a 0.3MW PCS Power supply, section II bus is powered by the 380V port of the energy router, section III bus is powered by the 2 # 10KV / 0.38KV transformer. Section I and II busbars are reserved for each other, and section II and III busbars are reserved for each other. The 380V port of the energy router works in the voltage / frequency working mode, and the rated power of the port is 0.5MW.

The DC ± 750V port works in the voltage source working mode. The two PCS in the AC / DC power distribution room are set to the hot standby state and work in the power source working mode, forming a closed loop with the port. The DC± 750V port of the energy router works in the voltage source working mode. The 2.5MW PCS tool and the DC ± 750V port of the energy router are electrically connected to work as a hot standby in the power source working mode. The DC ± 750V port of the energy router and the PCS are true bipolar topologies. The positive and negative switches of each tie switch of the DC ± 750V can be operated independently.

4.2. Operating Mode Switching Mode

In the operating mode switching mode, the energy router DC ± 375V port block output is controlled by timing, and the PCS system is switched from the power source working mode to the voltage source working mode to realize the switching control of the DC ± 375V main and backup power supply, and the energy router DC is controlled by timing The output of the 375V port is unblocked, and the PCS system is switched from the voltage source working mode to the power source working mode to realize the restoration of the DC ± 375V main and standby power supply.

By timing control of the energy router DC ± 750V port block output, the PCS system is switched from the power source working mode to the voltage source working mode to realize the switching control of the DC ± 750V main and backup power supply, and by timing control the energy router DC ± 750V port to unblock the output The PCS system is changed from the working mode of the voltage source to the working mode of the power source to realize the restoration of the main power supply of DC ± 750V.

By timing control, the power contact switch on DC ± 750V is switched from on to off, and the PCS system is changed from the power source working mode to the voltage source working mode, and the energy router and the PCS system are each partly loaded with open loop operation. The power contact switch is switched from on to off, and the PCS system is changed from the voltage source working mode to the power source working mode to realize the closed loop operation of the energy router and the PCS system.

By timing control the energy router AC 380V port block output and segment switch closing, realize the transfer of the AC II mother load from I and III mothers, by timing control the energy router AC 380V port lift the block output and segment switch open, will be by I 2. The II mother load of the III mother power supply is restored to the AC 380V port of the energy router.

AC 10KV operation mode operation blocking and control, that is, after the AC 380V, DC ± 750V, DC ± 375V port load is completed, it can accept the higher order to achieve the control of AC 10KV operation mode switching, otherwise the 10KV operation mode operation is blocked.

4.3. Operating Mode Switching Mode

The operation of key equipment is mainly to control the four-port energy router, PCS system and DC circuit breaker.

For a four-port energy router, the DC side adopts a true bipolar topology, and the positive and negative poles can be controlled separately. The 10KV port of the energy router works in the power source working mode, and the 380V port of the energy router, ± 750V DC, and ± 375V DC Voltage source working mode; after 10KV fault or loss of voltage, the energy router judges the 10KV fault and then blocks the output of each port. If 10KV recovers, the unblocking control of each port is controlled by the energy router itself, and currently does not accept external control commands; energy The router currently only operates as an independent voltage source and does not work in parallel with other systems on the voltage source; the communication protocol between the energy router and the monitoring system is 104, and the fast communication interaction is realized through the custom protocol 60044-8.

For the PCS system, the true bipolar topology is adopted, and the positive and negative poles can be controlled separately for control; the communication protocol between the PCS system and the monitoring system is 104, and the fast communication interaction is realized through the GOOSE mechanism of 61850, including switching, export, analog, etc. GOOSE information; the DC side of the PCS system can receive external control commands to work in the voltage source / power source working mode; the communication protocol between the PCS system and the monitoring system is 104, and the fast communication interaction is realized through the custom protocol 60044-8.

For DC circuit breakers, the operating time is controlled to be less than 70ms.

5. Timing Verification

Taking the network model of the AC / DC distribution network in Figure 4 as an example, the coordinated control method when the operation mode is switched, the energy router is controlled by the timing to realize the blocking output of the AC and DC ports, and the conversion of the working mode of the PCS system on the DC side and The AC bus power supply line is converted, and the AC and DC ports are unblocked and output through the sequence control energy router again, thereby realizing the control of the operation mode switching. The specific flowchart is shown in Figure 5.

Only after the transfer of the AC 380V, DC ± 750V, and DC ± 375V port loads as shown in Figure 5 can be accepted, the higher order can be accepted to achieve the operation blocking and control of the AC 10KV operation mode, otherwise the 10KV operation mode operation is blocked.

The coordinated control method proposed in this paper is based on the cooperative control of timing coordination, using the timing to control the working mode of each port of the four-port router, so that the working model of each feeder of the AC and DC distribution network can be quickly converted, and the AC and DC load can be realized. Fast transfer, plug-and-play of distributed power and energy storage devices, the timing diagram is shown in Figure 6.

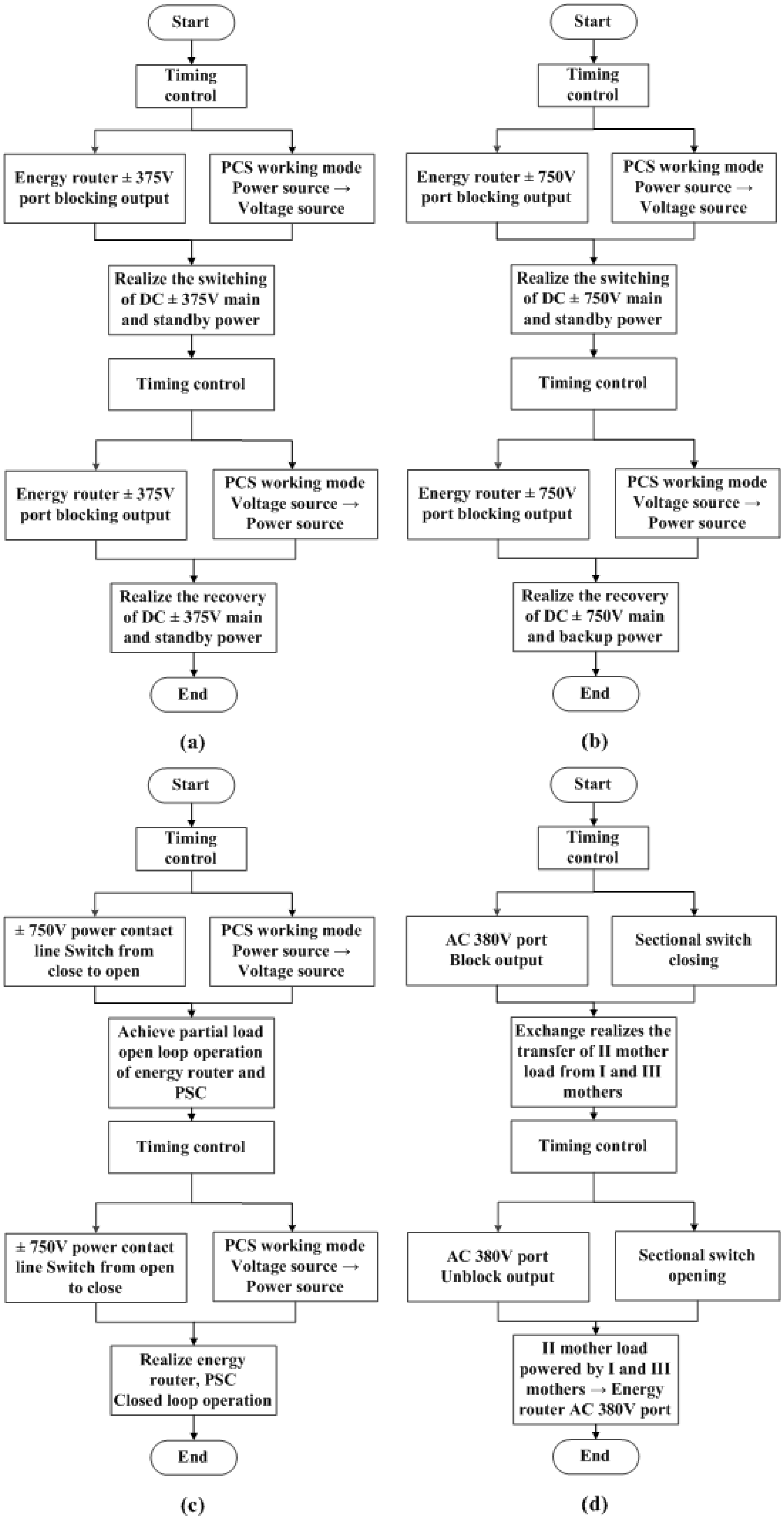

Figure 5. Flow chart of coordinated control method when operating mode is switched

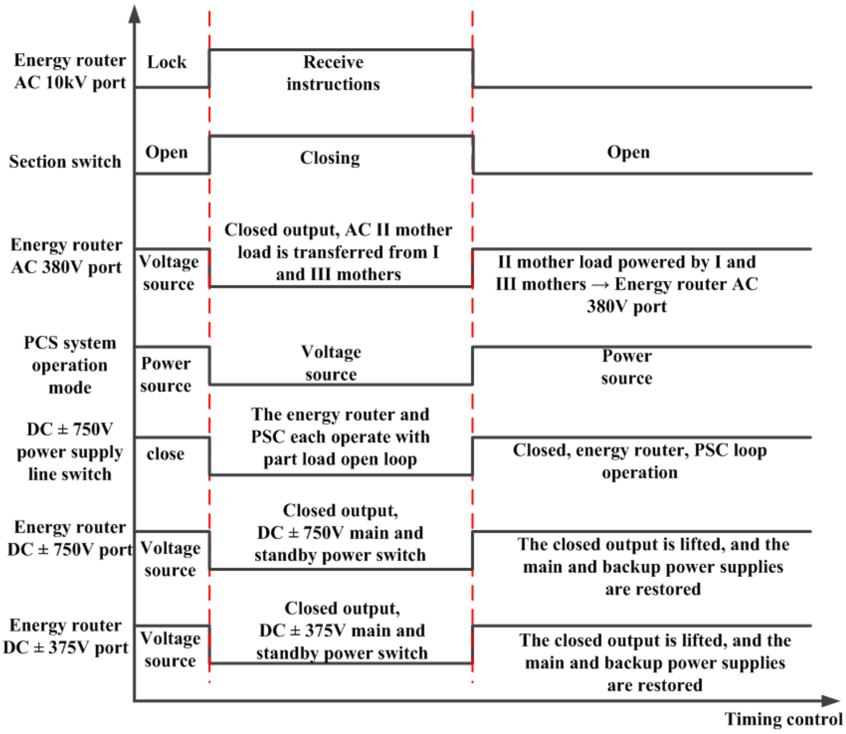

Figure 6. Time sequence diagram of coordinated control of AC/DC distribution network based on four-port router

6. Conclusion

This paper proposes a coordinated control method for AC and DC distribution networks based on a four-port energy router. The four-port energy router can provide a communication interface to support the monitoring and operation control of the upper-level system; provide a fast communication interface, support process level networking with external stability control devices, interact with switching and control commands, and can receive external naming Perform the corresponding control; in the voltage source working mode, it has the ability to operate in a closed loop with other voltage source devices for a short time. Taking full advantage of the above characteristics of the four-port energy router, the control strategy of the AC and DC distribution network in normal operation mode, operation mode switching and key equipment operation is proposed, which can achieve flexible access to distributed power and DC load, and comprehensively Regional stability has high application value.

References

[1] ZHANG Zhaoyun, LIN Pu, WANG Xinghua. “Review on relay protection of AC/DC hybrid distribution grids,”Power System Protection and Control, 47(5): 179-187. 2019.

[2] Peng Ke, Zhang Cong, Chen Yu, et al. “Power flow calculation method for AC/DC distribution network with multiple converters in parallel,” Electric Power Automation Equipment, 38(09): 129-134. 2018.

[3] KONG Li1, PEI Wei1, YE Hua, et al. “Review of pattern, control and stability for hybrid AC/DC distribution power systems,” Advanced Technology of Electrical Engineering and Energy, 36(9): 1-10. 2017.

[4] YMUSOLINO V, PIEGARI L, TIRONI E, et al. “Simulations and field test results for potential applications of LV DC distribution network to reduce flicker effect,” Proceedings of 14th International Conference on Harmonics and Quality of Power, , Bergamo, Italy: 1-6. Sep 26-29, 2010.

[5] TANG Guangfu. “High-voltage direct current transmission technology based on voltage source converter,” China Electric Power Press, 2009.

[6] FU Yuan, HUANG Xinyi, XU Yan, et al. “Controllable inertial control strategy of rotating electric machine in DC distribution network,” Electric Power Automation Equipment, 38(10): 32-38. 2018.

[7] He Li, Li Yong, Cao Yijia, et al. “Flexible Voltage Control Strategy of DC Distribution Network Considering Distributed Energy Storage,” Transactions of China Electrotechnical Society, 32(10): 101-110. 2017.

[8] ZHENG Shu, ZHAO Jingtao, “TAN Kuo, et al. Research on protection and control of AC/DC distribution network considering DC flexible device,” Power System Protection and Control, 46(19): 132-136. 2018.

[9] SHU Yinbiao. Planning Design of Distribution Network, China Electric Power Press, 2018.

[10] JIA Junguo, PANG Songnan, DONG Ruibiao, et al. “AC/DC Coordinated Control of Power Router Based on Virtual Synchronous Generator Control Technology,” Modern Electric Power, 36(2): 33-39. 2019.

[11] LIU Wei, HE Dacheng, XU Xinzhe. “Research on Combined DC Transformer for Terminal Power Conversion of DC Distribution Network,” Electric Power Automation Equipment, 38(07): 43-50. 2018.

[12] PU Tianjiao, LI Ye, CHEN Naishi, et al. “Key Technology and Research Framework for Optimal Operation Control of Hybrid AC/DC System Based on Power Electronic Transformer,” Power System Technology, 42(9): 2752-2759. 2018.

[13] Peng Ke, Zhang Xinhui, Chen Yu. “Power flow calculation method for AC/DC distribution network with multi-terminal flexible interconnection,” Electric Power Automation Equipment, 37(01): 22-27. 2017.

[14] WANG Cong, XU Xiao-xian, SHA Guang-lin, et al. “Power flow algorithm of AC/DC microgrid based on energy router,” Advanced Technology of Electrical Engineering and Energy, 37(7): 33-40. 2018.

[15] She Xu, Wang Fei, Burgos R, et al . Solid state transformer interfaced wind energy system with integrated active power transfer, reactive power compensation and voltage conversion

functions, Proceedings of 2012 IEEE Energy Conversion Congress and Exposition. Raleigh, NC: IEEE, 2012: 3140-3147.

[16] MIAO Jianqiang, ZHANG Ning, KANG Chongqing. "Analysis on the Influence of Energy Router on the Optimal Operation of Distribution Network," Proceedings of the CSEE, 37(10): 2832-2839. 2017.