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Research and exploration of direct current power supply and distribution systems for Antarctic research stations

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Abstract The power supply and distribution systems for Antarctic research stations have special characteristics. In light of a worldwide trend toward a gradual increase in the application of renewable energy, an analysis was performed to assess the feasibility of achieving a direct current power supply and distribution at Antarctic research stations by comparing the characteristics of direct current and alternating current electricity. Research was also performed on the status quo and future trends in direct current power supply and distribution systems in Antarctica research stations in combination with case studies.

Keywords **direct current, alternating current, renewable energy, Antarctic, research station**

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1 Introduction

Covered by snow and ice all year round and far away from other continents, Antarctica is the only continent without a permanent population. Despite the highly inhospitable environment, the continent's strategic, geographical, scientific, and economic qualities have always inspired human interest. According to information from the Council of Managers of National Antarctic Programs (COMNAP), there are 76 research stations and many more camps, refuges, shelters, and depots scattered across the continent of Antarctica, representing 33 countries. All these facilities function as platforms for supporting the work and lives of scientists in Antarctica.

Although buildings in Antarctic research stations have many similarities with other conventional scientific research buildings or residential buildings, many differences remain during design, construction, operation and maintenance because of geographical location, climate, and meteorology. There are also many differences embodied in electricity power supply and distribution, lighting, and grounding systems. For example, the self-sufficiency of the power supply system is a characteristic that sets it apart from conventional buildings. Antarctic research stations cannot be powered by a municipal grid; instead, they must rely on their own diesel generators, solar power, or wind power (Li et al., 2021). These components or subsystems that provide energy belong to the power supply system. The system that transfers energy from the generation side to the power load side and realizes the protection function belongs to the transmission and distribution system. Of all these forms of power, alternating current (AC) diesel generators have always been the first option, with AC being used in research stations. This is because it provides the safest and most reliable power supply. However, with the rapid development of photovoltaic (PV) and other forms of renewable energy, whether an AC power supply is still the only way of supplying power and whether there might be more suitable methods are problems that must be considered by people responsible for plan, design, operation and maintenance, and management of these research stations.

Power generation and distribution for research stations

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are performed based on the theory of the normal municipal civil grid. Therefore, understanding the history of the development of the civil grid can be beneficial in explaining the characteristics of AC and direct current (DC) power supplies.

At the end of the nineteenth century, AC could conveniently transmit energy across long distances by applying transformers to increase or reduce voltage, propelling humans into the era of AC electricity. Even today, municipal power grids globally use AC electricity, so electronic loads accessing the grid also inevitably use AC power as their input. At the beginning of the twenty-first century, super high voltage DC transmission technology gradually matured and was put into use with the development of power electronics. Consequently, the percentage of DC electronic products in use increased. Because the grid can only provide AC, AC must first be rectified into DC before it can power the DC electronic products.

For example, given the development and maturation of light-emitting diode (LED) technology, thanks to advantages such as high light efficiency, easy controllability, and quick response, LED gradually replaced traditional light sources such as incandescent bulbs, fluorescent lamps, and metal halide lamps to become the first choice for both indoor and outdoor lighting. LED chips are powered by DC, so with an AC power supply the voltage must first be rectified, filtered, and converted to DC, and a DC-DC constant current source can power the LED.

In the computer and internet industry, switch mode power supply is commonly used to convert AC into +/–12 V, +/–5 V and +3.3 VDC which can power processors, memory chips and other electronic chips. A study carried out by Lawrence Berkeley National Laboratory found that using DC power in data centers could cut energy costs by 20% (Chen, 2006).

Consequently, when the electricity is provided by power grids in AC, manufacture of electronic devices will naturally rely on this as the power input restricted condition. However, if only the demands of devices are considered, then a DC power supply is a more suitable way of providing energy. As the DC voltage matches, it becomes possible to directly connect the electricity to these electrical loads. Compared with AC supplies, DC power supplies reduce the AC/DC power processing sector, resulting in reduced costs and energy consumption (Li et al., 2020).

In the power generation field, the development of distributed generation and renewable energy in recent years also provides conditions for DC power supplies. Because greenhouse effects have led to global warming and environmental degradation, all countries have gradually reached a consensus, from the Kyoto Protocol to the Paris Agreement, on the need to limit the use of fossil fuels and reduce carbon emissions. As a result, more attention has been paid to renewable energy and other related technologies. Once PV energy, wind power, biofuels, hydrogen power, or other renewable energy or clean energy are set up as power supply by source consumers, the effective format of the output of these renewable energy sources is DC electricity. Furthermore, because of these self-sufficient methods of providing electricity, municipal and other AC power supplies will no longer be the only choices available to source customers (Glasgo et al., 2018; Zhang et al., 2015).

In this context, the DC power supply has developed from concept to practice, while related technology and products are also gradually being perfected. DC power supply system might provide power from laboratories to industrialization. In fields like data centers, vehicles, railways, naval navigation, aviation, and spacecraft, DC applications are already widespread and very mature (Yuan et al., 2019). For civil architectures, there are also some successful case studies involving DC power supply. Taking the data center as an example, utilization of DC power supply in comparison to the AC system can enhance transmission efficiency by approximately 7%, resulting in a reduction of hardware costs by 6% and space requirements by 33% (Zeng et al., 2018).

However, in Antarctic research stations, there are issues such as high standards for power supply safety, no reconstruction fund, complicated maintenance and unmatched DC power with AC loads. No research station has yet managed to achieve a DC power supply on a large scale. This paper focuses on the power supply system selection in Antarctic research stations and possibilities of DC power supplies in Antarctic research stations. The advantages and disadvantages of DC power supply versus AC power supply will be analyzed, and questions, such as prospects for DC power distribution in Antarctic research stations, will be discussed.

2 Feasibility of DC power supply in research stations

Unlike conventional civil buildings, research stations in Antarctica cannot obtain power from the municipal grid and they must generate their own electricity. Consequently, in theory, they can decide whether to use a DC or AC power supply according to their own power source, without being constrained by the specifications of an AC power supply provided by the municipal grid. However, all year-round research stations still use AC diesel fuel power generators to provide power currently in considering both reliability and economic efficiency—the primary reason for choosing AC power supplies. In recent years, given the gradual maturation of PV, wind power and other renewable energy, many countries have initiated more research and applications regarding renewable energy power generation in the Antarctic. According to observation data and research work, although Antarctica is located at a very high latitude, solar radiation is relatively weak, and low temperature, storm, villainous weather condition, polar nights impact the efficiency of PV power generation, the light that is present during polar daytime in the summer can ensure that photovoltaic systems provide energy to some seasonal stations (Cantuária et al., 2017).

Furthermore, Antarctica's katabatic wind ensures relatively stable wind environments that are well-suited to generating electricity all year round in the vicinity of most research stations. Although photovoltaic and wind power generation are not stable enough and have a certain amount of uncertainty, they can supplement conventional fossil fuel energy sources. In addition to having a power grid with diesel generators, many stations also have photovoltaic power generation and wind power generation systems connected to the original grid. Newly built stations have significantly increased the proportion of renewable energy they use (Tiago et al., 2016). According to data from COMNAP, at least 29 facilities in Antarctica have installed renewable power generation (Lucci et al., 2022). Table 1 lists some examples of renewable energy installation in Antarctic research stations (Li et al., 2021a).

Table 1 Renewable energy information for some Antarctic research stations

Country	Name of station	Installed wind power generation capacity/kW	Installed PV generation capacity/kWp
Australia	Casey Station	–	30.0
Australia	Mawson Station	1×300	–
U.S./New Zealand	McMurdo Station/Scott Base	3×330	–
Belgium	Princess Elisabeth Station	9×6	50.6
Brazil	Comandante Ferraz Antarctic Station	8×6	8.4
China	Zhongshan Station	3×10	10.0
France	Dumont d'Urville Station	2×10	–
Germany	Neumayer Station III	3×10	–
Italy	Mario Zucchelli Station	–	65.0
Japan	Syowa Station	–	55.0
Norway	Troll Station	–	762.5
Republic of Korea	Jang Bogo Station	–	40.0
United Kingdom	Rothera Station	–	8.8

Notes: Some data are from the official websites of these research stations (Tina et al., 2010); "–" meaning not yet installed.

PV system gives DC voltage as its output, while wind power generation system's rectifiers convert wind speed-related AC voltage into DC voltage; the type and form of the conventional output of renewable energy can be defined as DC. However, in actual applications, these research stations all use converter method and turn DC into AC to connect to the grid. In the end, renewable energy is providing power to stations using a form of AC. The inversion sector in the network adds to the system's complexity and decreases energy efficiency (Cantuária et al., 2017). In terms of addressing this problem, the following is an overall analysis and comparison that looks at the feasibility of the DC power distribution adopted by Antarctic research stations regarding technology, economics and safety.

2.1 Requirements analysis of voltage amplitude conversion

A significant advantage of an AC power supply is that it can conveniently use a transformer to convert voltage and transmit energy over long distances with less energy waste. Looking at the current situation at Antarctic stations, with the exception of the extensive Amundsen-Scott South Pole Station (16107 m^2 of the area under roof) and the McMurdo Station (32750 m^2 of the area under roof), which use a 4160 VAC power supply and need transformers to transmit energy inside the station, the total building area for all other research stations is less than 10000 m^2. Some countries' seasonal stations are less than 100 m^2, and require only low-voltage electricity to satisfy their needs. Alternatively, they can also set up multiple power stations to ensure that they have a power supply nearby, avoiding the problem of excessive energy waste when transmitting low-voltage high-current energy. Because there is no need to use a transformer to increase or reduce the voltage amplitude and transmit energy over long distances, AC is not always necessary for power distribution systems in stations (West et al., 2016). On the other hand, the DC system must use power electronics device to realize voltage matching and energy interaction between different power grids and DC networks (Xiong et al., 2018).

2.2 Convenience of connecting to the grid

Connecting different power sources to the grid is one of the most complicated parts of operating a station's power system. First, natural conditions in Antarctica are very harsh, so it is essential to ensure that research stations have a reliable power supply. Applying redundant power sources is the most used method to enhance the safety and reliability of power supply systems. This method includes setting up multiple backup diesel generators that complement one another in scattered locations within stations, and choosing multiple forms of energy, such as diesel generators, PV cells, wind power generators, and energy-storing batteries to provide power in stations (Li et al., 2021b). These electricity sources must operate on a fundamental grid and be able to connect to and disconnect from the grid as necessary to ensure the uniform distribution of power.

Currently, all research stations use an AC grid, and during a process of connecting to the grid, to synchronize a power source, four conditions must be met simultaneously, namely phase sequence, voltage magnitude, frequency and phase angle; only then will it be able to access the network smoothly (Li et al., 2021a; Shen et al., 2019). If even one of the four parameters diverges, it will fail to connect to the grid, and could even cause the grid to collapse. However, if a DC power supply is applied, the grid-connection process becomes much simpler; the network can be accessed seamlessly if the voltage magnitude of the accessed power source is within a range that the voltage amplitude of the fundamental DC grid can handle. Compared with an AC grid-connection, a DC grid can do so with much less difficulty and are more convenient to maintain—a noticeable advantage for Antarctic stations that must regularly connect to the grid (Cantuária et al., 2017).

On one hand, because these research stations connect to the grid by using multiple power sources. On the other hand, it is a challenge to integrate renewable energy sources directly into the grid because of their intermittence, randomness and the uncertainty caused by Antarctic special meteorological factors (Planas et al., 2015). In this sense, smart microgrids must be set up to coordinate the balance and stability of power supply and distribution systems, so they can be managed and allocated uniformly.

The U.S. Department of Energy defines the microgrid as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode" (Hernández Mayoral et al., 2021; Ton and Smith, 2012) (Figure 1). Microgrids contribute to modifying flexibility, reliability, resiliency, and accessibility of green and safe energy with the ability to participate in demand response, cost optimization, and grid-balancing programs. Microgrids can be categorized via different aspects ranging from the structure such as DC, AC, or hybrid (Anvari-Moghaddam et al., 2021). According to the case study, the optimization strategy of intelligent microgrid for civil buildings can reduce the annual cost by 5.2% and achieve the effect of energy saving (Ni and Zheng, 2023).

The power electrics devices in a DC grid can be controlled more easily and precisely than conventional switchgear found in an AC grid, and they are also a closer match with microgrids (Raimi and Carrico, 2016).

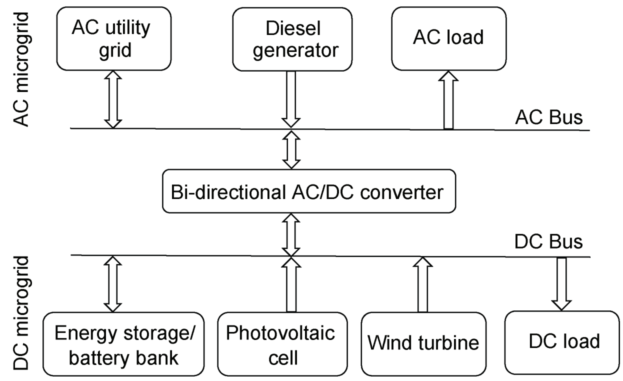

Figure 1 Topological graph of microgrid.

2.3 Safety of human and equipment

Both DC and AC can function normally and ensure the safety of the human body and equipment when conforming to the relevant standards and codes. However, if a direct or indirect electric shock occurs, in terms of the physiological effect that electrocution has upon personnel, AC will cause more serious ventricular fibrillation and carry a greater risk of severe injury or even death than DC of the equivalent voltage amplitude. Furthermore, if an extra-low-voltage DC supply is used, the power system will be of a higher degree of safety; this is extremely important in places like Antarctic stations, which have limited medical resources.

Second, because DC power supplies usually use floating or high-impedance grounding, even if a first insulation fault were to occur, the system only has a line capacitive current, which is very tiny and presents a negligible risk to human beings. This means that the safety level of personnel at the research station has been greatly improved. It is not necessary to isolate the fault by cutting off power. Thus, after being alerted, operation and maintenance personnel can deal with the electrical problem as soon as possible. Compared with the passive method of protection used in AC systems, where electrical protective components are used to cut off the power immediately, this proactive method of operation and maintenance ensures the continuity of the power supply, is more reliable, and much safer in terms of the risk of suffering an electric shock for personnel in research stations, as well as the risk of an electrical fire existing in a station building (Zhang and Dai, 2019).

Nevertheless, an insulation monitoring device (IMD) is obligatory in the DC power supply system to monitor the system's insulation. Operating and maintaining the system is more complicated than a conventionally grounded system. Considering that Antarctic research stations have professional electric engineers who are constantly monitoring the systems in those stations 24 hours a day, 7 days a week, as well as the station's limited areas, it means that the operation and maintenance of these systems can be guaranteed. China's Kunlun Station, France's Dumont d'Urville Station, and Japan's Fuji Dome Station currently use AC IT earthing systems (all live parts of the power supply are insulated from the earth); although these cannot be directly applied to DC systems, the principle and topology of their monitoring systems are similar.

2.4 Electric power quality

The directions and magnitudes of the DC power supply voltage do not change based on time. No harmonics exist in the power system, and the DC power quality is higher than that of AC all of which is more friendly toward electronic loads. There is no such thing as reactive power in DC networks, so the system does not adjust reactive power. A DC grid can provide higher power quality and lower equipment costs than an AC grid (Whaite et al., 2015).

2.5 Analysis of electric loads

In terms of function, electric loads in Antarctic stations predominantly include lighting, scientific research equipment, kitchen equipment, electrical heating equipment, electromotors such as fans and pumps, mechanical equipment, charging devices, medical equipment, and electronic devices for daily life. Types of loads include electric resistance heating, switch mode power sources, electromotors, lighting driver modules, converters and electronic devices. These devices generally all use AC power supplies, but some devices cannot function properly if a DC power supply is used. Electric heating devices, LED lighting, DC recharging devices, and computers and network devices with switch mode power supplies can either use DC power supplies directly or receive their power supply from DC after slight modification (Sun, 2019; Zhao et al., 2020).

Network terminals based on IEEE802.3af and IEEE802.3at can be Powered over Ethernet (PoE) technology with DC output up to 30 W for each device. Some cases include wireless access point, wireless access controller, and network video cameras, which can be directly powered by DC from PoE switch. These are currently the most mature DC power supply products and systems. Electromotors that use voltage-source frequency converters can also be powered by DC. For loads like office equipment, electronic devices used in daily life, and medical equipment equipped with switch mode power supplies, when powered by a DC grid, a suitable voltage amplitude must be adjusted at the position between the DC grid and the load input-end, which indicates that the devices must therefore be modified. Because AC is necessary to set up a rotating magnetic field, induction motors must use AC electricity for their power supply to operation (Figure 2).

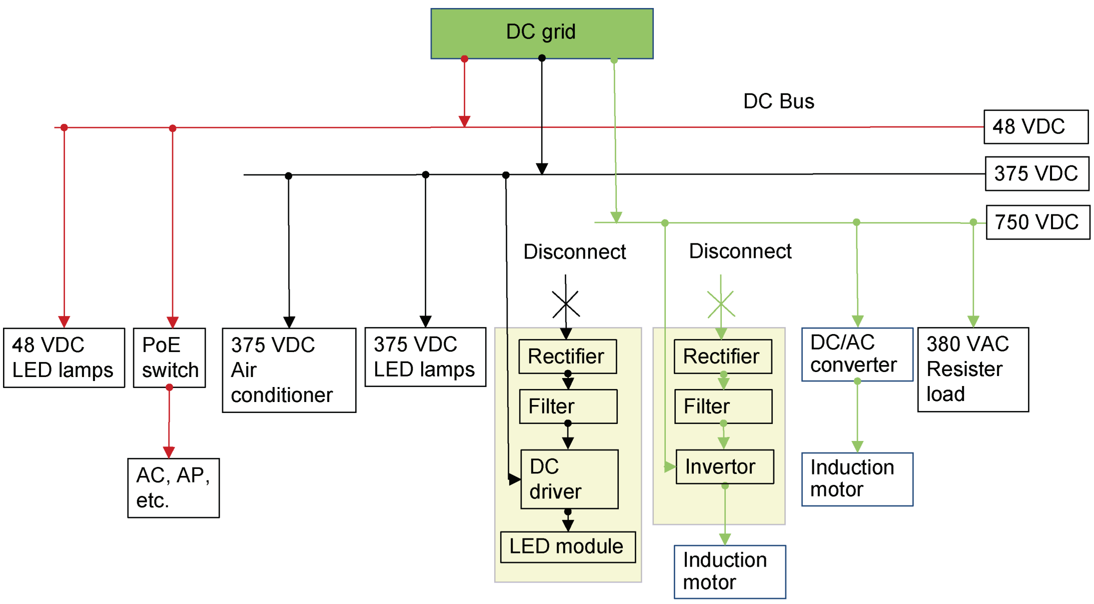

Figure 2 Different ways for electrical loads connecting to DC grid.

Consequently, one can see that the types of devices and loads that can directly connect to DC power grids is relatively limited; most devices require modification on the power input or the use of an adaptor to access DC. Although some devices can function correctly only if they are powered by AC, a converter would be set up to convert the voltage so it can then provide AC power to such devices—one of the most significant obstacles to applying DC power.

The use of DC power supplies in Antarctic research stations is theoretically feasible in terms of technology, safety, economical and maintenance. Unfortunately, when considering the reliability of the power source and specific loads, most research stations must still use AC diesel fuel power generators to obtain their power under current circumstance, and it is still not possible for them to obtain all their energy from DC power supplies. However, some loads or facilities can use DC or AC and DC power supplies together, with the power supply source having both AC and DC. These feasible methods can be applied to Antarctic research stations in their current form.

3 DC power supply practices

The analysis in section 2 demonstrates that DC power supplies can easily connect to grids and are convenient for consuming and receiving renewable energy. These are the main reasons for DC to be applied to Antarctic research stations.

There are many successful examples of projects with zero energy consumption, such as the Powerhouse Brattørkaia building in Norway, the Unisphere office building in the U. S., and the Petinelli headquarters in Brazil (Jiang et al., 2021). These practices either use renewable energy as their primary power source with the municipal grid serving as a backup, or even not access the grid at all and primarily (or entirely) use DC power supplies inside the building. These projects all at least have partially achieved their goals of DC illumination, DC charging, and DC supplies for some electronic devices (Li et al., 2020; Omrany et al., 2022).

Reliability is the basic principle for Antarctic research stations, therefore most year-round stations cannot use renewable energy alone as their primary energy supply. Consequently, the primary strategy for DC power supply and distribution in stations involves relying on renewable energy and trying to achieve breakthroughs with electric heating, DC lighting, and DC charging.

During 2004 to 2010, one 10-kW wind power generator was installed in China's Zhongshan Station, with generated energy serving to melt ice into freshwater. Because the heater is a resistance load, it can operate with both DC and AC electricity, whereas the task of melting ice does not have any special requirements in terms of the continuity of the power supply or the electric power quality. Wind power generation delivers significant energy savings of over 3 MWh per month, equivalent to saving 600 L of diesel fuel. Not only does this reduce the cost of operating a research station, but it also reduces research stations' nitrogen oxide emissions as well as the noise from diesel generators (Qian et al., 2008).

Many Antarctic stations apply PV power. By combining energy storage batteries, they are used as the main power source in some cabins and shelters set up for scientific research that are far away from the power center of the stations. However, the power supply mode generally involves using PV DC to recharge storage batteries and then supplying power to equipment via AC by the converter. For most projects that only involve video cameras, satellite communication systems, and monitoring devices, such as unmanned monitoring platforms in protected ecological areas, remote automatic meteorological stations, and iceberg monitoring stations, they can operate under DC mode only with the energy supplied by PV and wind power along with storage batteries.

In the case of the lighting project for Zhongshan Station's gymnasium space designed by Architectural Design and Research Institute of Tsinghua University Co. Ltd, 24 down-light LED lamps were installed 7.4 m above the floor level. Instead of selecting standard 220 VAC input LED lamps with AC/DC drivers for each lamp, the designer chose concentrated lamp drivers that supply 48 VDC to each LED lamp. Each driver has a rated output power of 2400 W, with 20% of the excess quantity to extend the life span of the drivers and reduce temperature increases. Compared with having separate AC/DC driver in each lamp on the roof, concentrated drivers were installed in an electrical room for easy maintenance; and the total energy consumption of three concentrated drivers was 4% less than that of 24 single-lamp drives, with 23% less total harmonic distortion of current because of high quality AC-DC rectifier and DC filter. From this example, a concentrated AC/DC driver for LED lamps has a significant advantage in power quality improvement and energy savings. In some specific spaces, local areas or even entire stations, DC can be applied to the lighting systems. This DC application is currently the most mature and easy-to-implement.

The author also once participated in constructing Brazil's Antarctic Comandante Ferraz Station as a consulting engineer. In its design proposal, two types of renewable energy, PV and wind turbines, were used in the station to save fuel consumption, and lithium batteries were set up to store energy and cooperate with the diesel generators to jointly provide power to the station. In 2013, during the design optimization stage, the author envisioned separating the station's power source into a DC and AC segments, and using a smart microgrid to controll them separately. Unfortunately, it was impossible because no mature and reliable dual DC and AC microgrid controller was available on the market at that time. The sole AC output was kept as the original design, with each DC unit connecting to the AC grid via a converter. After 2021, several types of mature dual AC and DC microgrid control systems based on renewable energy applications emerged in the market, providing technological support for the future development of DC (Planas et al., 2015).

The author also participated in a project to modify an offshore island's power supply and distribution system. Although the project was not in Antarctica, this case was still helpful as a reference. The total area of the building on the island was nearly 3500 m^2, separated from the mainland by the channel. No municipal grid could be accessed, and two 150 kW diesel generators had been set up as the main power source previously. After renovation, the original two 150 kW diesel fuel power generators were adjusted as a backup power source. Newly installed 200 packs of 350 Wp polycrystalline silicon solar panels with a peak power of 70 kWp, and four 30 kW wind power generators mounted on the windward side of the island with a peak output of 120 kW together served as the main power source. A 400 Ah lead-acid storage battery was connected to the local grid to store the surplus energy and balance the load.

The power supply and distribution used a new hybrid mode DC-AC electricity mode. Two complementary 150 kW energy routers were installed as grid controllers at the power source side. Energy routers combined microgrid DC bus technology to integrate multiple AC and DC power sources into separate AC and DC buses. The two buses are related and mutually independent, simultaneously giving an output of AC and DC electricity. In this project, the PV, wind power and the batteries accessed a DC power source, while the diesel generators accessed an AC power source. On the load side, two categories of LED lamps with different rated voltages of 48 VDC and 375 VDC were used for indoor and outdoor lighting, respectively. The previous variable-frequency fans and pumps based on a 220 VAC converter were all modified to 375 VDC input. After renovation, new DC variable frequency air-conditioner were powered by 375 VDC. Devices for daily living and research experiments were still supplied by 220 VAC electricity (Figure 3).

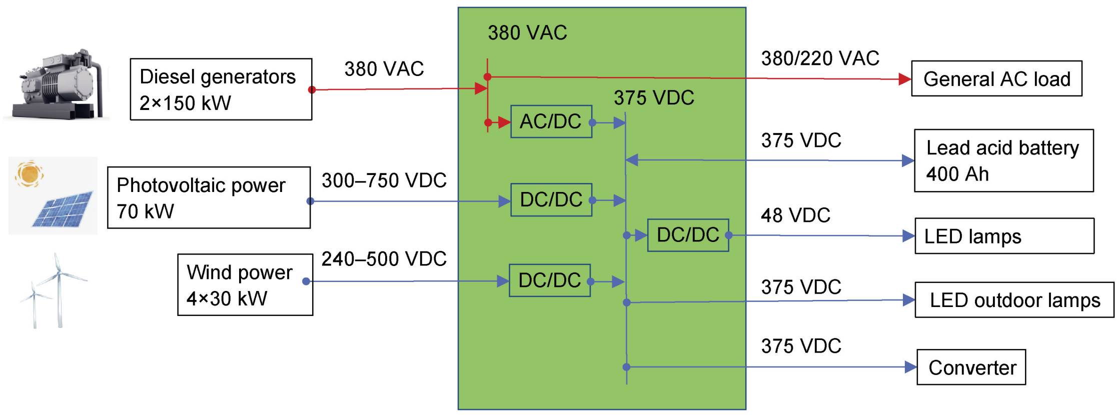

Figure 3 A topological map of an energy router system on an offshore island.

In a power distribution system, an energy router functions as power source convergence and load distribution, exerting control using a smart microgrid and prioritizing renewable energy consumption. Excess energy is used to charge batteries, while an optimal charging strategy is adopted for the batteries, to reduce their charging and discharging cycles for the extension of their life spans (Wang, 2016). If the capacity of electricity generated by renewable energy cannot meet the requirements of the loads on the island, batteries can be used to supplement energy; if the combined power is still insufficient or if the battery power gets used up, the backup diesel generators will then be activated to provide power.

The whole system has been operating well after modifications. Because there is abundant wind on the island, the wind power generators operate for over 7000 h at full power per year, generating more than 670 MWh of electricity. Furthermore, PV power generates around 60 MWh of electricity per year. Because renewable energy can almost satisfy the island's load requirement, diesel fuel generators must only operate for less than 40 $h \cdot a^{-1}$. This has resulted in savings of over 200000 USD annually in diesel fuel costs compared with that before the renovation. After the modifications, the DC system increased both the safety and reliability of the power supply while maintaining the AC system to satisfy the requirements of the induction motors and standard AC input devices. This example is a reference for hybrid AC and DC power systems in Antarctic stations.

4 Problems and exploration related to DC power supplies

DC power supplies have the following advantages compared with AC power supplies when applied in Antarctic research stations.

(1) When multiple types of renewable energy or batteries must connect to the grid, choosing DC mode can reduce the complexity of connecting to the grid.

(2) When providing electrical power to DC devices, rectifying and filtering AC is no longer necessary, which could simplify the power supply system and reduce the system's energy consumption.

(3) It is much safer for human beings when low-voltage or floating grounding DC power supplies are used.

(4) DC monitoring systems for floating or high-impedance grounding systems can increase the reliability and continuity of power supplies, increase the level of operation and maintenance, and reduce the risk of electrical fires in stations.

(5) DC power grids do not have the problem of harmonic waves, and have higher power quality than AC grids.

There are also several disadvantages of DC power supply systems.

(1) In DC grids, transformers cannot be used to change the voltage when transmitting energy over long distances, and a more complicated DC-DC power converter is

required.

(2) Induction motors do not operate on a DC grid.

(3) AC diesel generators cannot access DC power grids directly, and a converter must be set up.

(4) DC electricity systems usually use floating or high impedance grounding systems because an IMD is required during operation, thus system operation and maintenance are more complicated than grounding systems.

(5) There are fewer types of components for DC power distribution systems than those for AC systems.

(6) Some electronic devices using AC inputs cannot access DC power grids directly or only access them after the devices have been modified or through an adaptor.

(7) The ripples in DC systems can reduce the quality of the electric power.

Further, because theories about DC power distribution have not yet been perfected, some technologies are not mature enough, and there are still some issues in the application of DC power supplies.

First, the specifications, codes and standards of low-voltage DC power supplies have not yet been perfected. Because low-voltage DC power supplies have developed only gradually in recent years in light of the application of renewable energy and power electronics, the specifications for civil buildings are based on AC power supplies, so there are not yet perfected specifications and standards that can support the design, manufactory, operation, and maintenance of low-voltage DC power supplies (Ou et al., 2022). However, WG9 in TC8 of International Electrotechnical Commission has standardized the voltage levels of medium and low voltage DC distribution systems, and in China, "Guideline for Standard Voltages of Medium and Low Voltage DC Distribution System (GB/T 35727—2017)" has also been published (Zeng et al., 2018). On the other hand, with products as an example, there is not yet a uniform market standard for DC power sockets and error prevention plugs, let alone requirements for different voltage level categories, and safety protection (Mo and Yu, 2019). There is still a long way to go to achieve the goal of the widespread promoting and applying DC electricity. However, it can be seen that DC products in some areas have formed a scale and established standards, for example, the notebook high-power USB Type-C standard power interface technology has been very mature and widely used. Standard commercial power plugs for 400 VDC systems up to 2.6 kW and compliant with IEC TS 62735-1 have already entered the market.

Second, there are not yet enough low-voltage DC power distribution products. AC power distribution systems have already been developed for over a century, and the entire product category is very comprehensive; these products are mature, have been perfected, and can satisfy the requirements of different applications. Because the area for applying a DC system is still relatively narrow, industry research and development cannot yet be comparable to what they are for an AC system, leading to many limitations in selecting and procuring power distribution components.

Interference from DC system ripples is another central problem with DC applications and research. Ripples reduce the efficiency of power sources, interfere with precision digital devices, and cause surges in voltages and currents, all of which can cause the failure of electronic devices. Therefore, attention should be paid to the ripple effect. Since ripple is the AC component of DC voltage, it is mainly caused in the AC-DC rectification and filtering stage. Therefore, adopting fully controlled polyphase rectification process and matching appropriate filtering measures can effectively reduce the ripple content at DC side (Liao et al., 2018).

Fortunately, more research is being put into these disadvantages of DC systems, which will help in promoting and applying DC power supply and distribution systems. Only policymakers, operators, manufacturers, and consumers working together can promote the development of DC systems.

What is expected is the use of fuel cells, which convert chemical energy of a fuel directly into DC electricity by electrochemical reactions. As long as fuel and oxygen are supplied uninterruptedly, electricity can be produced continuously. Then the problems of reliability and continuity of power supply in Antarctic stations can be solved perfectly. Compared with alternators, fuel cells have the characteristics of higher efficiency, lower noise, lower vibration, much less or near zero emissions, and are applied in Antarctic research stations with less impact on the surrounding environment. The current problems for fuel cells are the complexity of the operation, insufficient power capacity, short lifespan, high cost and the safety issue of hydrogen. If fuel cells can achieve reliable commercial applications, their DC output characteristics may fundamentally promote the popularity and development of DC systems.

In the AC power supply field, variable speed diesel generators allow the operation of the diesel engine at an optimal speed according to the electrical load, but require additional electrical equipment and control to maintain the power output to electrical standards. Results show a 27% fuel saving at 10% load down to 3.5% fuel saving at 80% load when running the engine at variable speed from 1200 $r \cdot min^{-1}$ to 1800 $r \cdot min^{-1}$ (Raisa et al., 2022), resulting in low greenhouse gases emissions and operating costs compared to a conventional diesel generator. This can also be one of the development directions for power supply research in Antarctic research stations.

5 Conclusion

Because Antarctic research stations are in a unique geographic location, renewable energy will become more crucial for supplying power to these stations in terms of energy savings and emissions reduction. The technology of smart DC microgrid is becoming more and more mature.

When adopting demand-side energy management's control strategy, the smart grid as simulated, can save fuel by 8.6% under certain circumstances (Tiago et al., 2019). If an appropriate control strategy can be formulated for the Antarctic research station, it will be more conducive to the promotion of a smart DC microgrid. Given these conditions and the advantages of DC power distribution systems in terms of the grid connection, energy savings, and safety, DC and hybrid AC and DC power supply and distribution systems are inevitable trends for future green and low-carbon Antarctic research stations.

6 Future work

In the next step, the author tries to create a hybrid power model based on the current generators, PV and wind turbines in Zhongshan Station, to simulate the operation of DC power distribution, and to compare it with the current AC mode in the station. And the differences in energy consumption, operation and maintenance and investment between DC and AC system will be quantified thereafter. I hope this work can provide data support for DC system application in future construction and renovation of Antarctic research stations.

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