Optimum Design of Converter and Circuit Breaker in High Voltage DC System

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Abstract. Recently, the shortage in fossil fuel causes the inflation around the world. Every nation is aware of the energy dependence on the imported oil and starts to invest on the replaceable energy such as fuel cell, solar cell and wind power. Besides of exploring more energy, cutting off the energy waste is another solution. At present, there are more digital electronics and applications of variable-frequency motors utilized at home or in office building in order to enhance the efficiency and performance. In addition, in IT industry, the amount of energy consumption in data centers is always an issue worthy to be considered. Due to the strict requirement of electricity quality, uninterruptable power system and protection facility are implemented which would result in loss in the process of electricity transmission. Therefore, with a little improvement in efficiency, considerable energy waste would be saved.

1. Introduction

Nowadays, with more energy consumption in the form of DC (direct current) power, the feasibility of DC low voltage distribution regains the attention since the war between AC (alternate current) power and DC power in 1870 to 1900. Applications utilized DC distribution technique are also investigated in different fields[1]. The main niche in DC power system lies on the features of power decoupling and transmission efficiency within low distance or high voltage. Power decoupling makes energy with different frequency can join together easily and higher transmission efficiency is achieved due to the absence of reactive power. As more and more DC loads, such as digital electronics and variable frequency motors, and DC generators, such as fuel cell and solar cell, are utilized in the distribution system, efficiency enhancement of using DC distribution would be more apparent. Due to this benefit, data centers manufactures and buyers are also interested in how much power can be saved through DC distribution[2].

2. The utilized ratio between AC-fed and DC-fed loads

For considering the factors of lighting abilities such as, stability, start-up speed and utilized efficiency, conventional electromagnetic ballasts are gradually eliminated from the market. The basic topology of electronic ballasts is as indicated in Figure1. The circuit topology is similar to application of variable-frequency motor. First, AC power is converted to DC power by the rectifier and then high frequency voltage is provided to the load by resonant converter after power factor correction (PFC) circuit. Supposed that DC distribution is applied, rectifier and PFC circuit can be saved and resonant converter can be directly fed by DC bus in DC distribution[3].

From the examples above, although residential and commercial facilities all operate in AC power now, many electronic loads are fed by DC voltage in the end of power transmission or by the AC
voltage with determined frequency and magnitude after adjusted by the inverter from the DC voltage. For these loads to operate normally in DC distribution, the only modification is to remove front end circuit[4].

According to statistics of Bureau of Energy, Ministry of Economic Affairs, the average utilizing electricity per year are separated into five categories. After calculating electricity utilizing ratio and the efficiency in different distribution of each type of load, Here, HVAC, lighting, video/audio groups are classified to DC loads, while kitchen and hygienic appliances are referred to AC loads. One assumption is made here that conversion stages are calculated from PCC to end user. The result shows that with high proportion of energy consumption on kitchen and bathroom application, efficiency of AC distribution is better than DC one. However, if the proportion of DC application, such as variable frequency motors, increases in these two fields. The overall efficiency in DC distribution would exceed AC one[5].

3. Power loss analysis

For calculating conduction loss in CSC, current average and rms values run through transistor are required. This is achieved by calculating the current flowing through one bridge leg within one pulse half period. One assumption should be made here that on the AC side, each phase current flows from the mains is in phase with each voltage and is also a perfect sine wave; while on the DC side, the DC current is a constant. Modulation index, which is the ratio of the peak value of AC current to DC current. The conduction loss results from the current through the transistors and diodes. The switching loss in transistor is turn-on and turn-off loss, while the switching loss in diode is mainly turn-off loss, i.e., reverse recovery energy[6]. Figure 2 shows the AC phase current operated in rated power. The peak value of phase current complied with theoretical value is close to 120 amperes. As indicated in Figure 3, the total harmonic distortion of phase current is calculated as 2.5%. To verify the functionality of PFC, the phase current is shown with phase voltage in Figure 4 as well as the power factor which is 0.99[7].

![Figure 1 Front end circuit of the lighting under DC distribution](image)

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![Figure 2 Phase current at mains operated in rated power](image)
At first, two converters qualified with the specified voltage levels and power rating have been chosen as the desired converters employed in dc distribution. Then, the operation principles and the proposed carrier-based space vector control of CSC were introduced. After that, the simulation results validated the proposed method. Following the same track, the operation principles and simulation results of DAPF with ZVS H-bridge converter were also shown. Furthermore, power losses in switching and conducting are calculated with simplified model of switching components and some assumptions. Finally, after deciding a standard characteristic of 66 switching component and other parameters to calculate power loss, a brief comparison between two converters is shown. As can be seen in the results, DAPF with H-bridge has almost equal performance with CSC, but better efficiency instead. Therefore, DAPF with H-bridge should be the best selection considering performance and efficiency at the same time.

4. Operation Principles and Simulation Results of AC Breakers

U.S. Navy has been investigating the implementation of a DC Zonal Electric Distribution System (DC ZEDS) for the next generation of surface combatant. In replacing the AC radial distribution system, appreciable improvements can be realized in enhancing the survivability and lowering weight, manning and cost. As observed generator transforms the mechanical energy from prime mover into AC electricity and then transmitted to each electrical zones via the port and starboard buses after converted to DC power by a rectifier[9].

Step-down DC-DC buck converter connects each bus to an electrical zone and adjusts the bus voltage downward to the level appropriate for the requirements of DC-AC inverter and other DC loads. Then, the inverters would serve to provide single or three-phase power to the AC load in the zone.
Parallel structures of converters and inverters would enlarge the power capacity and offer the needed redundancy[10].

5. Conclusion
A research on feasibility of a DC network for commercial facilities has been carried out in Chalmers University of Technology, Sweden. A case study in practice was done by analyzing the supply to the building, Department of Electric Power Engineering. In that research, voltage drop and power loss calculations yielded by transmission lines were compared for different voltage levels.

In this thesis the operating principles and design rules of four different topologies employed in the DC low-voltage environments are discussed. With the calculated parameters, the simulation results are shown to verify the theory. Finally, a brief comparison respect to the stress on the component and maximum fault current is given. With these outcomes, a suitable breaker can be selected according to the requirement of the DC system.

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