Research on operation control strategy of user-side power routing device in market environment

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Abstract. Considering the demand of distributed power trading, a user-side power routing device topology is designed. The operation scenario of the device is divided into eight operation states, and the operation control strategy of the device system oriented to power trading is proposed for the eight operation states. In the process of power trading, grid-connected converters adopt Direct Power Control (DPC) to realize constant power trading. Super Capacitor (SC) adopt constant voltage control, Lithium battery adopt droop control, the Super Capacitor and the Lithium battery work together as the system bus voltage control unit. A simulation model is built on PSCAD/EMTDC platform, and two typical scenarios of power trading mode and non-trading mode are compared and analyzed. The simulation results verify the effectiveness of the proposed strategy.

1. Introduction

China is in a critical period of urbanization development. New urban construction faces the problem of high energy consumption and insufficient utilization of clean energy [1]. Building a new type of urban energy Internet with the characteristics of interconnection, production and marketing, and diversified transactions is an important technical means to solve the energy problems in China's urbanization process [2].

With the development of the energy Internet, a variety of green powers, including wind and light, enter the market. The energy market presents a trend of structural ecology, diversified entities, and multilateral transactions. Energy consumers have broader energy choices and more flexible purchase plan. In the market environment, the demand for distributed green energy transactions has increased dramatically, and the demand for user autonomous power management has also increased. Electric energy is the main form of transmission and utilization of energy. Electric energy trading plays a dominant role in the energy market. Traditional distributed generation devices can not realize the active dispatch and self-management of power on the user side, and the user side still lacks the support equipment to implement the execution link of power trading.

Literature [3] summarizes the development history of power routers. According to the idea of energy Internet and the demand for power routers, the basic architecture and basic functions of power routers are explained from the perspective of power system and power electronics technology.
Literature [4] established a multi-port power router topology, analyzed the typical operation mode and proposed a coordinated control strategy for energy storage voltage regulation. Literature [5] is aimed at the potential stability of the power router to the current traditional distribution network and the power electronic distribution network, and deduces the small signal impedance model of the power router under dq coordinates. The system structure of the power exchanger is designed in detail, and the future configuration of the distribution network based on the power exchanger is studied [6]. Literature [7] believes that the configuration of redundant sub-modules can improve the reliability of the equipment, but at the same time increase the cost. Based on the current mainstream power router topology, the reliability of different redundant control modes of the equipment is analyzed and compared. The most reliable and economical redundancy configuration. Literature [8] establishes the energy model of the power router, and gives the integrated control strategy of the grid-connected operation of the power router based on the energy balance relationship.

The above literature mainly discusses the stability, key technologies and control strategies of the energy routing device, and does not take into account the energy trading needs in the market environment. Based on the characteristics of distributed energy trading and user-side energy and load structure, this paper designs a user-side energy routing device topology structure. Considering the execution elements of power transaction on the user side, this paper studies the operation control strategy of power routing device on the user side, which aims to realize the energy transmission link of auxiliary energy transaction and the management of the user-side energy routing.

2. System structure of user-side power routing device

The topology of the user-side power routing device is shown in Figure 1. It is mainly composed of a distributed power supply, a hybrid energy storage device, and a power electronic converter (DC/DC, DC/AC). The user-side power routing device is based on an AC-DC hybrid architecture, and has a 380V AC bus, ±375V, and 48V DC bus. The 380V AC bus is the energy interaction interface between the user side and the grid side, and is also the AC load (three-phase, single-phase) power supply interface. The ±375V DC bus provides a DC bus interface for distributed power, energy storage (via converter access), and provides a power supply interface for DC loads at the corresponding voltage levels (375V, 750V). The 48V DC bus provides a power supply interface for low voltage DC loads (48V). This architecture is not only compatible with the original AC equipment, and also supports plug-and-play access of DC equipment, reducing AC/DC conversion redundancy, improving energy conversion efficiency, and meeting the diversified power demand of users [9].

![Figure 1. Topology structure of user-side power routing device.](image-url)
2.1. Hybrid energy storage droop control strategy

The user-side power routing device uses a hybrid energy storage type of “Super Capacitor and Lithium battery”. Both Super Capacitor and Lithium batteries are connected to DC buses through their Buck-Boost converters. Hybrid energy storage can give full play to the characteristics of high energy density of Lithium batteries, fast response speed and high power density of Super Capacitor so as to improve the dynamic flexibility and operation life of the system [10].

The Super Capacitor adopts constant voltage control, and its control algorithm is shown in Figure 2. The instantaneous value $U_{DC}$ of DC bus voltage is monitored and compared with the reference value $U_{DCref}$ of DC bus voltage to judge whether the Super Capacitor is charged or discharged. The PI controller obtains the charging reference current $I_{SCchar_ref}$ or the discharging reference current $I_{SCdisc_ref}$, which is compared with the Super Capacitor instantaneous current $I_{SC}$, respectively. Finally, the PWM generator generates PWM pulses to buck circuit and boost circuit respectively.

The Lithium battery adopts droop control, and its control algorithm is shown in Figure 3. The instantaneous value $U_{SC}$ of the Super Capacitor voltage is brought into the droop curve to obtain the Lithium battery charging reference current $I_{Batchar_ref}$ or the discharge reference current $I_{Batdisc_ref}$. PWM pulses are generated by PWM generator to buck circuit and boost circuit respectively.

The sag curve of Lithium batteries is shown in Figure 4. If the Super Capacitor voltage is in the interval $[U_{SC_{LU}}, U_{SC_{HU}}]$, the Lithium batteries will not operate; if the Super Capacitor voltage is in the interval $[U_{SC_{L1}}, U_{SC_{H1}}]$, the Lithium batteries will be charged according to the droop curve; if the Super Capacitor voltage is in the interval $[U_{SC_{Min}}, U_{SC_{L1}}]$, the Lithium batteries will be charged with constant current; the situation is similar in the interval $[U_{SC_{H1}}, U_{SC_{Max}}]$.

![Figure 2. Super capacitor control block diagram.](image2)

![Figure 3. Lithium battery control block diagram.](image3)
2.2. Direct power control strategy of grid-connected converter

In order to achieve direct control of the grid-connected instantaneous power, the grid-connected converter uses Direct Power Control (DPC). DPC can realize fast and efficient control of active power and reactive power exchanged between converter and grid. It also has the characteristics of simple algorithm, fast dynamic response and no influence of coordinate transformation [11].

The direct power control block diagram is shown in Figure 5. The network side voltage signal \( u_i (i = a, b, c) \) and the current signal \( i_j (i = a, b, c) \) are collected, and the instantaneous power \( p \) and \( q \) are calculated by the instantaneous power theory. \( p \) and \( q \) are respectively subtracted from the reference active powers \( P_{ref} \) and \( Q_{ref} \), and the result is sent to the hysteresis comparator to obtain \( S_p \) and \( S_q \). The voltage signal \( u_i (i = a, b, c) \) is sent to the sector selector to obtain \( \Theta_n \), and the obtained \( S_p \) \( S_q \) \( \Theta_n \) is brought into the switch vector table to obtain the switching signal \( S_a \) \( S_b \) \( S_c \) of the converter, thereby controlling the converter switching action [12].

3. Operation control strategy of single device system oriented to electric energy trading

According to the user's electricity data and the transaction quotation information, the power trading platform matches the transaction, generates the transaction scheme, and sends the transaction...
instructions to the user-side power routing device. Aiming at the electric energy transaction, the operation strategy of the device system is designed to assist the smooth execution of the electric energy transaction. The user-side energy routing device can access PV, power grids, AC and DC loads, and allocate a certain amount of energy storage. The adjustable variables of the device system are photovoltaic power, battery power, the unadjustable variables are grid status and load power, and the external variables are power trading instructions. Therefore, based on the net photovoltaic power (photovoltaic power minus load power), battery power, grid state and power trading instructions, all operation scenarios can be divided into several operation states, designing operation control strategies for each operation state. The control strategy is shown in Figure 6.

In Figure 6, the device system is divided into eight operating states \( S_i (i = 1, 2, \ldots, 8) \), and the converter control strategies corresponding to the eight operating states are shown in Table 1. Among them, the state \( S_2 \) has the largest area, which is the typical operating state of the device, and is also the key research object of this paper. State \( S_2 \) is the state of the user after receiving the power trading instructions. Considering the photovoltaic power generation and load power fluctuation during the power trading process, the grid-connected converter adopts constant power control mode to realize the power transmission and trading with constant power and ensure the smooth execution of the power trading. As the main control unit of DC bus voltage, the Super Capacitor adopts constant voltage control. The Lithium battery operates according to the droop curve of the Super Capacitor voltage, and cooperates with the Super Capacitor to suppress the bus power fluctuation and stabilize the bus voltage.

**Table 1.** Control strategy of converter in device system.

| Operating status | Operating mode | Grid-connected converter | Photovoltaic unit | Super Capacitor | Lithium battery | Load |
|------------------|----------------|--------------------------|-------------------|-----------------|-----------------|------|
| S1               | Grid-connected operation | constant voltage control | MPPT control | standby | standby | constant voltage control |
| S2               | Grid-connected operation | constant power control | MPPT control | constant voltage control | droop control | constant voltage control |
| S3               | Grid-connected operation | constant voltage control | MPPT control | standby | constant voltage charging |
| S4               | Island operation | droop control | MPPT control | constant voltage control | droop control | normal |
| S5               | Island operation | standby | constant voltage control | standby | standby |
| S6               | Island operation | standby | MPPT control | constant voltage control | droop control |
| S7               | Island operation | standby | constant voltage control | standby | constant voltage charging |
| S8               | Island operation | standby | constant voltage control | standby | constant voltage charging | load shedding |
Figure 6. Operation control strategy of single device system.

For other operating states, the control strategy is designed based on the principle of preferential participation in transactions, so that it will gradually change to state S2. In this way, the device runs in S2 state for most of the time, which promotes the occurrence of electricity trading behaviour, improves users’ electricity sales revenue or cost savings, and improves the utilization rate of distributed new energy on the user side.

4. Case study

Based on the user-side power routing device topology in Figure 1, the device model is built on PSCAD/EMTDC platform, and typical scenarios are selected to verify the strategy proposed in Section 3.

4.1. Electric energy trading model

Under this mode, photovoltaic power generation gives priority to load supply, and the surplus part can be traded. The power trading adopts constant power trading mode. The photovoltaic adopts MPPT control strategy, and the Super Capacitor acts as the main control unit of DC bus voltage. The Lithium battery operates on the droop curve according to the voltage of Super Capacitor, and cooperates with the Super Capacitor to stabilize bus power, keeping the voltage of Super Capacitor in normal range. Aiming at the two trading modes of selling electricity and purchasing electricity, the corresponding scenario is constructed, as shown in Table 2, and is simulated.

Table 2. Trading scenario.

| Trading status          | Trading mode | Trading power | Trading time |
|-------------------------|--------------|---------------|--------------|
| Power selling mode      | Constant power | 1900W         | 1.0-1.5s     |
| Power purchase mode     | Constant power | 1500W         | 1.0-1.5s     |
(1) Power selling mode

![Figure 7. System operation curve.](image)

(2) Power purchase mode

![Figure 8. System operation curve.](image)
In Figure 7 and 8, the grid-connected converter runs in the constant power control strategy and the Lithium battery runs in the droop control strategy during the trading process. After the transaction, the grid-connected converter is switched to droop control strategy, the Lithium battery is switched to charge control strategy, and the Super Capacitor is always operated in constant voltage control strategy. It can be seen from the figure that the entire trading process performs constant power trading with set power, during which the DC bus voltage remains stable.

4.2. Non-trading model
Under this mode, the photovoltaic power generation gives priority to load supply, the surplus part gives priority to battery charging, and then merges into the power grid, which promotes the device to change to the power trading mode. The photovoltaic system adopts MPPT control strategy, and the Super Capacitor is the main control unit of DC bus voltage. The grid-connected converter operates on the droop curve according to the Super Capacitor voltage, and cooperates with the Super Capacitor to stabilize the bus voltage, so that the Super Capacitor voltage can be maintained within the normal range.

In Figure 9, the grid-connected converter runs in the droop control strategy, the Super Capacitor runs in the constant voltage control strategy, and the Lithium battery adopts the charging control strategy. As can be seen from the figure, in the non-trading mode, the photovoltaic surplus power generation gives priority to battery charging, and the grid-connected converter cooperates with the Super Capacitor as the voltage control unit to maintain the voltage stability of the DC bus.

![Figure 9. System operation curve.](image-url)

5. Conclusions
With the development of the energy market, distributed trading will be an important driver for solving urban energy problems. This paper considers the user side energy and load characteristics, designs a user-side power routing device topology, analyses the user-side energy transaction execution link...
elements, and proposes a device system operation control strategy for energy trading. This paper selects two typical operating states, trading status and non-trading status of the device, and simulates on the PSCAD/EMTDC platform.

The simulation results show that in the trading state, the proposed strategy can ensure the smooth implementation of power trading, while maintaining the stable operation of the system; in the non-trading state, the proposed strategy can give priority to the surplus power to charge the lithium battery, if there is any surplus, it will be incorporated into the grid, so as to promote the device to the state suitable for power trading.

In the future research work, the factors that affect the power transaction will be considered in the operation strategy, such as photovoltaic power prediction error, power grid price, energy storage charge and discharge cost, and the proposed strategy will be further optimized.

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References
[1] The State Council of the People’s Republic of China. 2014 National new urbanization planinge (2014-2020). http://www.gov.cn/gongbao/content/2014/content_2644805.htm
[2] Yuping Zheng, Dan Wang, Can Wan, et al. 2019 Key Technologies and Applications of Energy Internet for New Town. Automation of Electric Power Systems 43(14) 2-16
[3] Zhengming Zhao, Gaohui Feng, Liqiang Yuan, et al. 2017 The Development and Key Technologies of Electric Energy Router. Proceedings of the CSEE 37(13) 3823-3834
[4] Zhen Li, Wanxing Sheng, Qing Duan, et al. 2015 Coordinated Control Strategy of AC/DC Hybrid Power Router Based on Energy Storage Voltage Regulator. Automation of Electric Power Systems 32(1) 13-18
[5] Qing Duan, Wanxing Sheng, Zhen Li, et al. 2019 Stability Analysis of Power Routers Connected to Power Electronic Distribution Grid Proceedings of the CSEE 43(1) 227-235
[6] Wanxing Sheng, Qing Duan, Ying Liang, et al. 2015 Stability Analysis of Power Routers Connected to Power Electronic Distribution Grid Power System Technology 43(1) 227-235
[7] Qing Duan, Shaoxiong Nie, Wanxing Sheng, et al. 2017 Redundancy Design for Energy Router. Power System Technology 41(07) 2064-2070
[8] Gaohui Feng, Zhengming Zhao, Liqiang Yuan 2017 Integrated Control Technology of Power Router Based on Energy Balance Transactions of China Electrotechnical Society 32(7) 34-44
[9] Yandong Chen 2014 Research on the Key Techniques of Multi-inverter Control System in Microgrid Hunan University
[10] Runquan Meng 2015 DC Microgrid Hybrid Energy Storage Control and Hierarchical Coordination Control Strategy High Voltage Engineering 41(7) 2186-2193
[11] Chongwei Zhang, Xing Zhang. 2003 PWM Rectifier and Its Control Beijing: Machinery Industry Press 12 25
[12] Toshihiko Noguchi, Hiroaki Tomiki, Seiji Kondo, et al. 1998 Direct Power Control of PWM Converter Without Power-Source Voltage Sensors IEEE Transactions on Industry Applications 34(3) 473-479