# DC filter design

Performance requirements

The maximum acceptable equivalent disturbing current Ieq(x) at any location along the DC line corridor or electrode line corridor are Bipolar Operation 3000mA Monopolar mode with metallic or ground Return 6000mA.

The DC Filtering System

The Filtering system consists of the following elements: Smoothing Reactor, DC Filters, Neutral Bus Capacitors.

Smoothing Reactor

The Smoothing Reactor at each station are located in the DC pole circuit between the Converter and the DC Filter. In addition to participating damping harmonic currents, the Smoothing Reactor forms a part of the overvoltage protection by preventing steep lightning surges from penetrating into the Converter. It also limits the discharge current due to a short circuit in the Converter or due to a DC line Fault. Furthermore it is an essential part of the DC system from the control point of view. The inductance of the Smoothing reactor is 300mH. The choice of this value avoids resonance at the fundamental and second harmonic frequencies between the DC filter and the Smoothing Reactor.

DC Filter scheme

Two double tuned 12/24 filters per Station connected between DC pole and neutral buses each with HV Capacitor of 0.8uF.

Two double tuned 6/42 filters per Station connected between DC pole and neutral buses each with HV Capacitor of 1.4uF.

The filter design is identical for both Stations.

Neutral bus Capacitors

The neutral bus Capacitor bank serves to provide a low impedance in Station Return path for mainly the triple order harmonic currents driven through the Transformer stray Capacitances and thus minimize the flow of these harmonics in the electrode line and the pole line. The value of the neutral bus Capacitance is chosen to provide a sufficiently low impedance path for the triplen order harmonic currents, while avoiding resonance with the electrode line at critical frequencies. One Capacitor of 20uF is connected between neutral bus and ground for each pole at each station. Thus, in Bipolar Operation, the total neutral bus Capacitance at each station is 40uF, while in monopolar Operation it is 20uF.

DC Filter performance

The configurations studied for the performance calculation are:

Balanced Bipolar

Monopolar Operation with ground and metallic Return

The Ieq values in all the three specified basic modes of Operation are within the specified limits with considerable margins. The following values are the highest values occurring in either normal direct voltage Operation or reduced voltage Operation, with all filters in service, and with the direct current level anywhere in the range from minimum to 1.0 p.u. The actual maximum values for all the three modes occur under normal voltage Operation and with the direct current of 1 p.u.

|  |  |  |
| --- | --- | --- |
| Components | 12/24 | 6/42 |
| Total number of filters | 4 | 4 |
| Tuning frequency Hz | 600/1200 | 300/2100 |
| C1, uF | 0.8 | 1.4 |
| L1, mH | 29.274 | 5.584 |
| C2, uF | 3.619 | 3.988 |
| L2, mH | 14.604 | 51.854 |
| R1, Ohm | 5000 | 200 |
| q-factor (Reactor) | 100 | 100 |
| tan delta (at 50Hz) of capacitors | 0.0002 | 0.0002 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Mode | DC Voltage | Ieq (mA) |  |  | Limit Ieq (mA) |
|  |  | Pole Line | Electrode line, Matiari | Electrode Line, Lahore |  |
| Bipolar | Normal | 1369 | 1261 | 1079 | 3000 |
|  | Reduced | 1704 | 1436 | 1405 | 3000 |
| Monopolar ground return | Normal | 3490 | 1335 | 1066 | 6000 |
|  | Reduced | 4168 | 1743 | 1556 | 6000 |
| Monopolar metallic return | Normal | 3322 | - | 938 | 6000 |
|  | Reduced | 3942 | - | 1603 | 6000 |

The minimum filter requirement of DC Filter is that there should be at least one filter per pole per Station to operate.

DC Filter Insulation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Filter | Component | Position | LIPL | LIWL | SIPL | SIWL |
|  |  |  | kVcrest | kVcrest | kVcrest | kVcrest |
|  |  | HV Terminal | 1469 | 1763 | 1243 | 1500 |
|  | C1 | Across |  |  | 1606 | 1928 |
|  |  | LV Terminal | 435 | 544 | 363 | 436 |
|  |  | HV Terminal |  | 496 |  | 450 |
|  | C2 | Across |  | 179 | 119 | 143 |
|  |  | LV Across |  | 496 |  | 421 |
|  |  | HV Terminal | 435 | 544 | 363 | 436 |
| 12/24 | L1 | Across | 412 | 515 | 384 | 461 |
|  |  | LV Terminal |  | 496 |  | 450 |
|  |  | HV Terminal |  | 496 |  | 450 |
|  | L2 | Across |  | 179 | 119 | 143 |
|  |  | LV Terminal |  | 496 |  | 421 |
|  |  | HV Terminal | 435 | 544 | 363 | 436 |
|  | R1 | Across | 412 | 515 | 384 | 461 |
|  |  | LV Terminal |  | 496 |  | 450 |
|  |  | HV Terminal | 1469 | 1763 | 1243 | 1500 |
|  | C1 | Across |  |  | 1685 | 2022 |
|  |  | LV Terminal | 557 | 697 | 442 | 531 |
|  |  | HV Terminal |  | 496 |  | 450 |
|  | C2 | Across |  | 198 | 132 | 159 |
|  |  | LV Terminal |  | 496 |  | 421 |
|  |  | HV Terminal | 557 | 697 | 442 | 531 |
| 6/42 | L1 | Across | 512 | 640 | 464 | 557 |
|  |  | LV Terminal |  | 496 |  | 450 |
|  |  | HV Terminal |  | 496 |  | 450 |
|  | L2 | Across |  | 198 | 132 | 159 |
|  |  | LV Terminal |  | 496 |  | 421 |
|  |  | HV Terminal | 557 | 697 | 442 | 531 |
|  | R1 | Across | 547 | 684 | 420 | 504 |
|  |  | LV Terminal |  | 496 |  | 421 |
| Neutral Bus | NBC | HV Terminal/ Across |  | 496 |  | 421 |

DC Filter Control

The control functions are implemented at DC Station. The control of each DC filter has the following functions:

Monitoring and control of disconnecters and earthing switches of DC Filter

Control mode selection of DC filter

Connection/ disconnection of DC Filter

Connection and disconnection of DC Filter in the automatic mode

If the DC Switchyard is in the automatic control mode, the connection/ disconnection sequence control of the DC filters can be implemented through the connection/ disconnection order issued by the background. The connection sequence is open earthing switch, close Isolator, close breaker. The disconnection sequence is open breaker, open Isolator, close earthing switch. When the DC Filter protection acts, tripping line disconnector of DC Filter, the DC Filter will execute disconnection sequence control if it is in the disconnection control mode

Connection and disconnection of DC filter in Manual control mode.

If the DC Switchyard is in the Manual control mode, the connection/ disconnection sequence control of DC Filter can be realized by manually operating corresponding disconnectors and earthing switches. The interlocking conditions of disconnectors and earthing switches in the Manual mode are consistent with those in the automatic mode. If two DC Filter banks at each pole of the two poles are connected, it is prohibited from disconnecting the two DC Filter banks that have been connected.

DC Station control cabinet

The host cabinet of DC Station control system is equipped with EPU20B board for DC Switchyard sequence control, DC Switchyard switch control and monitoring.

DC Filter Protection Configuration

For the Capacitors, Reactors and resistors of DC Filters, necessary protection is provided according to the type of the component supplied. These protections protect all components from overstress due to excessive harmonic current or overvoltage. They provide the monitoring protection for the DC Filter state. The functions of DC Filter protection are:

1. Resistor overload protection: Scope and purpose of protection. It detects the total harmonic current of the resistance in the DC Filter. If the setting is exceeded, the protection will operate. Protection coordination. The setting is subject to the thermal endurance of the Filter Resistance. Criteria and setting principle. Alarm section: IZR>(1.03\*IXR)^2, an Alarm will be sent. Action stage: IZR>(1.05\*IXR)^2, the disconnector on the HV side will be opened. I\_XR is the reference value of Resistance R: 8.25A (HP12/24 Filter Resistance R for Station A), 9.35A (HP 12/24 Filter Resistance R for Station B), 112.54A (HP 6/42 Filter Resistance R for Station A), 112.33A (HP6/42 Filter Resistance R for Station B). Backup protection: DC Filter differential protection,
2. Reactor overload protection. Reactor overload protection. Scope and purpose of protection. It detects the total harmonic current of the Reactor in the DC Filter. If the setting is exceeded, the protection will be enabled. Protection coordination. The setting is subject to the thermal endurance of the Filter Reactor. Criteria and setting principle. Alarm section: IZL> (1.03\*IXL)^2, an Alarm will be sent. Action stage: IZL> (1.05\*IXL)^2, the disconnector on the HV side will be opened. IXL is the Reference value of Reactor L: 151A (HP12/24 L1 for Station A and B), 148A (HP6/42 L1 for Station A and B), 581A (HP12/24 L2 for Station A),699A (HP12/24 L2 for Station B), 99A (HP6/42 L2 for Station A and B),
3. Differential protection: Scope and purpose of protection. The internal earthing Fault of the DC Filter is detected by measuring the current difference on HV and LV side of the DC Filter. If the setting is exceeded, the protection will be enabled. Criteria and setting principle. I\_DIFF=|IZT1rms-IZT2rms|>delta. 1-segment: delta = max(40 A, 0.5\*IZT1), delay 200ms. In case of IZT1<320A, the disconnector on the HV side will be opened. In case of IZT1>3320A, Y will be blocked and pole isolation and tripping of AC circuit breaker will occur. 2-segment: delta= max(180A, 0.5\*IZT1), delay of 20ms. In case of IZT1<320, the disconnector on HV side will be opened. In case of IZT1>320 A, Y will be blocked and pole isolation and tripping of AC circuit breaker will occur. Backup protection. DC Pole differential protection.
4. Detuning protection. Scope and purpose of protection. It monitors the Detuning of the DC Filter. Operating principle and strategies of protection. The monitoring is conducted by comparing the DC Filter current of 2 poles. During symmetrical Bipolar Operation, the current of the two DC Filters shall be equal. If the difference between the Filter currents exceeds the preset value, an alarm will be given. Criteria and setting principle. I\_DIF=|IZT2-IZT2\_OP|, IDELSUM=|IDEL1+IDEL2|. Protection criteria: I\_DIF>20A and IDELSUM< 0.02 p.u., delay of 10s, an alarm will be sent.
5. High voltage Capacitor unbalance protection. Scope and purpose of protection. It detects the short circuit Fault of Capacitor unit of HV Capacitor bank of DC Filter. Operating principle and strategies of protection. The protection calculates the ratio of unbalanced current (IZT11) and the current (IZT2) on the LV side. When the ratio is greater than the setting, the protection will alarm. Criteria and setting principle. Protection criteria: IZT11/IZT2> 0.006, delay of 10s, alarm is sent.

Optical CT measured values of DC switchyard include the current at HV and LV side of DC Filter of both poles and unbalance current of DC Filter of both poles. The measured values are output in the form of optical fiber by the optical CT merging unit and are sent to the EOT11C board of measurement and interface cubicle. The DC Switchyard CT measurement values of DC Filter Reactor current, DC Filter resistor current and DC Filter arrester current of both poles shall be collected by DFU410 device of control and protection, and sent to ESP10C board of HCM3000 System measurement interface cubicles A, B and C. The measured values are sent to the corresponding pole control and protection host through TDM bus protocol after being pre-processed by the boards of HCM3000.

DC Pole protection cubicles have HCM3000 system software and EPU20B boards with local judgement function of DC Filter protection. Interfaces to primary measuring devices are installed in the local terminal box. Sampling signals are measured for Reactor current, Resistor current and Arrester current of DC Filter as well as conventional CT output.

The harmonic monitoring system of the DC transmission project can provide 50 times of harmonic analysis for the DC voltage and current signals of Pole 1 and Pole 2. Each Station has one harmonic monitoring system panel with domestic DZ300E DC power quality on-line monitoring devices. It is used to monitor the power quality data like harmonics, unbalance, frequency, voltage deviation, power and power factor.

DC Filter Capacitor Operation and Maintenance

The DC Filter Capacitor is used to provide impedance channel for AC component of DC system.

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| --- | --- | --- | --- | --- | --- | --- |
|  | Model | Protection way | Capacitor bank/ Rated Capacitance of unit, uF | Capacitance Failure tolerance of unit (ratio nameplate value) | Rated Capacitance of bridge arm (uF) | Inter-arm Capacitance tolerance |
| HP12/24 DC Filter Capacitor C1 | TDL1058.17-0.8-W | Bridge differential protection | 0.8/44.8 | Decrease by above 7.3% or increase by above 50% | 0.8/0.8 | <=0.001 |
| HP12/24 DC Filter Capacitor C2 | TDL107.53-3.619-W | / | 3.619/5.43 | Increase by above 10% | / | / |
| HP6/42 DC Filter Capacitor C1 | TDL1026.58-1.4-W | Bridge differential protection | 1.4/78.4 | Decrease by above 7.4% or increase by above 50% | 1.4/1.4 | <=0.001 |
| HP6/42 DC Filter Capacitor C2 | TDL36.98-3.988-W | / | 3.988/3.99 | Increase by above 10% | / | / |

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| --- | --- | --- |
| Appearance Inspection | Inspect the Capacitor unit, oil paint, connector lug, flange, sealing cover, container of porcelain bushing, capacitor plate on the Capacitor bushings, tubular busbar, bolts, gaskets, crimp terminal between connection position and busbar for bulges, leaks, oil stains, superheat symptoms, blackening, paint drop, cracks, Deformation and rust. | Daily (uninterruptible power maintenance), as required (no power maintenance), one year (minor overhaul), 3-5years (major overhaul) |
| Infrared thermography Inspection | Record temperature of tubular busbar, wire connector, Capacitor container, lead terminals of Capacitor. The container temperature must not exceed 70°C. The terminal temperature must not exceed 80°C. | Every week (uninterruptible power Maintenance), as required (no power maintenance), as required (minor overhaul), |
| Recording for unbalanced current | Recording should be made on Capacitor branch current, voltage and unbalance current. Unbalance current must not exceed one third of Alarm value. | One month (uninterruptible power Maintenance), as required (no power Maintenance), one year (minor overhaul). |
| Capacitance Test | Measure the total single phase Capacitance value for every H type and 4 inter-arm using Capacitance meter VICTOR6013. The Capacitance must not exceed the specified tolerance percent. Measure Dielectric Loss using AI6000D. | One year (minor overhaul), 3-5 years (major overhaul) |
| Internal grading Resistance measurement | The Resistance value must not exceed 1.4MOhm. | One year (minor overhaul), 3-5 years (major overhaul). |

Filter Resistor service manual

|  |  |  |
| --- | --- | --- |
|  | HP6/42 | HP12/24 |
| Number of units | 6 | 2 |
| Installation | Outdoor | Outdoor |
| Rated Resistance | 200 Ohm | 5000 Ohm |
| Cold Resistance | 187 Ohm | 4673 Ohm |
| Maximum tolerance | +- 10% | +-10% |
| Resonant frequency | 300/2100 Hz | 600/1200 Hz |
| Inductance with resonant frequency | <0.5mH | <5mH |
| Rated current |  |  |
| Maximum continuous current Icont | 112.33 Arms | 9.35 Arms |
| Temporary current |  |  |
| Max temporary current 10min | 114.57 Arms | 9.54 Arms |
| Maximum temporary current 0min | 116.87 Arms | 9.8 Arms |
| Nominal current | >0.7\*Icont | >0.7Icont |
| Minimum current | 0 Arms | 0 Arms |
| Transient current | 2.2kAcrest | 0.085 kAcrest |
| Impulse energy | 95.8kJ | 20.2 kJ |
| LIWL |  |  |
| BIL(H/L) | 697kV | 544 kV |
| BIL(H/G) | 684kV | 515 kV |
| BIL(L/G) | 496kV | 496 kV |
| Material | SUS316L | SUS316L |
| Resistance element material | NiCr3020 | NiCr3020 |

|  |  |  |
| --- | --- | --- |
| Appearance Inspection | Check whether the resistor elements are not covered with dirt or foreign matter. Check the resistor and its parts for damage. Clean the insulators with high pressure steam. Check each connection for screw rotation using marker position. | 6 months |
| Resistance measurement | Measure the Resistance of Filter resistor. Perform Insulation Resistance test using 2.5kV Megger. The Resistance should be greater than 100MOhm in dry environment. | 1 year |
|  |  |  |

DC Filter Surge Arresters

|  |  |  |
| --- | --- | --- |
| HP12/24 HV | Y75.5W1-177/435W | 2 sets |
| HP6/42 HV | Y91W1-219/557W | 2 sets |
| HP12/24 L1 parallel | Y7.6W1-186/412W | 2 sets |
| HP6/42 L1 Parallel | Y11.9W1-219/512W | 2 sets |
| HP12/24 LV | Y10W1-63/125W | 2 sets |
| HP6/42 LV | Y10W1-66/134W | 2 sets |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | HP12/24 HV | HP6/42 HV | HP12/24 L1 | HP6/42 L1 | HP12/24 LV | HP6/42 LV |
| Model | Y75.5W1-177/435W | Y91W1-219/557W | Y7.6W1-186/412W | Y11.9W1-219/512W | Y10W1-63/125W | Y10W1-66/134W |
| Rated voltage | 177kV | 219kV | 186kV | 219kV | 63kV | 66kV |
| Continuous operating voltage | 142kVcrest | 88.2kVcrest | 71.3kVcrest | 22.6kVcrest | 55kVcrest | 45.1kVcrest |
| Nominal discharge current | 75.5kA | 91kA | 7.6kA | 11.9kA | 10kA | 10kA |
| DC 1mA reference voltage | 245kV | 305kV | 265kV | 310kV | 85kV | 90kV |
| The maximum residual value under switching impulse current | 363/11.5 kV/kA | 442/7.2kV/kA | 384/3.6kV/kA | 464/3.9kV/kA | 119/5.1kV/kA | 132/10.2kV/kA |
| The maximum residual value under lightning impulse current | 435/75.5 kV/kA | 557/91kV/kA | 412/7.6kV/kA | 512/11.9kV/kA | 125/10kV/kA | 134/10kV/kA |
| Withstand capability of large current impulse 4/10us 2 times | 100kA | 100kA | 100kA | 100kA | 100kA | 100kA |
| Pressure release capability (large current 0.2s) | 63kA | 63kA | 63kA | 63kA | 63kA | 63kA |
| Insulation withstand strength of sheath, rated lightning impulse voltage | 544kVpeak | 697kVpeak | 544kVpeak | 697kVpeak | 562kVpeak | 562kVpeak |
| Insulation withstand strength of sheath, rated switching impulse voltage | 436kVpeak | 531kVpeak | 436kVpeak | 531kVpeak | 500kVpeak | 500kVpeak |
| Equivalent creepage distance of sheath | 6820mm | >=6820mm | >=6000mm | 6000mm | 2500mm | 2500mm |
| Partial discharge Testing voltage (partial discharge amount <=5pC) | 212kV | 263kV | 224kV | 263kV | 77kV | 80kV |
| Maximum radio interference voltage | 500uV | 500uV | 500uV | 500uV | 500uV | 500uV |

Maintenance of surge arresters

|  |  |  |
| --- | --- | --- |
| Visual inspection | Sheath must not have discharge, flange must not have crack or damage, conducting wires and ground leads must not have burn marks or broken strands, sheath surface must not have dirt, the arrester action counter must be firm, operate reliably and must not have any moisture inside it. The sheath RTV coating must be good. | Routine patrol, 6 months |
| Online Monitoring Test | The leakage current of the surge arrester must be checked with online monitor. Acceptance test must be conducted. | 1 year |
|  |  |  |

DC Electronic CT

NR PCS-9250-EAVD DC Electronic CT is mainly used for DC current and harmonic current measurement in HVDC Converter Station. It outputs the signal for the protection and control equipment. It senses DC current with current divider, senses harmonic current with air core coil, outputs signal with remote module based on laser power supply, transmits signal with optical fiber, makes sure Insulation with optical composite insulator. It has suspension structure and pillar structure with reliable insulation design and good linearity.

|  |  |  |
| --- | --- | --- |
| Voltage level | 660kV |  |
| DC withstand voltage | 1020kV, 60min |  |
| Lightning impulse withstand voltage | 1800kV |  |
| Operation impulse withstand voltage | 1600kV |  |
| Rated primary current | 3030.3A |  |
| Current measurement accuracy | 0.5 |  |
| Rated secondary output | 1388H |  |
| Working environment temperature | -40 to 70°C |  |
| Rated short time thermocurrent | 34kA/3s |  |
| Rated dynamic current | 60kA |  |
| Weight | 650kg |  |

Maintenance requirements

|  |  |  |
| --- | --- | --- |
| Infrared temperature measurement | Check according to DL/T664-2008 Application rules of infrared diagnosis for live Electrical equipment. | 1 month |
| Ultraviolet patrol | Ultraviolet patrol equipment and conductor connection. There should be no obvious discharging point. | 1 year |
| Metal component Inspection | No rusting or discoloration of metal components | 1 month |
| Earthing flat iron | The earthing metal must be well earthed without rusting. | 1 month |
| Composite insulator Inspection | No obvious dirt, traces of discharge, damage or filamentous crack | 1 month |
| Operation sound Inspection | No discharging sound or abnormal smell | 1 month |
| Remote Module driving current Inspection | Check the LED of merging unit. There should be no RTU laser driving current high alarm during normal operation | 1 month |
| Merging unit data Electrical Level Inspection | Check the LED of merging unit. There should be no RTU data Electrical level low alarm during normal operation | 1 month |
| Merging unit Inspection | Check the SCADA system. There should be no alarm of merging unit. Operation light should be on. Alarm light should be off. |  |