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PERFORMANCE OF LFAC TRANSMISSSION SYSTEM FOR TRANSIENT STATE

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ABSTRACT

This paper deals with the transient performance of a low-frequency ac (20Hz) transmission system for a wind ramp event. The LFAC system is interconnected with the 50Hz grid with a Cycloconverter. The wind power from the offshore is in the form of dc, and is interconnected to the LFAC transmission line with a twelve-pulse thyristor inverter. The graphs of transient response of proposed system parameters are plotted. The circuit model of LFAC system is simulated in MATLAB/SIMULINK.

KEYWORDS: LFAC, Wind Power, Cycloconverter, Wind Ramp.

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.

Offshore wind power plants in future will have significant importance for electric generation due to its greater space availability and better wind energy potential in offshore locations [1]. Research is ongoing for the integration of offshore wind power plants with the grid. Recently, high-voltage ac and high-voltage dc are well-established technologies for transmission [2].

HVAC transmission is advantageous because it is easy to design the protection system and to change voltage levels using transformers. But, the high capacitance of submarine ac power cables leads to 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[3].

Two classes of HVDC systems exist, depending on the types of power-electronic devices used: 1) line-commutated converter HVDC using thyristors and 2) voltage-source converter HVDC using self-commutated devices, for example, insulated-gate bipolar transistors (IGBTs)[4].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[5].

LCC-HVDC systems are capable of handling power up to 1 GW with high reliability[3]. LCCs consume reactive power from the ac grid and introduce low-order harmonics, which results in the requirement for auxiliary equipment, such as capacitor banks, ac filters, and static synchronous compensators. 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[2]. HVDC is applied for distances greater than 100 km for offshore wind power transmission.

Due to these limitations of HVAC and HVDC when applied for offshore wind farms, low-frequency ac (LFAC) transmission has been a alternative solution[6] − [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, typically to one-third its value. 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. After the transformer was invented, different voltage levels could be used flexibly in generating, transmitting, and consuming electricity to guarantee efficiency for different segments of the power system.

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,

$$X = 2\pi f L$$

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 [7].

PROPOSED OFFSHORE WIND POWER LFAC SYSTEM

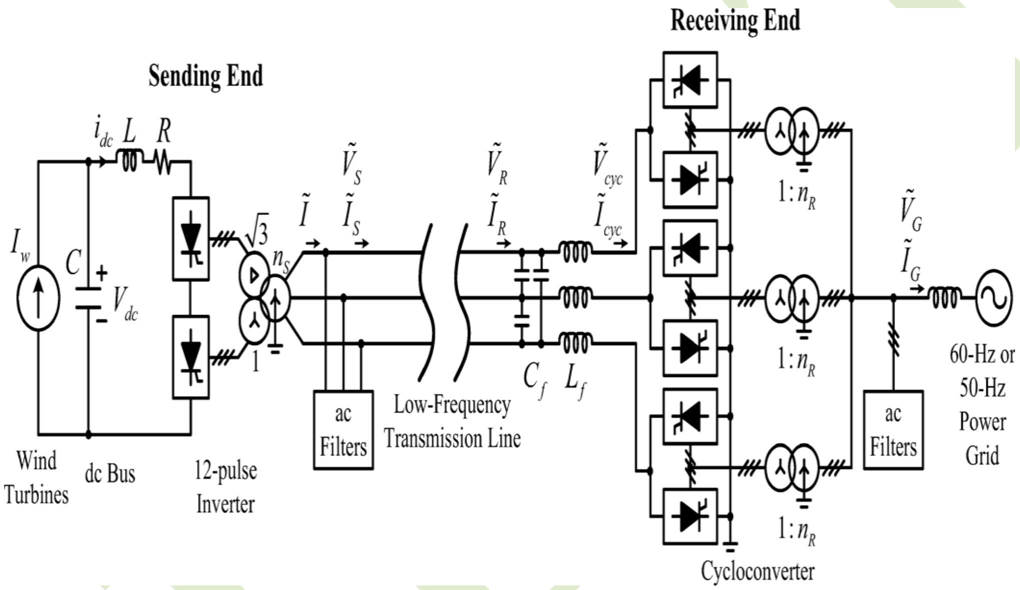

Figure 1: Configuration of LFAC Transmission System

The LFAC transmission system is shown in Fig.1, assuming a 50-Hz main grid. At the sending end, a medium-voltage dc collection bus is formed by rectifying the ac output power of series-connected wind turbines. A dc current source represents the total power delivered from the wind turbines. A dc/ac 12-pulse thyristor-based inverter is used to convert dc power to low-frequency (20-Hz) ac power. It is connected to a three-winding transformer that raises the voltage to a higher level for transmission. AC filters are used to suppress the 11th, 13th, and higher-order (23rd) current harmonics, and to supply reactive power to the converter. A smoothing reactor is connected at the dc terminals of the inverter. At the receiving end, a three-phase bridge (6-pulse) Cycloconverter is used to generate 20-Hz voltage. A filter is connected at the low-frequency side. At the grid side, ac filters are used to suppress odd current harmonics, and to supply reactive power to the Cycloconverter.

Simply, the operation of the LFAC transmission system can be understood to proceed 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.

POWER SYSTEM STABILITY

Stability of a power system is its ability to return to normal or stable operating conditions after having been subjected to some form of disturbance. Usually power system stability is categorized into Steady State, Transient and Dynamic Stability[9].

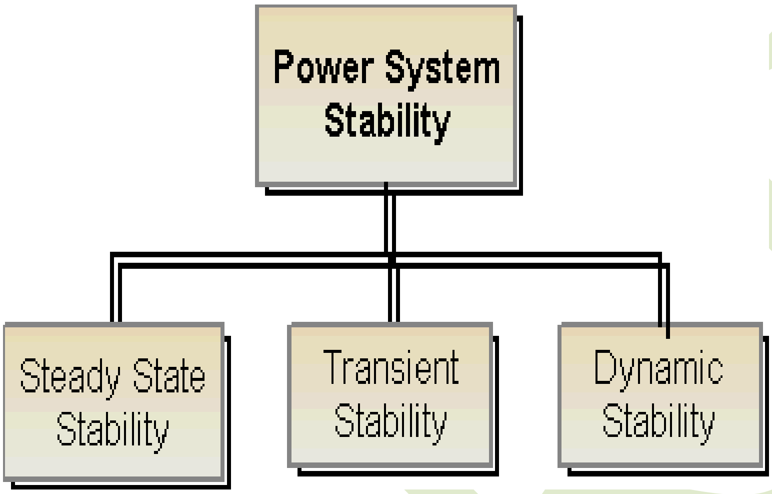

Figure 2: Types of power system stability

Steady state stability is the ability of the system to develop restoring forces equal to or greater than the disturbing force and remain in equilibrium or synchronism after small and slow disturbances.
Dynamic stability is the ability of the power system to maintain stability under continuous small disturbances also known as small-signal stability.
Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance such as the occurrence of a fault, the sudden outage of a line or the sudden application or removal of loads.
Compare to the steady state, the transient stability have to be given more attention since its influence greatly on the power system. Transients are disturbances that occur for a very short duration and the system is quickly restored to original operation provided no damage has occurred due to the transient. For transients to occur there must be a cause, some of the more common causes of transients are: Atmospheric phenomena (lightning, solar flares, geomagnetic disturbances),Switching loads on or off, Interruption of fault currents, Switching of power lines, Wind ramp event (in case of wind power).

Taking into consideration the stability of system it is very necessary to study and analyze transient performance of a system to improve the overall power system performance. Hence, in this paper the transient performance of LFAC system which connects offshore wind power with 50Hz power grid is analyzed during a wind ramp event.

Definition of Wind Ramp: Wind ramp is defined as the change in power output that has large enough amplitude for a relatively short period of time[10].

Causes of Wind ramp:

- Cold front

- Thunderstorm outflow
- Onset of mountain wave event
- Sea breeze
- Warm front

As the penetration of wind energy continues to increase around the world, the impact of wind energy on the management of electrical grids is becoming increasingly evident. Wind power brought great threaten to the system stability because of fluctuation and uncertainty of the wind. Ramp events are induced by a variety of meteorological phenomena. It has potential impacts on power system reliability and efficiency. Therefore, it is very important to forecast the ramp events to enhance system performance and power system security[10].

SIMULATION MODEL

To verify the transient performance of LFAC system, simulations have been carried out using Matlab/Simulink. The Simulink model of LFAC system designed for transient response is shown in fig.3.

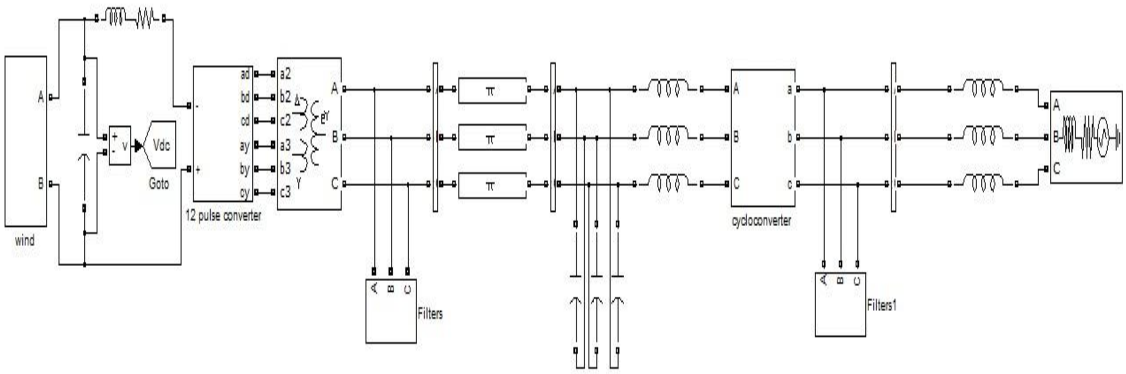

Figure 3: Simulink model of LFAC system for transient state

The wind power plant is rated at 180 MW, and the transmission distance is 160 km. The simulation model is developed where the wind power from the turbines ramp from 0 to 180 MW at the rate of 60 MW/s (perhaps unrealistically fast, but chosen to demonstrate that the system is stable even for this large transient).The transient response of various parameters of LFAC system is shown in the simulation results.

SIMULATION RESULTS

Following are the results of a transient simulation where the power from the wind turbines ramps from 0 to 180 MW, at a rate of 60 MW/s. Fig.4,5,6,7 shown are the transient responses of the dc bus voltage at the sending end, the magnitude of the fundamental component of the 20-Hz voltage generated by the cycloconverter, the active power injected into the 50-Hz power grid, and the transmission efficiency (which reaches a value of 93.3% at rated power).

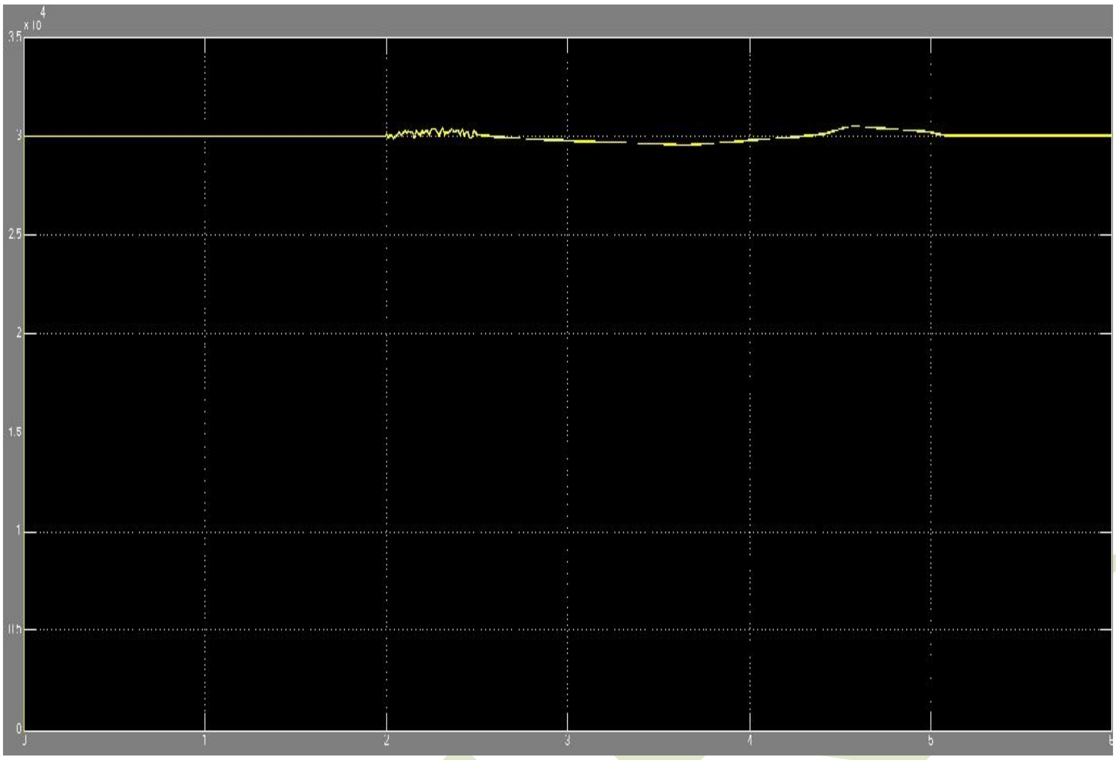

Figure 4: Transient response of DC bus voltage at the sending end side

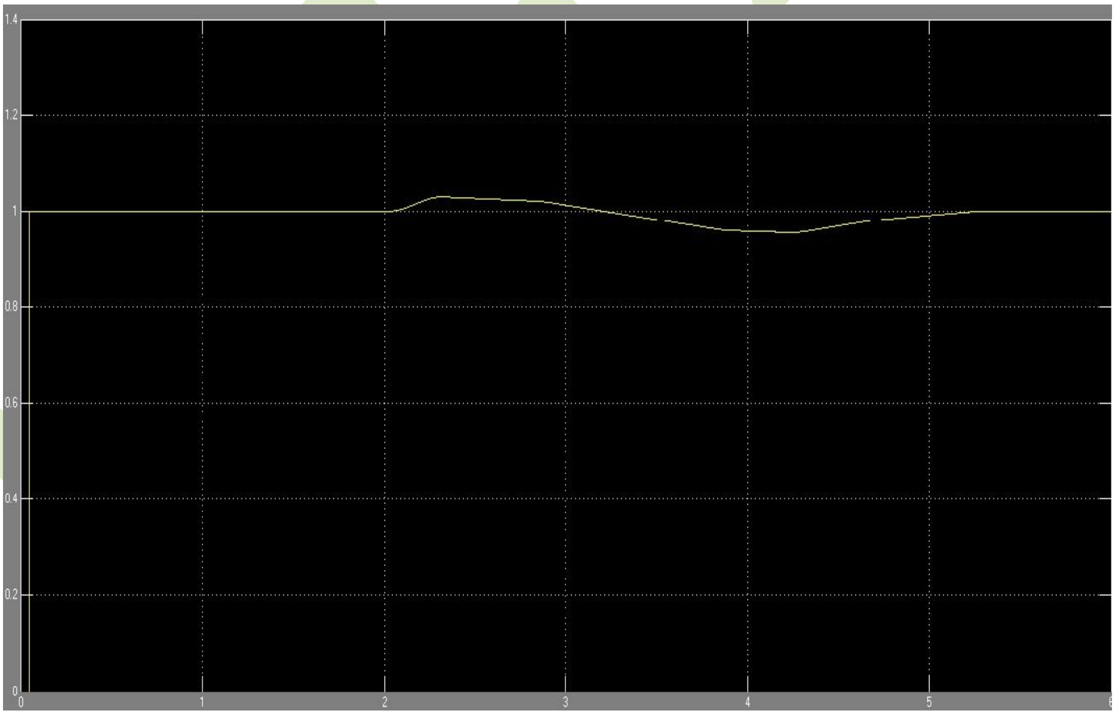

Figure 5: Transient response of 20 Hz voltage generated by Cycloconverter

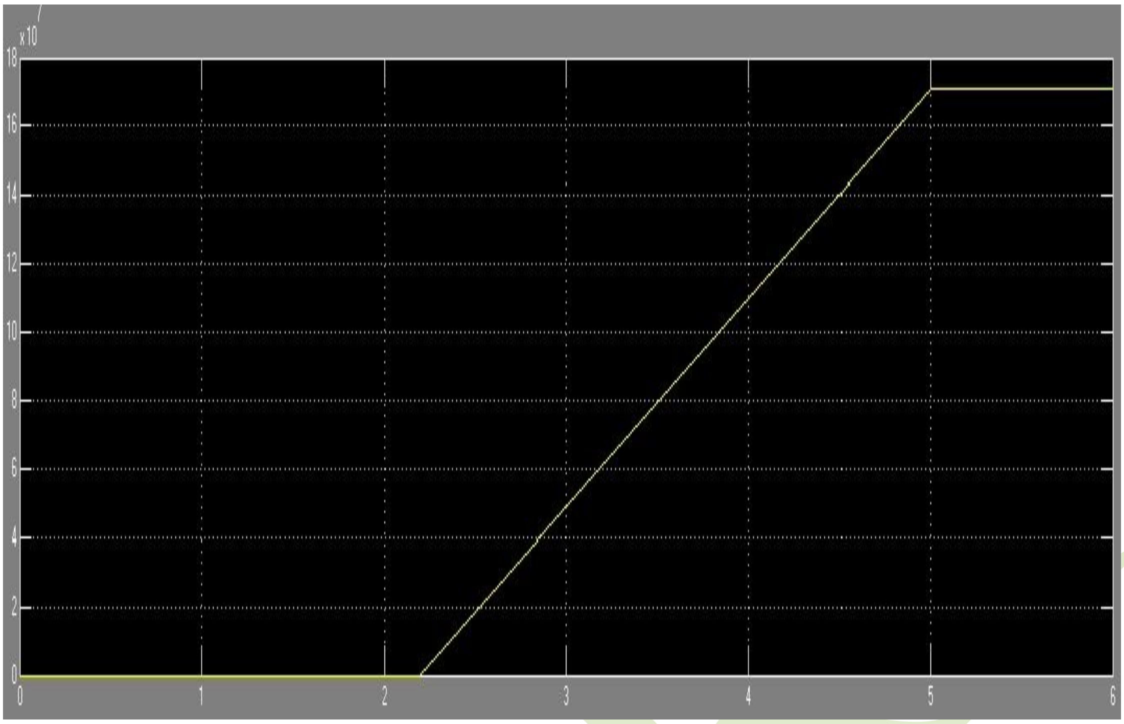

Figure 6: Transient response of active power injected in the 50 Hz power grid

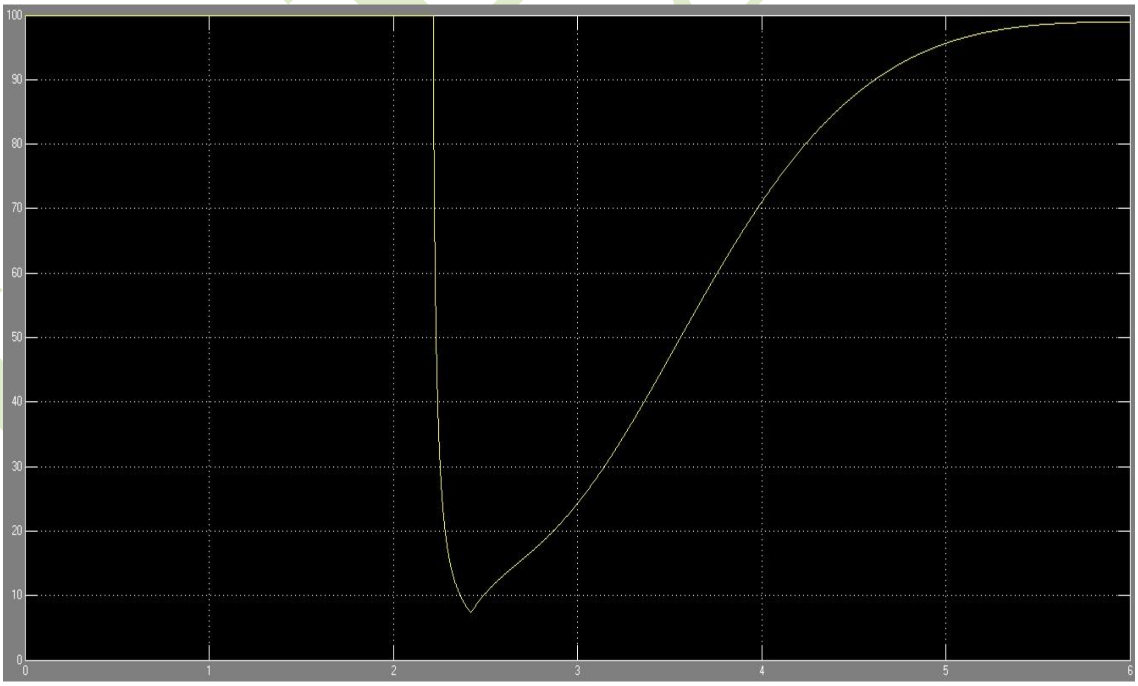

Figure 7: Transient response of Transmission efficiency

CONCLUSION

In this paper the transient state performance of LFAC system is verified using Matlab/Simulink. The simulation results illustrates that even for wind ramp event the transmission efficiency of LFAC system reaches about 93.3% at the rated power. Thus, LFAC system appears to be feasible during transient response for power transmission compared to HVAC and HVDC.

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