

THD ANALYSIS OF LFAC TRANSMISSION SYSTEM

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ABSTRACT

This paper deals with the design of filters and THD analysis of a low-frequency ac (20Hz) transmission system. The LFAC system is interfaced with the 50Hz main power grid with a cycloconverter. The wind power is collected in dc form, and is connected to the LFAC transmission line with a twelve pulse inverter. The waveforms at the sending end and receiving end of the transmission line are plotted. THD analysis of LFAC system is carried out. The circuit model of LFAC system is simulated in MATLAB/SIMULINK.

KEYWORDS: LFAC, Wind Power, Cycloconverter.

INTRODUCTION

The wind is a clean and inexhaustible resource available all over the world. Recent progress in wind technology let the capacity of wind power increases significantly year by year. The challenges wind power introduces into power system planning and operation are mainly related to the fluctuating nature of wind velocity. Besides, the remote locations of many wind power plants often create significant bottlenecks for large-scale transmission of generated electricity.

Wind energy in particular, has shown strong growth and penetration, with several technologies showing sound economic fundamentals, even in the presence of minimal government subsidies. Significant levels of wind-penetration are being seen, with similar high levels targeted in many countries over the next two decades. As the world moves towards higher level of penetration of wind resources on the grid, there is increasing pressure to locate the large wind farms offshore, where the issues of noise and the impact on the landscape are somewhat ameliorated. Several offshore wind farms have been recently completed, providing experience of the challenges faced and the

solutions needed. The integration of offshore wind power plants with the main power grid is a subject of ongoing research. Presently, high-voltage ac (HVAC) and high-voltage dc (HVDC) are well-established technologies for transmission [1].

HVAC transmission is advantageous because it is relatively straightforward to design the protection system and to change voltage levels using transformers. However, the high capacitance of submarine ac power cables leads to considerable charging current, which, in turn, reduces the active power transmission capacity and limits the transmission distance. HVAC is adopted for relatively short (up to 50–75 km) underwater transmission distances.

Two classes of HVDC systems exist, depending on the types of power-electronic devices used: 1) line-commutated converter HVDC (LCC-HVDC) using thyristors and 2) voltage-source converter HVDC (VSC-HVDC) using self-commutated devices, for example, insulated-gate bipolar transistors (IGBTs) [2]. The main advantage of HVDC technology is that it imposes essentially no limit on transmission distance due to the absence of reactive current in the transmission line [3].

LCC-HVDC systems are capable of handling power up to 1 GW with high reliability [2]. LCCs consume reactive power from the ac grid and introduce low-order harmonics, which inevitably results in the requirement for auxiliary equipment, such as capacitor banks, ac filters, and static synchronous compensators. On the other hand, VSC-HVDC systems are able to independently regulate active and reactive power exchanged with the onshore grid and the offshore ac collection grid. The reduced efficiency and cost of the converters can be identified as drawbacks of VSC-HVDC systems [4]. HVDC is applied for distances greater than 100 km for offshore wind power transmission. Due to the limitations of HVAC and HVDC when applied for offshore wind farms, low-frequency ac (LFAC) transmission has been an alternative solution [5] – [8].

In LFAC systems, an intermediate-frequency level is used, which is created using a cycloconverter that lowers the grid frequency to a smaller value, to one-third its value. In general, the main advantage of the LFAC technology is the increase of power capacity and transmission distance for a given submarine cable compared to 50-Hz HVAC. This leads to substantial cost savings due to the reduction in cabling requirements.

PRINCIPLE OF LFAC SYSTEM

The ac electricity supplied by grid has two basic parameters: voltage and frequency. Using transformer, different voltage levels could be used flexibly in generating, transmitting, and consuming electricity to guarantee efficiency for different segments of the power system. The lower frequency electricity can be used to transmit larger power for longer distance, and the higher frequency electricity can be used more efficiently to drive the electric tools.

There are three factors limiting transmission capability, i.e., the thermal limit, stability limit, and voltage drop limit. For the long-distance ac transmission, the thermal limitation is not a significant impediment. Its load ability mainly depends on the stability limit and voltage drop limit.

The stability limit of an ac transmission line can be approximately evaluated by

$$P_{max} = \frac{V^2}{X}$$

where V is the normal voltage, and X is the reactance of the transmission line. We can see from the above equation that transmission capacity is proportional to the square of the normal voltage and inversely proportional to the reactance of the transmission line. The voltage drop ΔV % can be evaluated by

$$\Delta V\% = \frac{QX}{V^2} \times 100$$

where Q is the reactive power flow of transmission line. Thus, the voltage drop is inversely proportional to the square of voltage and proportional to the reactance of the transmission line.

Therefore, in order to raise transmission capability, we can either increase the voltage level or decrease the reactance of the transmission line. The reactance is proportional to power frequency f ,

$$X = 2\pi fL$$

where L is the total inductance of the transmission line. Hence, decreasing the electricity frequency f can proportionally increase transmission capability.

The LFAC uses fractional frequency to reduce the reactance of the transmission system; thus, its transmission capacity can be increased several fold. For instance, when frequency is 20 Hz, the theoretically transmission capability can be raised three times[6].

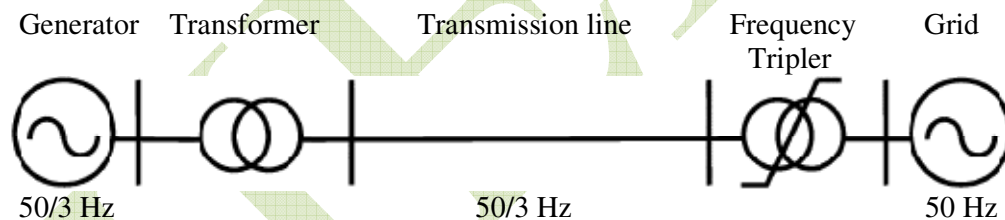


Figure 1: Basic structure of LFAC

The basic structure of LFAC is illustrated in Fig.1. The wind power generator in the figure generates ac power of low frequency (say 50/3 Hz), which is then stepped up by a transformer and transmitted to the receiving end of the transmission line where the low frequency ac power is stepped up to the industrial frequency. The wind power generator can easily generate low-frequency electric power because its rotating speed is usually very low. To generate low-frequency power, the only change for the generator is to reduce its pole number.

For the transformer, since the electric power that has to be stepped up is of low frequency, the core section area and the coil turn number must be increased. Therefore, the cost of the transformer in LFAC is higher than that of the conventional transformer. The conventional transmission line can be used in LFAC without any change. The frequency changer is the key equipment in LFAC, which can be either the saturable transformer or the power electronic ac-ac frequency changer, such as the cycloconverter. The ferromagnetic frequency changer has advantages of simpler

structure, lower cost, and more reliable operation, while the electronic type is superior in higher efficiency and more flexible in installation[6].

LFAC SYSTEM FOR OFFSHORE WIND POWER

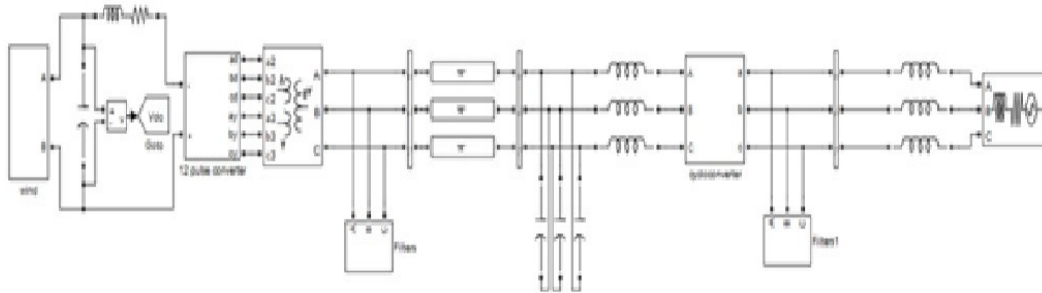


Figure 2: Configuration of LFAC Transmission System

In LFAC transmission the wind turbines are assumed to be interconnected with a medium-voltage dc grid. DC collection is becoming a feasible alternative with the development of cost-effective and reliable dc circuit breakers, and studies have shown that it might be advantageous with respect to ac collection in terms of efficiency and improved production costs.

The required dc voltage level can be built by using high-power dc-dc converters [9] and or by the series connection of wind turbines. By eliminating grid-side inverters, a medium-voltage dc collection system can be formed by interconnecting the rectified output of the generators[10].

The main reason for using a dc collection system with LFAC transmission is that the wind turbines would not need to be redesigned to output low-frequency ac power, which would lead to larger, heavier, and costlier magnetic components (e.g., step-up transformers and generators).

At the sending end of the LFAC system, a dc/ac 12-pulse thyristor-based inverter is used to generate low-frequency (20-Hz) ac power, as shown in Fig. 1. At the onshore substation (the receiving end), a thyristor-based cycloconverter is used as an interface between the low-frequency side and the 50-Hz onshore power grid. Thyristor-based converters can transmit more power with increased reliability and lower cost compared to VSC-HVDC systems. However, large filters are necessary at both ends to suppress low-order harmonics and to supply reactive power. Furthermore, the system can be vulnerable to main power grid disturbances.

The operation of the LFAC transmission system can be understood as follows. First, the cycloconverter at the receiving end is activated, and the submarine power cables are energized by a 20-Hz voltage. In the meantime, the dc collection bus at the sending end is charged using power from the wind turbines. After the 20-Hz voltage and the dc bus voltage are established, the 12-pulse inverter at the sending end can synchronize with the 20-Hz voltage, and starts the transmission of power. The cycloconverter which is used as a frequency changer produces harmonics of low order, hence filters are needed to add in the system[7].