Optimum Design Operation Principles and Simulation Results of DC Breakers in High Voltage DC System

Dedong Meng
Wuhan Institute of Marine Electric Propulsion, Wuhan, China.

Abstract. The feasibility DC power applied in distribution system is discussed. The efficiency and topologies of applying DC distribution for different purposes are investigated as well. For applying DC distribution, there are two key components, AC/DC converters and DC breakers. This thesis investigates the specification of converters suitable for applying in DC distribution system. In those converters, power losses are calculated as an index to compare their overall efficiency. Voltage control on the DC side and power factor correction on the AC side are also the primary requirements. Due to the absence of natural zero crossing current, the design of DC breakers is different from AC ones, therefore, in this thesis, the design rules of different DC breakers are investigated and their performance are also compared as a reference when selecting suitable DC breakers.

1. Introduction
In DC distribution system, the breaker is another key component besides the converter mentioned in the last chapter. However, the breaker design in DC distribution is not as simple as the mechanical breakers used in AC distribution due to the absence of natural zero crossing. In order to cut off direct current, other topologies of breakers applicable in DC environment have been investigated[1]. DC distribution gives several advantages. Converters and inverters in DC ZEDS possess the monitoring function and protecting the system during fault conditions. Because the input to converters is DC current, the complexity of design the current sensor and the algorithm required to detect fault conditions can be simplified. Therefore, the elimination of time lag associated with detecting AC faults would diminish the detection time and bring about improved continuity of power which means fewer uninterruptable power supplies may be required[2].

2. Sensitive commercial consumers distribution topology
At present, there are four types of sensitive commercial consumers and their power distribution topologies are not the same due to different requirements. They are power systems for generating station/substation, hospital, voice and data communication and data center. These systems are all implemented with emergent and auxiliary power system and their implementations, load types and system requirements are also different. Generating station and substation are crucial parts for whole power structure of one country. They are responsible for monitoring and operating the facilities in station to control the transmission of electricity. Especially when fault occurred, broken facilities should be repaired instantaneously. Therefore, the auxiliary power system of generation station and substation should possess independent power generating system to make sure that all facilities within the station can work normally under any faults to prevent devastating accidents[3].

Fuses, circuit breakers and switches are used to protect whole DC power system. Among them, the DC circuit breakers and switches directly utilize the ones used in AC power system with one pole
connecting to two phases and another pole connecting to third phase. Positive and negative poles use different cables to transmit electricity to prevent from short circuit occurrence. On the grounding issue, high impedance components are implemented to diminish the effects of ground faults. In addition, a monitoring system is installed to supervise the condition of under-voltage, over voltage and ground fault[4].

The electricity distribution in the station is presented in Figure 1. Most loads within are fed by low DC voltage. On the conversion from AC to DC, two converters are utilized to enhance the stability of system. 400 AC voltage is rectified to 110 DC voltage through rectifier and then provides electric power to DC load directly or proceeds to drop the voltage level to 24 DC voltage for other DC loads. On 110 DC voltage bus, batteries are implemented as a backup power.

![Figure 1 Electric power system in generating station and substation](image)

Hospitals are vital in the society today for providing people with medical services and responsible for managing the crisis. Therefore, independent power supply, water supply and communication system are necessary for hospitals to prevent any emergency. Power system of hospital is different from other end-users. For enhancing its usability, the power system is connected to the utility with two paths and diesel generator is linked to power system for preventing emergency. The advantage of high stability in DC distribution makes itself a better choice than AC distribution in medical equipments which are highly sensitive to power quality[5].

3. Industrial building distribution topology

Typical loads in industrial building are most motor-driven application, such as mechanical arm, refrigerating equipments, automatic conveyer, etc. Other loads used by operators, such as electronics, PC, lighting and HVAC, etc. only take a small part of total electricity consumption. Conventional industrial building distribution is illustrated in Figure 2. Besides for AC-fed motors, other applications driven by variable-frequency motor would require at least one stage of power conversion and auxiliary facilities used by operators which are most digital electronics would require two stages to connect with the utility. To prevent the cost caused by fault and outages, UPS system is used to protect critical load for short period and diesel generator is used to provide long-time power support[6]. With DC distribution applying within industrial building, as shown in Figure 3, except for AC motor which would require one additional stage of conversion like the case in commercial building, other loads could utilize DC power directly through centralized AC/DC converter and save the cost of individual converters. For auxiliary power system, energy-storage components, such as battery, could be easily achieved the function of power support during outage for long duration[7].
4. Operation principles and design rules
The solid-state breaker consists of one semiconductor switch and one varistor. The operating process has only two stages which are described as followed:

Stage 1:
As same as three topologies mentioned before, the fault current in the semiconductor switch increases until the maximum tolerable current of the switch is met which is shown in Figure 4(a).

Stage 2:
After the switch T is turned off, the varistor begins to demagnetize the fault current as shown in Figure 4(b).

5. Conclusion
DC distribution system, nowadays, has been applied to some fields for years. Due to more digital electronics and renewable energy application emerging to the market, the advantages of DC distribution over AC distribution have been discussed recently. Although loads at present are fed by AC voltage, most of them can be considered as DC without their individual rectifier at front end.
Therefore, the ratio between AC and DC loads are adjusted and the feasibility of applying DC distribution is reconsidered. The efficiency of DC distribution for different purposes has been discussed. From the view of load end, applying DC distribution can save conversion stages to enhance overall efficiency. From the view of generator end, DC distribution is superior if the amount of renewable energy occupies a large part of total energy consumption. Finally, the environmental feasibility of DC distribution has been discussed. In this thesis, the key components in DC distribution, AC/DC converters and breakers, are discussed. The operating principle and comparisons between different topologies are presented at next chapter.

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