Xiangping Wang, PGGI, ABB Engineering (Shanghai) Co. Ltd., Nov. 2016

ABB 1000kV Grid Integration AIS Solution in PP
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1000kV Grid Plan
National EHV grid development during period of ‘12.5’ (3 vertical & 3 horizontal)

- 3 Vertical
  - Ximeng ~ Beijing (E) ~ Tianjin (S) ~ Jinan ~ Xuzhou ~ Nanjing
  - Zhangbei ~ Beijing (W) ~ Shijiazhuang ~ Henan (N) ~
    Zhumadian ~ Wuhan ~ Nanchang
  - Neimeng (W) ~ Sanxi (M) ~ Sanxi (ES) ~ Nanyang ~ Jingmen ~ Changsha

- 3 horizontal
  - Shanxi (N) ~ Sanxi (N) ~ Shijiazhuang ~ Jinan ~ Weifang
  - Jingbian ~ Sanxi (B) ~ Henan (N) ~ Xuzhou ~ Lianyungang
  - Yaan ~ Leshan ~ Chongqing ~ Changshou ~ Wanxian ~
    Jingmen ~ Wuhan ~ Anhui (S) ~ Zhejiang (N) ~ Shanghai
1000kV Grid Plan
Demand and advantage of EHV grid

- Transmission over long distance
- Reduce land occupation of corridor
- Enhance interconnection of national grid
- Strengthen security & stability of grid operation

- Improve the structure of grid
- Enlarge integration of remote area renewables
- Reduce PM2.5 emission

Optimum Voltage level for energy transmission

Data from A. Clerici, ABB Italy.

Single transmission line circuit (200/2000km distance)
Transmission Power vs Optimum Voltage

Requirement of transmission line corridor (5000MW)
Demand and advantage of EHV grid integration in PP

- No line corridor or no spare bay at opposite substation (500kV grid integration)
- 1000MW generator units being pushed forward 1000kV EHV grid integration by National policy
- Reduce intermediate step-up process, shorten electrical distance, and save land resource and project investment by adopting EHV grid integration
- Upgrading power transmission capability and efficiency of a channel unit and improving benefit from PP and grid performance when EHV concentration output exploited at large scale energy base
Advantage of EHV integration AIS solution in PP

- Cost of construction moderate and cutting down the investment of early stage by AIS solution
- Lead time of equipment production is short than that of GIS
- Easily expandable, convenient maintenance and test
- Optimal tradeoff between land occupation and investment saving in case of the land of electric power station near coal-mines is relatively sufficient or loose
Relevant EHV specification

- Q/GDW 1786-2013 Code for design of 1000kV substation
- Q/GDW 312-2009 Technical specification of Oil-immersed Transformer for 1000kV System
- GB 50697-2011 Code for design of 1000kV substation
- GBZ 24842-2009 Overvoltage and insulation coordination of 1000kV UHV AC transmission project
- GBZ 24838-2009 Specification for 1100 kV alternating-current high-voltage circuit-breakers
- GBZ 24837-2009 Specification for 1100 kV alternating-current disconnectors and earthing switches
- GBZ 24841-2009 Technical specification for capacitor voltage transformers of 1000kV AC system
- GBZ 24845-2009 Specification of metal-oxide surge arresters without gaps for 1000 kV AC system
- GBZ 24840-2009 Technical specification for bushing of 1000 kV AC system
Relevant EHV specification

- **Q/GDW 1786-2013 Code for design of 1000kV substation**

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  **Main electrical circuit connection and 1000kV conductor**

  Simplified connection scheme with less circuit breakers shall be used.

  6.1.3 1000kV 电气接线的最终接线方式，当线路、变压器等连接元件较少时，宜采用 3/2 断路器接线。

  当初期线路、变压器等连接元件较少时，可根据具体的元件总数采用断路器数量较少的简化接线形式，但在布置上应便于过渡到最终接线。

  当采用 3/2 断路器接线时，同名回路应配置在不同串内，电源回路与负荷回路宜配对成串。如接线条件受限制时，同名回路可接于同一侧母线。

  6.1.6 当采用 3/2 断路器接线时，避雷器和电压互感器不应装设隔离开关；1000kV 线路、变压器回路，当变电所初期为 2 个完整串运行时，线路、变压器元件宜装设出口隔离开关。

  6.4.7 **1000kV 导体**

  a) 导体选型应根据 1000kV 配电装置的特点，结合制造能力、地震等因素进行综合技术经济比较后确定。

  b) 架空导线宜选用 4 分裂钢导线，分裂间距宜取 600mm，单根钢导线的最小直径宜不小于 66mm。

  c) 在满足地震安全要求条件下，1000kV 设备间连线可采用单根大直径铝合金管，铝合金管外径不应小于 200mm。
Relevant EHV specification

Recommended transitional type for 3/2 breakers main electrical circuit connection
### Relevant EHV specification

#### Min. clearance for 1000kV outdoor switchgear installation

<table>
<thead>
<tr>
<th>符号</th>
<th>适用范围</th>
<th>安全净距</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>Split conductor to ground, Tubular conductor to ground</td>
<td>6.80</td>
</tr>
<tr>
<td>A₁”</td>
<td>均压环至接地部分之间</td>
<td>7.50</td>
</tr>
<tr>
<td>A₂</td>
<td>带电导体相间</td>
<td></td>
</tr>
<tr>
<td></td>
<td>分裂导线至分裂导线</td>
<td>9.20</td>
</tr>
<tr>
<td></td>
<td>均压环至均压环</td>
<td>10.10</td>
</tr>
<tr>
<td></td>
<td>管型导体至管型导体</td>
<td>11.30</td>
</tr>
<tr>
<td>B₁</td>
<td>1. 带电导体至围栏</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. 运输设备外轮廓线至带电导体</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. 不同时停电检修的垂直交叉导体之间</td>
<td>8.25</td>
</tr>
<tr>
<td>B₂</td>
<td>网状遮拦至带电部分之间</td>
<td>7.60</td>
</tr>
<tr>
<td>C</td>
<td>单根管型导体</td>
<td>17.50</td>
</tr>
<tr>
<td>D</td>
<td>分裂架空导线</td>
<td>19.50</td>
</tr>
</tbody>
</table>

**注**
1. 表中数据为海拔 1000m 时的安全净距；海拔高于 1000m 时应按 GB/Z 24842 的要求进行修正。
2. 交叉导体之间需要同时满足 A₂ 和 B₁ 的要求；
3. 平行的导体之间需要同时满足 A₁ 和 D 的要求；
4. 当带电作业时，人体活动半径取 0.75m。
Relevant EHV specification

Overvoltage level and protection level for ZnO arrestor

6.8.4 变电所的过电压水平宜符合下列规定：
   a） 相对地工频过电压水平不宜超过下列数值：
      1） 线路断路器的变电站侧：1.3 p.u；
      2） 线路断路器的线路侧：1.4 p.u.（持续时间不大于 0.5s）。
   b） 最大的相对地统计操作过电压不宜大于 1.6 p.u.，最大的相间统计操作过电压不宜大于 2.9 p.u.

6.8.5 1000kV 系统用氧化锌避雷器的保护水平应符合表 6 的规定。

表 6 1000kV 系统用氧化锌避雷器的保护水平（kV）

<table>
<thead>
<tr>
<th></th>
<th>额定电压（有效值）</th>
<th>持续运行电压（有效值）</th>
<th>8/20μs、20kA 下雷电冲击残压（峰值）</th>
<th>1/10μs、20kA 下陡波冲击残压（峰值）</th>
<th>30/60μs、2kA 下操作冲击残压（峰值）</th>
</tr>
</thead>
<tbody>
<tr>
<td>线路侧母线侧</td>
<td>828</td>
<td>638</td>
<td>≤1620</td>
<td>≤1782</td>
<td>≤1460</td>
</tr>
</tbody>
</table>

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### Relevant EHV specification

#### 1000kV equipment insulation level rating

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Equipment Name</th>
<th>Rated Impulse Withstand Voltage (kV)</th>
<th>Lightning Impulse Withstand Voltage (kV)</th>
<th>Rated Short-Time Withstand Voltage (kV)</th>
<th>Rated Long-Time Withstand Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000kV</td>
<td>Transformer, Reactor TR</td>
<td>2400</td>
<td>2760</td>
<td>2400</td>
<td>1100 (5min)</td>
</tr>
<tr>
<td></td>
<td>GIS (CB, DS)</td>
<td>2500</td>
<td>-</td>
<td>-</td>
<td>1100 (1min)</td>
</tr>
<tr>
<td></td>
<td>Bushing, Reactor (IS, ES)</td>
<td>2400</td>
<td>-</td>
<td>-</td>
<td>1100 (1min)</td>
</tr>
<tr>
<td></td>
<td>CVT</td>
<td>2400</td>
<td>-</td>
<td>-</td>
<td>1200 (5min)</td>
</tr>
<tr>
<td>110kV</td>
<td>Switchgear longitudinally</td>
<td>2400+900</td>
<td>-</td>
<td>1675+900</td>
<td>1100+635 (1min)</td>
</tr>
<tr>
<td></td>
<td>Transformer Neutral Point TR NP</td>
<td>325</td>
<td>-</td>
<td>-</td>
<td>140 (1min)</td>
</tr>
<tr>
<td>110kV</td>
<td>Transformer Neutral Point (nos. 3)</td>
<td>650</td>
<td>-</td>
<td>-</td>
<td>275 (1min)</td>
</tr>
</tbody>
</table>

**Notes:**

1. Data in the table are applicable to equipment with an altitude not exceeding 1000m.
2. All insulation levels are tested at 5 minutes for impulse withstand.
3. For direct grounding methods, if using a different grounding method, consult the manufacturer for specifications.
4. Insulation levels are calculated based on the specific application and requirements.
Relevant EHV specification

Circuit breaker and disconnector

7.4 断路器
7.4.1 试验示范工程经过充分论证，将东南变电站 1000kV 采用 GIS，南阳、荆门变电站 1000kV 采用 HGIS。南阳开关站 1000kV 曾考虑采用 AIS，后来从国内设备制造厂生产能力、设备安全运行、工程工期以及节约土地资源等综合考虑，改为 HGIS。
7.4.2 由于 1000kV 超高压线路电阻小，系统短路电流的直流分量衰减慢，时间常数加长，造成断路器开断直流分量加大，电流过零点延迟，另一方面，断路器开断短路电流时的暂态恢复电压（TRV）也与超高压断路器有较大的区别。在端相故障的条件下，TRV 的上升率为延伸 IEC 标准略高；在失步的条件下，开断 TRV 时的情况更加严重。因此，需根据系统条件，进行详细研究后确定时间常数、TRV 等参数。

7.5 隔离开关
7.5.1 隔离开关仅在电网无荷载情况下进行分合间操作，因此其所能开断的电流仅为空载线路与大地间（即导体与零电位）产生容性电流和空载线路与其他带电线路（即导体与某电位导体）感应电流，即感应性电流与其旁并行线路中的电流及其相互间的耦合系数有关；而容性电流与其旁并行线路的电压、其相互间的耦合系数以及耦合部分的线长有关；所有的耦合系数由导线在空间的几何位置确定。隔离开关开合电容电流和开合电感电流的能力应根据具体工程而定。根据 1000 kV 配电装置型式，母线距地最小高度软母约 28 米，进出线距地最小高度约 38 米，拟采用四分裂空芯扩径导线，相间距离约 15 米，在此情况下，一般空载线路的容性电流约为 0.3A，感性电流约为 0.5A。

Height of bus to ground, about 28m; Height to outgoing line to ground, about 38m.
Distance of phase to phases: about 15m
Relevant EHV specification

Bay width of 1000kV switchgear and VFTO of disconnector

7.5.2 1000kV 配电装置间隔宽度 54m，使用悬吊铝合金管母线较困难，而采用分裂导线作为母线，因此，一般不宜采用垂直伸缩式隔离开关。双柱水平伸缩式采用单断口，开关动作时机械载荷较大，三柱水平旋转式和三柱水平伸缩式采用双断口，开关动作时机械载荷相对较小。因此，1000kV 特高压推荐采用水平断口三柱式隔离开关。

7.5.3 SF₆ 气体绝缘开关装置中隔离开关切合空载母线时，由于触头运动速度慢、隔离开关灭弧能力弱等原因，触头间可能会发生重击穿，产生波头很陡的行波，在 GIS 内发生多次折反射，形成快速暂态过电压（very fast transient overvoltage，VFTO）。

根据科研单位研究结果，初期工程中东南站的 GIS 隔离开关可不装分间合闸电阻。VFTO 最大为 2057kV，不超过雷电冲击耐受电压水平，是安全的。但当系统进一步扩展，间隔数增加至 4 串时，个别操作方式下 GIS 串内产生的 VFTO 最大值可能达到 2710kV，可能影响 GIS 开关的绝缘。变压器单元电容较大，VFTO 数值不高，加之邻近避雷器也有一定程度的保护作用，不存在严重问题。认为装设分间合闸电阻可完全解决这一问题。研究结果表明，1000kV 的隔离开关如需装设电阻抑制 VFTO 时，电阻取值可采用 500Ω。
ABB step-up substation scheme in PP EHV Switchgears
Single-line diagram types for 1000kV step-up substation

(1) Expanded-unit scheme/2 generators & 1 line
(2) Triangle scheme / 3 outgoings
(3) One and half breaker scheme (2 diameters) / 3 outgoings
(4) One and half breaker scheme (3 diameters) / 6 outgoings
(5) One and half breaker scheme (4 diameters) / 6 outgoings
(6) Hexagon scheme / 6 outgoings
(1) Expanded-unit scheme/2 generators & 1 line
(1) Expanded-unit scheme/2 generators & 1 line

- Expanded line-transformer unit, two generators and one line;
- Two circuit breakers, save one breaker compared to triangle scheme;
- Similar to triangle scheme, power output from two generators by one line, but this connection is unsuitable to be retrofit to one and half breaker scheme at a later stage;
- Two generator units can be put in or out of service separately without mutual influence;
- It is suitable for no later extension project, while two generators can be built by stages;
- If a permanent fault occurs on line, two generators should be outage therefore and no power from PP can be output;
- For AIS plane layout, refer to the following:
(2) Triangle scheme / 3 outgoings

20m + 3x54m + 20m (202m)

11m + 4x52m + 11m (230m)
(2) Triangle scheme / 3 outgoings

- Three circuit breakers, 3 outgoings (line or generator-transformer unit);
- Similar to 1 1/2 breaker scheme, with high reliability and many performance cases;
- For example, it has been adopted in Pingwei PP and will be retrofit to 1 1/2 breaker scheme at a later stage with a bigger change;
- It is suitable for no later extension project the same as the initial scheme;
- Power output from two generators by one line
- If a permanent fault occurs on line, two generators should be outage therefore and no power from PP can be output;
- For AIS plane layout, refer to the following:
(3) One and half breaker scheme (2 diameters) / 3 outgoings

20m + 3x54m + 20m (202m)

11m + 6x52m + 11m (334m)
(3) One and half breaker scheme (2 diameters) / 3 outgoings

- Five circuit breakers, 3 outgoings (line or generator-transformer unit);
- With high reliability and many performance cases;
- Two more circuit breakers compared to triangle scheme;
- Flexible and convenient for extension at a later stage;
- It can be formed and transited from earlier triangle scheme;
- More easily and expediently expandable at a later stage for AIS solution;
- Power output from two generators by one line. If a permanent fault occurs on line, two generators should be outage therefore;
- It is widely used in 500kV step-up substation of PP (GIS, AIS solution);
(4) One and half breaker scheme (3 diameters) / 6 outgoings
(4) One and half breaker scheme (3 diameters) / 6 outgoings

- Nine circuit breakers, 6 outgoings (line or generator-transformer unit);
- With high reliability and many performance cases;
- Three more circuit breakers compared to Hexagon scheme;
- Power output from four generators by two lines. If a permanent fault occurs on line, the power from four generators can still be output;
- It is often used as the future scheme in planned 1000kV PP;
- It is widely used in 500kV step-up substation of PP (GIS, AIS solution);
- There is no performance case of transiting from earlier scheme up to now in 1000kV PP (perhaps lasting for 8 years in triangle scheme);
(5) One and half breaker scheme (4 diameters) / 6 outgoings
(5) One and half breaker scheme (4 diameters) / 6 outgoings

- Ten circuit breakers, 6 outgoings (line or generator-transformer unit)
- With high reliability and many performance cases;
- Four more circuit breakers compared to Hexagon scheme;
- One more circuit breaker compared to same scheme with three diameters;
- There is less interface to earlier stage compared to three diameters because of an independent part consists of two diameters;
- Power output from four generators by two lines. If a permanent fault occurs on line, the power from four generators can still be output;
- It is widely used in 500kV step-up substation of PP (GIS, AIS solution);
(6) Hexagon scheme / 6 outgoings
Six circuit breakers, 6 outgoings (line or generator-transformer unit)

- It does not lead to one line or generator outage in case of one CB maintenance;

- Three circuit breakers less than the scheme with three diameters

- Power output from four generators by two lines. If a permanent fault occurs on line, the power from four generators can still be output;

- A fault in one bay (line/generator) circuit shall result from hexagon string opened, two more lines/generators outage will happen in case another fault furtherly occurs;

- It is suitable for PP constructed at one time with no further extension at a later stage;
ABB step-up substation scheme in PP EHV Switchgears

Highlights of the scheme

- The adopted steel structure layout is the same as the filter circuit in the EHV converter station;
- The design style is a kind of 1 1/2 breaker matrix scheme;
- Independent and very clear to single bay maintenance and test for AIS solution, and with less affected area;
- A hybrid GIS FES is adopted for the rapid ES on the line side;
- It is irrespective of VFTO, because there is no reflection problem of transient wave for AIS solution;
- Insulation level under the pollution class of corresponding environment has been taken into account for AIS solution (IV Class);
- It is necessary for PP to benefit from appropriate connection scheme and land occupation;
- Reduce construction cost of equipment in step-up substation.
Roadmap of ABB 1000kV grid integration AIS solution in PP

- Advantage of HPL CB; Big cost difference
- ABB EHV AIS solution in PP
- Acknowledged By Customer
- Power DI participation
- SGCC expert group approval

Introduction to step-up station EHV AIS solution in PP by ABB team roadmap

Detailed feasibility design solution provided by DI and approved by SGCC expert group

PG BD in charge of integrating all PG resource