**Reactive Power Impact of Power Electronic Devices in the HVDC Grid**

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***Abstract*— Reactive power usage in the modern power systems is a topic of increasing significance, especially with the proliferation of power electronic technologies. This research delves into the complexities introduced by power electronics and their impact on reactive power. Through a comprehensive analysis, we uncover the deviations from traditional paradigms, emphasizing the importance of apparent power and its role in understanding the dynamics of reactive power exchange in power systems. We also investigate the effects of AC system disturbances on reactive power consumption in DC systems. This research contributes to a deeper understanding of the evolving landscape of reactive power consumption and its implications for modern power grids.**

***Index Terms*—** **Reactive power, Power electronics, Apparent power, Power factor, DC systems, AC systems, Commutation failures.**

1. **Introduction:**

In traditional power distribution system, inductors and capacitors, as passive components, can absorb reactive power from the system or send reactive power to the system [1]. Since the voltage and current are both sinusoidal waveforms, the problem of reactive power consumption can be well understood, and there are specific components, overall, there is no need to elaborate.

However, the development and wide application of power electronics technology causes the current to distort in the power network [2-3]. The traditional concept of reactive power consumption by specific components is difficult to explain the reactive power phenomenon under the condition of current and voltage distortion. In order to better understand the reactive power consumption caused by power electronic components [4-6]. A simple but typical example can be used to illustrate the thyristor control circuit shown in Fig. 1. The load in the figure is a pure resistor, but with the trigger angle α, when the power supply voltage waveform is sinusoidal, the current waveform flowing through the resistor is distorted. This circuit can calculate its power factor:

Where VR stands for the effective value of the voltage across the resistor, V stands for the effective value of the sinusoidal voltage of the power supply, and I stands for the effective value of the loop current [7-9]. According to Figure 1, the effective value VR of the voltage across the resistor can be obtained.

It can be concluded that its power factor is:

It can be seen from equation 1 that although the load is pure resistor, the larger the trigger angle α, the larger the current distortion and the smaller the cosα are. This result is completely contrary to the conclusion that the power factor of the pure resistance load in the sinusoidal circuit is equal to 1 [10-11]. In this case, the phenomenon that the power factor is less than 1 occurs not due to the energy storage element in the load but due to current distortion. Looking further, within the range of 0-α angle, the instantaneous power is zero, that is, the power supply stops transmitting power. In a cycle, p≥0, so there is no power transmission from the load to the power source, only power transmission from the power source to the load, that is, there is no energy exchange between the power source and the load [12-14].

Since the apparent power VI of the power supply in this circuit is greater than the average power VRI of the load, when the power supply generates the load power VRI, the power supply has to provide a part of the current that is not needed to generate the load power [15]. That is, due to the control effect of the thyristor, the circuit consumes not only the average power but also some useless power. The larger the trigger angle α, the larger the useless power consumption.

There are many converter units consisting of thyristors and relevant converter transformers in DC power transmission system. The leakage reactance of the converter transformer affects the duration of the commutation process [16-17].

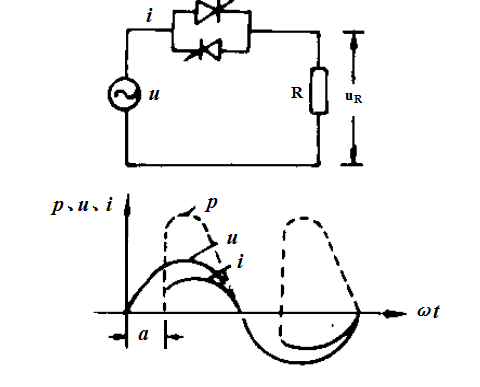
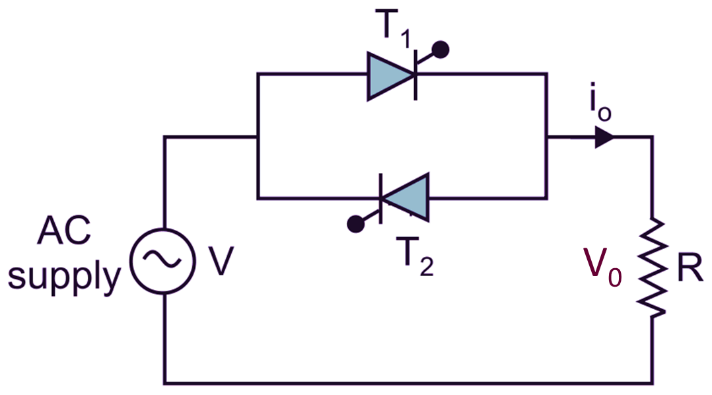


Fig. 1. Thyristor control circuit and its waveform of voltage, current and power

. In stable operation period, the main factor affecting reactive power consumption is the change of the commutation process. As the DC current increases, the commutation process also becomes longer. More AC filters are required to compensate for the reactive power consumption in AC system.

Therefore, the problem of reactive power consumption of power electronic devices cannot be explained by the traditional concept of specific components providing or consuming reactive power [18]. However, it can be explained by the concept of apparent power in the power system, that is, in the process of power transmission of power electronic devices, the apparent power is greater than the average power of the load, indicating that the power transmission of power electronic devices is accompanied by reactive power consumption [19].

When the AC system fault on the inverter side of the DC system causes commutation in the DC system, the voltage amplitude of the AC system drops and the DC current rises, which means that the turn-off angle and commutation angle of the inverter side increase at this time [20]. The trigger angle on the rectifier side increases due to the decrease of the DC voltage on the inverter side, and the increase of the DC current also increases the commutation angle. Hence, the reactive power consumption is greatly increased [21].

1. **Analysis of reactive power consumption in DC system**

During the operation of the DC system, due to the leakage reactance of the converter transformer and the equivalent reactance of the system, it is mainly the leakage reactance of the converter transformer, which makes each valve consume a large amount of reactive power in the process of mutual commutation. The corresponding formula is used to calculate the reactive power consumption of the DC system during steady-state operation;

The reactive power consumed by the rectifier (12-pulse converter) can be obtained by the following formula (for inverters, α should be replaced by γ):

Where,

*“Qconv*” refers to the reactive power consumed by the rectifier,

*“Id*” refers to direct current

*“Udi0*” refers to the no-load DC voltage of each group of six-pulse converters

*“dx”* means inductive voltage drop

“u” refers to the commutation overlap angle

“α” refers to the trigger angle;

“γ” refers to the extinction angle;

Regarding the reactive power consumed by the DC system during the commutation failure process caused by the disturbance of the AC system, although there is a deviation in the calculation accuracy, the equation (2) can also be used for approximate calculation. However, due to the distortion characteristics of the AC system voltage at this time, the amount of calculation can only determine the magnitude of commutation angle by the actual commutation time of the measured current. Because of the voltage distortion of the AC system, the trigger angle and the turn-off angle are only approximate values, so the reactive power calculated by the above formula has deviation.

When the commutation failure of the DC system occurs, the DC voltage will drop rapidly and the DC current will increase rapidly. Due to the function of the DC control system, the trigger angle of the rectifier station and the turn-off angle of the inverter station will increase, which will consume a lot of reactive power. Both conventional ±500kV DC transmission projects and ±660kV DC transmission projects have this feature.

The reactive power exchanged between the AC system and the DC system mainly depends on the reactive power in two aspects. One is the reactive power consumed by the DC system during the commutation process. The amount of reactive power in this part mainly depends on the factors such as unload voltage, direct current, trigger angle or turn-off angle, commutation angle, etc. The other is the capacitive reactive power provided by the reactive power compensation device including AC filters and shunt capacitors. During normal operation, the reactive power consumed by the DC system is basically balanced with the reactive power provided by the reactive power compensation device, which means that the reactive power exchanged between the AC and DC systems is relatively small.

When the commutation failure of the DC system occurs, the DC current increases, the trigger angle or the turn-off angle increases, and the commutation angle increases. The combination of these factors leads to a significant increase in the reactive power consumed by the DC system, and the reactive power capacity provided by reactive power compensation device is constant, so the difference in reactive power must be absorbed from the AC system. If the reactive power consumption of the DC system reduces the voltage of the AC system, the reactive power provided by the reactive power compensation device will be further reduced. The AC system needs to provide more reactive power to make up for the reactive power consumed by the DC system.

The DC system absorbs a large amount of reactive power from the AC system. When the AC system fault is eliminated and returns to normal, the DC system should theoretically resume operation at the power level before the fault. In fact, the DC system has its own recovery characteristics and the current will decrease or even close to zero. The reduction of the transmission current means that the reactive power consumed by the DC at this time is greatly reduced, but the AC filter is not cut off at this time, so the DC system will send a large amount of reactive power to the AC system during the recovery process.

1. **Results:**

In this research endeavor, we have undertaken a comprehensive exploration of the complex realm surrounding reactive power utilization within power electronic systems, emphasizing the departure from traditional concepts based on specific components roles in absorbing or providing reactive power. As we have demonstrated, the development and widespread integration of power electronics technologies have introduced complexities in power networks, making it imperative to revisit our understanding of reactive power.

The investigation centered on a simple yet illustrative example, a thyristor control circuit with a resistive load. In this circuit, we showcased that even with a purely resistive load, the trigger angle, α, significantly influences current distortion and, consequently, the power factor. Contrarily to the conventional belief that a purely resistive load exhibits a power factor of 1 in a sinusoidal circuit, we unveiled that the power factor can be less than 1 due to current distortion. Furthermore, we identified a critical angle range (0-α) where instantaneous power becomes zero, signifying the absence of power transfer from the load to the source. This underscores the phenomenon of not only average power consumption but also the dissipation of useless power, which escalates with increasing trigger angles.

Moving beyond this specific circuit example, we extended our examination to the broader context of power electronic devices' impact on reactive power consumption. We emphasized that traditional paradigms, which attribute reactive power exchange to individual components, fall short in comprehending the complexities introduced by power electronics. Instead, we advocated for a focus on apparent power in power systems, highlighting that power electronic devices' operation entails apparent power exceeding the average power of the load, indicative of accompanying reactive power consumption.

Furthermore, the influence of AC system disturbances, such as commutation failures, on reactive power consumption in DC systems was explored. We found that such disturbances could lead to a rapid increase in reactive power consumption due to the interplay of various factors like DC voltage drop, DC current surge, and control system adjustments.

In the analysis of reactive power exchange between AC and DC systems, we underscored the interdependence of reactive power consumed by the DC system and the capacitive reactive power provided by compensation devices. During normal operation, these factors are balanced, but during commutation failures, the DC system's increased reactive power consumption necessitates additional reactive power from the AC system.

1. **Conclusion:**

This research highlights the evolving landscape of reactive power consumption in modern power systems, where power electronics technologies introduce complexities beyond the traditional understanding. Recognizing these complexities is vital for optimizing power systems, ensuring stability, and efficiently managing reactive power exchange between AC and DC systems. In the interplay between reactive power within AC and DC systems, we have emphasized the interconnected nature of reactive power consumption by the DC system and the compensatory capacitive reactive power supplied by associated devices. Under normal operating conditions, these elements remain in equilibrium. However, during instances of commutation failures, the heightened demand for reactive power by the DC system compels a supplementary supply from the AC system.

1. **Future Research:**

As the energy landscape continues to evolve, further research is needed to develop advanced control strategies and technologies that mitigate reactive power issues, improve energy efficiency, and enhance the overall reliability of power systems. This study serves as a foundational step in that direction, shedding light on the critical role of power electronics in the modern power grid.

**References:**

[1] R. Blasco-Gimenez, S. An˜o-Villalba, J. Rodrıguez-D’Derlee, F. Morant, ´ and S. Bernal-Perez, “Distributed voltage and frequency control of offshore wind farms connected with a diode-based HVdc link,” *IEEE Trans. Power Electron*., vol. 25, no. 12, pp. 3095–3105, Dec. 2010.

[2] J. Dai, D. Xu, B. Wu, and N. R. Zargari, “Unified DC-link current control for low-voltage ride-through in current-source-converter-based wind energy conversion systems,” IEEE Trans. Power Electron., vol. 26, no. 1, pp. 288–297, Jan. 2011.

[3] R. Li, S. Bozhko, and G. Asher, “Frequency control design for offshore wind farm grid with LCC-HVDC link connection,” IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1085–1092, May 2008.

[4] Z. Chen, J. M. Guerrero, and F. Blaabjerg, “A review of the state of the art of power electronics for wind turbines,” IEEE Trans. Power Electron., vol. 24, no. 8, pp. 1859–1875, Aug. 2009.

[5] J. Dai, D. Xu, B. Wu, and N. R. Zargari, “Unified DC-link current control for low-voltage ride-through in current-source-converter-based wind energy conversion systems,” IEEE Trans. Power Electron., vol. 26, no. 1, pp. 288–297, Jan. 2011.

[6] T. Zhou and B. Francois, “Energy management and power control of a hybrid active wind generator for distributed power generation and grid integration,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 95–104, Jan. 2011.

[7] J. Li, S. Bhattacharya, and A. Q. Huang, “A new nine-level active NPC (ANPC) converter for grid connection of large wind turbines for distributed generation,” IEEE Trans. Power Electron., vol. 26, no. 3, pp. 961–972, Mar. 2011.

[8] M. Liserre, R. Cardenas, M. Molinas, and J. Rodriguez, “Overview of ´ multi-MW wind turbines and wind parks,” IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1081–1095, Apr. 2011.

[9] N. Flourentzou, V. G. Agelidis, and G. D. Demetriades, “VSC-based HVDC power transmission systems: An overview,” IEEE Trans. Power Electron., vol. 24, no. 3, pp. 592–602, Mar. 2009.

[10] F. A. RaJowder and Boon Teck Ooi, “VSC-HVDC station with SSSC characteristics,” IEEE Trans. Power Electron., vol. 19, no. 4, pp. 1053– 1059, Jul. 2004.

[11] C. Guo and C. Zhao, “Supply of an entirely passive AC network through a double-infeed HVDC system,” IEEE Trans. Power Electron., vol. 25, no. 11, pp. 2835–2841, Nov. 2010.

[12] S. V. Bozhko, R. Blasco-Gimenez, Risheng Li, J. C. Clare, and G. M. Asher, “Control of offshore DFIG-based wind farm grid with linecommutated HVDC connection,” IEEE Trans. Energy Convers., vol. 22, no. 1, pp. 71–78, Mar. 2007.

[13] H. M. Turanli, R. W. Menzies, and D. A. Woodford, “A forced commutated inverter as a small series tap on a DC line,” IEEE Trans. Power Electron., vol. 4, no. 2, pp. 187–193, Apr. 1989.

[14] D. Jovcic, “Thyristor-based HVDC with forced commutation,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 557–564, Jan. 2007.

[15] J. W. Feltes, B. D. Gemmell, and D. Retzmann, “From smart grid to super grid: Solutions with HVDC and FACTS for grid access of renewable energy sources,” in Proc. IEEE Power and Energy Soc. General Meeting, Jul. 24–29, 2011, pp. 1–6.

[16] Electric Power Research Institute, CSG. (2011, Sep.). The ±200Mvar STATCOM has passed commissioning test in China Southern Power Grid (CSG).

[17] L. Luo, Y. Li, J. Xu, J. Li, B. Hu, and F. Liu, “A new converter transformer and a corresponding inductive filtering method for HVDC transmission system,” IEEE Trans. Power Del., vol. 23, no. 3, pp. 1426–1431, Jul. 2008.

[18] Y. Li, L. Luo, C. Rehtanz, K. Nakamura, J. Xu, and F. Liu, “Study on characteristic parameters of a new converter transformer for HVDC systems,” IEEE Trans. Power Del., vol. 24, no. 4, pp. 2125–2131, Oct. 2009.

[19] Yong Li, Zhiwen Zhang, C. Rehtanz, Longfu Luo, S. Ruberg, and ¨ Fusheng Liu, “Study on steady- and transient-state characteristics of a new HVDC transmission system based on an inductive filtering method,” IEEE Trans. Power Electron., vol. 26, no. 7, pp. 1976–1986, Jul. 2011.

[20] Yong Li, Z. W. Zhang, C. Rehtanz, L. F. Luo, S. Ruberg, and D. C. Yang, ¨ “A new voltage source converter-HVDC transmission system based on an inductive filtering method,” IET Gener. Trans. Distrib., vol. 5, no. 5, pp. 569–576, May 2011.

[21] M. Szechtman, T. Wess, and C. V. Thio, “First benchmark model for HVDC control studies,” Electra, vol. 135, no. 4, pp. 54–73, 1991. [22] Z. Wanjun, High Voltage Direct Current Engineering Technology. Beijing, China: Electric Power Press, 2004

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