The Topology of a New Energy Router and Its Coordinated Control Strategy

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Abstract. With the rapid growth of the permeability of distributed new energy and the development of Energy Routers based on power electronics technology, the construction of AC/DC hybrid distribution network based on Energy Routers is expected to become a new development direction of urban power grid. This paper proposes a hybrid AC/DC main urban power grid and Microgrid interconnection architecture based on a new Energy Router topology and its coordinated control strategy as the basic module of future urban power grid. In this paper, considering the current situation of land resource shortage in the central area of the city, the new energy generation and energy storage technologies represented by photovoltaic building integration and electric vehicles are considered and connected to the urban distribution network in the form of integrated Microgrid. Considering that the electricity production and consumption patterns of adjacent Microgrids may be greatly different, the interconnection architecture between the main power grid and the Microgrid can be constructed. So in this paper, the Energy Router integrated with AC and DC double busbar and four voltage source inverter, coordinated control strategy is a blend of PQ control strategy and V/f control strategy, based on the disturbance observation method of MPPT control strategy of photovoltaic power generation and the control strategy of energy storage system, it not only make full use of new energy, but also effectively ensure the quality of electricity supply. Simulation and analysis of each model and control strategy were carried out on MATLAB 2016a/Simulink simulation platform, and the results verified the effectiveness and reliability of the proposed Energy Router topology and coordination control strategy.

1. Introduction
The exhaustion of traditional coal and petroleum energy urgently needs the renewable clean energy to become the mainstream energy. The scarcity of land resources, especially in the central area of modern city in the process of development, it is urgent to improve the land resources comprehensive utilization benefits. These present status of energy and urban bring unprecedented challenges for the future development of urban power industry. In the recent years, the concept of Energy Interne put forward and the progress of technology in power electronics and communication makes the Energy Router develop rapidly\cite{1}.

Reference [2-3] point out that distributed power generation in the form of solar energy as renewable energy is one of the key technologies applicable to urban new energy generation and an effective means to achieve global greenhouse gas emission reduction targets. Photovoltaic building integration will directly use the existing building surface as the photovoltaic power generation infrastructure, can directly provide continuous electricity, heat or cooling to the building or the surrounding load. Reference [4-5] point out that with the continuous development of electric vehicles,
the integration of clean energy and charging and discharging facilities of electric vehicles to build an integrated Microgrid is conducive to improving the overall operating economic and environmental benefits of the system of electric vehicles. Reference [6] points out that the future urban Energy Router will "set point" for all kinds of energy and information, they will use advanced technology and means, to connect a variety of energy into a net, improve the efficiency of comprehensive utilization of energy and asset utilization, reduce carbon emissions and pollution of the environment. It mainly went through four stages: electronic form, intelligent form, high-voltage high-frequency form and multi-port routing form [7].

To sum up, based on the Energy Router topology structure studied by predecessors [8-10], this paper gives full consideration to the actual application scenarios of Energy Router in the future urban power grid, proposes the topology structure of AC/DC dual bus and four voltage source type inverters, and constitutes the connection architecture of AC/DC Microgrid and main network based on ER of urban distribution network.

2. Urban distribution network architecture design based on Energy Router

As shown in figure 1, the Energy Router, as an energy hub, establishes an electrical connection between the Microgrid and the main power grid, and takes such an interconnection form as the infrastructure of the future urban power grid to facilitate the renovation and expansion of the urban power grid.

The advantages of the urban distribution network architecture designed in this paper include:

(1) It provides a standard format interface to connect the distributed clean energy in the urban distribution network to the main grid;(2) After the distributed power is connected to the inverter of the energy router, form DC and AC Microgrid, and then interconnect with the main power grid, avoid when a large number of distributed power alone directly connected to the distribution network terminal, power grid voltage flicker and harmonic content is too big, too lower voltage power quality problems, harmful to power grid and the user;(3) The coordinated control strategy designed of the Energy Router is for the energy exchange priority between Microgrids, which promotes the energy exchange between adjacent Microgrids, reduces the dependence of the internal load of the Microgrid on the power supply of the main network, and promotes the capacity of the distributed generation system to be fully absorbed.

![Figure 1. Interconnect architecture based on Energy Router](image-url)
3. Energy Router

3.1. Topology and mathematical model of Energy Router

As shown in figure 2, it is an Energy Router schematic diagram based on voltage source inverter and shared bus.

![Energy Router Schematic Diagram](image1)

**Figure 2.** Schematic of the ER

As shown in figure 3 it is Energy router topology diagram, which can realize energy sharing and distribution among the main power grid, DC Microgrid and AC Microgrid. Among them, VSC0 connects the main power grid with the DC bus, VSC1 connects the DC bus with the AC bus, VSC2 and VSC3 connect the photovoltaic power generation system and hybrid energy storage system into the AC Microgrid respectively.

![Energy Router Topology Diagram](image2)

**Figure 3.** Schematic of the Energy Router

3.2. Control strategy of the Energy Router

3.2.1. VSC control mode. V/f control: also known as constant voltage and constant frequency control, the purpose is to ensure that the voltage amplitude and frequency of the system where the inverter is located remain unchanged no matter how the output power of the Distributed Generation changes [11]. Figure 4 shows the V/F control block diagram[12].PQ control: also known as constant power control, the purpose is to make the power output of the DG equal to the reference power value .Figure 5 shows the PQ control block diagram.

![V/F Control Block Diagram](image3)

**Figure 4.** the V/F control block diagram

![PQ Control Block Diagram](image4)

**Figure 5.** The PQ control block diagram
3.2.2. Control strategy of the Energy Router. Because Energy Router design in this paper, mainly for the future urban distribution network, main purpose is to realize the complementary energy priority between Microgrid, reduce the dependence of load for main power grid, thereby fully absorb new energy sources, so the selection V/f control for inverter as control mode between AC and DC bus, select PQ control for the interface inverter of the main power grid as control mode, and the resulting Energy Router coordinated control strategy proposed in this paper. The coordinated control strategy is shown in figure 6.

![Figure 6. The coordinated control strategy of Energy Router](image)

3.3. Control mode of the Energy Router

According to the power flow direction, six working modes of the Energy Router can be obtained.

Mode 1: $P_{DC} \geq 0$, $P_{AC} \geq 0$, $P_{Grid} < 0$. At this time, VSC0 works in inverting mode and VSC1 works in rectifying mode.

Mode 2: $P_{DC} < 0$, $P_{AC} \geq 0$, $P_{Grid} < 0$. At this time, VSC0 works in inverting mode and VSC1 works in rectifying mode.

Mode 3: $P_{DC} \geq 0$, $P_{AC} < 0$, $P_{Grid} < 0$. At this time, VSC0 works in inverting mode and VSC1 works in inverting mode.

Mode 4: $P_{DC} < 0$, $P_{AC} < 0$, $P_{Grid} \geq 0$. At this time, VSC0 works in rectifying mode and VSC1 works in inverting mode.

Mode 5: $P_{DC} < 0$, $P_{AC} < 0$, $P_{Grid} \geq 0$. At this time, VSC0 works in rectifying mode and VSC1 works in rectifying mode.

Mode 6: $P_{DC} \geq 0$, $P_{AC} < 0$, $P_{Grid} \geq 0$. At this time, VSC0 works in rectifying mode and VSC1 works in inverting mode.

4. Simulation and analysis

Using MATLAB R2016a/Simulink platform to establish simulation model of AC/DC hybrid distribution network and AC/DC Microgrid interconnection architecture based on the Energy Router. The simulation model of the whole system is shown in figure 7(a), and the simulation model of VSC0 is shown in figure 7(b), which is the same as that of VSC1, VSC2 and VSC3. The models of inverter V/f and PQ controller are shown in figure 7(c) and (d) respectively.
It is assumed that the simulated scene process is divided into three stages: the solar radiation intensity \((w \cdot m^{-2})\) is 1000; The radiation intensity changes from 1000 to 0; The radiation intensity is 0, and the simulation parameters are shown in table 1. Simulation result shown in figure 8. Figure 8(a) is power flow simulation result between the main power grid and the Microgrids, figure 8(b) is AC Bus voltage and current simulation result, figure 8(c) is Internal voltage effective value and frequency simulation result of AC Microgrid, figure 8(d) is DC Bus voltage and current simulation result.

**Figure 7.** MATLAB simulation model of interconnection architecture based on the Energy Router

**Table 1.** Simulation parameters

| Parameters                                      | Value (unit) |
|------------------------------------------------|--------------|
| Main power grid voltage                        | 10kV         |
| AC Microgrid voltage                           | 380V         |
| DC Microgrid voltage                           | 750V         |
| VSC0, VSC3 filter inductance, switching frequency | 3mH, 5kHz    |
| VSC1 filter inductance, switching frequency     | 2.5mH, 10kHz |
| VSC2 filter inductance, switching frequency     | 3mH, 10kHz   |
| AC Load                                        | 380V, 50HZ, 5kV |
| DC Load                                        | 100 Ω        |
Figure 8. Simulation result diagram

From the simulation results, the voltage and frequency of AC bus remain constant, and the voltage of DC bus remains constant. Energy Router operation mode analysis: (1) 0-0.41s, is mode 1, DC Microgrid output power, AC Microgrid output power, main power grid absorb power. \( P_{DC} \geq 0, P_{AC} \geq 0, P_{Grid} < 0 \). At this time, VSC0 works in inverting mode and VSC1 works in rectifying mode. (2) 0.41-0.43s, is mode 3, DC Microgrid output power, AC Microgrid absorb power, main power grid absorb power. \( P_{DC} \geq 0, P_{AC} < 0, P_{Grid} < 0 \). At this time, VSC0 works in inverting mode and VSC1 works in inverting mode. (3) 0.43-0.46s is mode 6, DC Microgrid output power, AC Microgrid absorb power, main power grid output power. \( P_{DC} \geq 0, P_{AC} < 0, P_{Grid} > 0 \). At this time, VSC0 works in rectifying mode and VSC1 works in rectifying mode. (4) 0.46-1s, is mode 4, DC Microgrid absorb power, AC Microgrid grid output power, main power grid output power. \( P_{DC} < 0, P_{AC} < 0, P_{Grid} > 0 \). At this time, VSC0 works in rectifying mode and VSC1 works in inverting mode.

5. Conclusion

In this paper, an Energy Router and the corresponding coordinated control strategy for the urban AC/DC hybrid distribution network are proposed, and an interconnection architecture between the main power grid and the AC/DC Microgrids is formed based on the Energy Router. The purpose is to achieve the flexible energy flow and power balance of the entire system through the interconnected architecture and Energy Router, and to make the maximum use of new energy generation by taking advantage of the complementary energy production and consumption between adjacent Microgrids. The rationality of the Energy Router topology and the feasibility of the coordinated control strategy are verified by simulation, and the operation mode of the Energy Router is analyzed. The interconnection architecture proposed in this paper will serve as the power supply infrastructure of the future urban power grid based on Energy Routers and new energy generation, and facilitate the development, renovation and expansion of the future urban power grid.
Acknowledgments
Thanks for “111” project (B14022) sponsorship of this paper.

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