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6. Substation Design

6.1 General

The following plans by the three countries and an overall planning for the region are summarized as follows:

Burundi

The HV transmission line connecting the hydro-electric power plant Rusumo Falls and Gitega has been determined as follows:

Rusumo Falls – Muyinga - Gitega

By this Muyinga has been defined as a future place of a HV substation before the line routing continues to Gitega. Furthermore another transmission line via Bujumbura is recommended in order to connect the existing power plants in the region (RWEGURA, RUSIZI I, Rusizi II) as well as planned power plants in the future (RUSIZI III, SISI 5 and gas power plants at Kibuye and Gisenyi) (see Annex 1.1 of the Executive Summary).

The (n-1) planning principle is fulfilled. In case of an outage of the transmission Rusumo Falls–Muyinga–Gitega it is possible to transport the generated power of the Rusumo Falls hydroelectric power plant using the planned transmission lines in Rwanda:

Rusumo Falls ➔ Kigali ➔ Gisenyi ➔ Kibuye ➔ Bujumbura ➔ Gitega

or

Rusumo Falls ➔ Kigali ➔ Kigoma ➔ Kibuye ➔ Bujumbura ➔ Gitega

The voltage level will be 220 kV. The line routing is very clear and the alternative near of the National park of Ruvubu was cancelled.

Recommendation

The voltage level of 220 kV is recommended because this will be the common voltage level for power transmission of the future in East and Central Africa. The existing substation in Gitega will be extended by

- reserve feeders
- bus sectionalizers
- 110 kV transformer feeder
- 220/110 kV transformer
- 220 kV feeder
- 220 kV reactor
Rwanda
The interconnection line from Rusumo Falls to Kigali is as follows

Rusumo Falls–Kigali New Airport–Birembo

The recommended line routing is via Kigali New Airport because with a future extension to Kibuye a transmission line circuit will be closed around Kigali. Furthermore, the new developing area near the new airport can be connected to the electrical grid (see Annex 1.1 of the Executive Summary).

The (n-1) planning principle is fulfilled as there will be various possibilities in the future to transport the generated power of the Rusumo Falls hydroelectric power plant using the planned transmission lines of Burundi:

Rusumo Falls ➔ Muyinga ➔ Gitega ➔ Bujumbura ➔ Kibuye ➔ Gisenyi ➔ Kigali (proposed / planned 220 kV line)

or

Rusumo Falls ➔ Muyinga ➔ Gitega ➔ Bujumbura ➔ Kibuye ➔ Kigoma ➔ Kigali

If the new power plants RUSIZI III (140 MW), SISI 5 (205 MW), the gas plants at Kibuye (100 MW) and Gisenyi (100 MW) will be realized in a short term, than a 220 kV grid in this area is needed and as a consequence and as a good completion, also the lines from Rusumo Falls to Birembo shall be designed and operated in 220 kV.

Because the gas plants at Kibuye (100 MW) will be realized in a short term, a 220 kV grid is needed in Rwanda. It is assumed, that the 220 kV substations in Kigali (Birembo) will be realized with the ongoing line project.

The administration of Rwanda will decide in the near future of an eventually relocation of the end point of the Rusumo falls line, because the area around Birembo is now heavy populated and in the next years an additional increase of the population is expected.

The 220 kV substation Birembo will be needed in the near future. Because there are different ongoing projects, it should be decided by the Rwandan authorities and the financing institutions which project shall handle which part of the Birembo 220 kV substation.

For this stage we assume that this project will consist of one 220 kV feeder OHL and one 220 kV feeder reactor.
**Tanzania**

A new 400 kV system is planned from Mbeya in the south via Dodoma, Singida to Shinyanga, from Singida the 400 kV systems will be extended to Arusha and then an interconnection to Nairobi is foreseen.

Another branch of the 400 kV systems is planned up to Geita. In the far west from Tanzania a 220 kV grid is foreseen. The new Masterplan is still in discussion.

Another Study for the western Region of Tanzania was established by SWECO. There an interconnection from Geita to Nyakanazi and then to Rusumo Falls was proposed. A final decision is not yet taken.

In parallel to the Masterplan the private company Kabanga Nickel is planning a 220 kV line from Bulyanhulu to Kabanga Nickel near the Burundian border (see Annex 1.2).

These activities shall be coordinated with the NELSAP planning for the 220 kV transmission line from Rusumo Falls to Nyakanzi/Biharamulo which has been the result of the discussions and analysis between the representatives of TANESCO and the Consultant during the pre-feasibility stage.

The connection of the mine Kabanga Nickel can be realized in the following:

- one extra 220 kV line from Rusumo Falls
- a T-Off connection from the line to Gitega
- One OHL from a new substation at the border to Burundi.
- a loop in to the line Rusumo Falls to Nyakanazi/Biharamulo.

**Overall planning**

There is an overall planning for a HV grid in eastern Africa.

The first planning shows an interconnected 220 kV grid from Kenya, Uganda and Tanzania. In 2005 the same grid indicates a voltage of 220 kV or greater.

The actual planning prefers a voltage of 400 kV for the inter African connections in Tanzania and Kenya (see Annex 1.2 of the Executive Summary). The voltage level for the interconnection Kenya - Uganda was foreseen for 220 kV but now a change to 400 kV is in discussion.

The HV grid ring around the Lake Victoria (see Annex 1.2) can be closed via Bukoba in Tanzania or via Rusumo Falls and Birembo (Kigali).

The decision shall be given by the related organizations like SAPP etc. and the financing institutes like AfDB, World Bank and the representatives of Burundi, Rwanda, Tanzania, etc.
Map 6-1 gives an overview of the project area including 220 kV transmission lines as well as the planned 220kV substations at

- Muyinga and Gitega (Burundi)
- Rusumo, Kigali New Airport and Birembo (Rwanda)
- Nyakanazi, 50 km south of Biharamulo (Tanzania)

There is an ongoing study for EAPP (East African Power Pool) regarding the future HV grid in the region. The results and decisions will be finalized by the end of 2010.

The actual situation and decision is to use 220 kV for the lines related to Rusumo Falls.
Installation and size of line compensation reactors

The installation and the size of the line compensation reactors can be done in different ways:
- design for each line section and connection direct to the line, which means less flexibility for the operation, difficulties in case of grid extensions which are planned for each country
- Design for the whole system and connection to the busbars, which means more flexibility for the operation and in the case of grid extensions.

The size of the line compensation reactors shall be harmonized within all 220 kV projects in the region.

In this planning stage we have chosen a size of 10 MVAR as standard size for the line compensation reactors in the region. This size was assumed in the substations Nykanazi and Kigali as well as in the Rusumo Falls Hydro Power plant, connected to the bus bars.

In other NELSAP projects a standard size of 20 MVAR was chosen. In these cases the lines are longer, line compensation reactors are only installed at one side of the line and the line characteristics are different, because the line conductors are different.

A harmonization of the line compensation reactors within all 220 kV projects in the region is recommended.

A general decision shall also be taken about the type of the substation:
- double bus bar system as for the existing substations in all related countries also for 220 kV
- one and a half (1 + 1/2) circuit breaker system as used in Kenya

In this planning stage we have used double bus bar systems.

6.2 Burundi

6.2.1 Environmental characteristics in Burundi

<table>
<thead>
<tr>
<th></th>
<th>Indoor</th>
<th>Outdoor</th>
</tr>
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<tr>
<td>Ambient air temperature</td>
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<td></td>
</tr>
<tr>
<td>Maximum</td>
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<td>+ 35°C</td>
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<td>24 hour average,</td>
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<td>Rainfall average annual</td>
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</table>
6.2.2 Electrical characteristic at Burundi substations

STATIONS CHARACTERISTICS

Existing 110 (123) kV system:

- Maximum operating voltage: 123 kV, 3-phase, 50 Hz
- Neutral earthing: solidly earthed
- Impulse withstand voltage: 550/650 kV peak (internal/external)
- Rated power-frequency short withstand voltage: 230/275 kV (internal/external) duration
- Short-circuit withstand ability: 31.5 kA, 1 s/ 80 kA
- Creepage distance: 16 mm/kV

Future 220 (245) kV system:

- Maximum operating voltage: 245 kV, 3-phase, 50 Hz
- Neutral earthing: Solidly earthed
- Impulse withstand voltage: 950/1050 kV peak (internal/external)
- Rated power-frequency short withstand voltage: 395/460 kV (internal/external) duration
- Short-circuit withstand ability: 31.5 kA, 1 s/ 80 kA
- Creepage distance: 16 mm/kV

6.2.3 Gitega substation

6.2.3.1 General

The substation is located some 60 km west from Bujumbura. The altitude of facilities is 1417 m. The substation was commissioned in 1990.

6.2.3.2 Existing facilities at Gitega

Currently, Gitega is a 110/30 kV transmission substation with following facilities:

110 kV switchgear
- AIS switchgear with single bus bar (flexible) system
- one 110/30 kV transformer bay
- one OHTL feeder bay (to RN1/Bujumbura) without circuit breaker

Transformers
- one 10 MVA, 110/30 kV network supply transformer

Auxiliary Systems
- 400/230 VAC auxiliary distribution system with sufficient capacity for NELSAP needs, however, the distribution board needs to be extended.
• Doubled 110 VDC auxiliary supply system with sufficient capacity for NELSAP needs, however, the distribution board needs to be extended.
• A single battery / double charger 48 VDC auxiliary supply system with sufficient capacity for NELSAP needs.

Control Building
The control building consists of
• control room with relay area,
• auxiliaries’ room, battery room,
• wash room,
• 30 kV switchgear room,
• auxiliary transformer room and
• diesel generator room.

Sufficient space for NELSAP needs is available within the control/relay room.

Substation Area
The fenced area offers some extension possibilities.
The additional necessary area (20m x 40 m) is shown in Annex 6.2. This area is available near to the existing substation.
A complete substation with 2 transformer feeders, one OHL feeder and one reactor feeder need an area of 80 m x 40 m.

Protection Systems
No Interconnection Project related facilities exist.

Control System
The existing control system facilities consist of:

• Bay level local emergency control from the switching equipment local control panels (LCP) within the switchgears
• Bay level local control from a mimic fitted in the bay outdoor marshalling panel
• Centralized remote control from conventional remote control panel (RCP) located in the control room in control building
• SCADA control from NCC through remote terminal unit (RTU) with hard wired process connections.

No interconnection project related facilities exist; however, the system can be extended to cover NELSAP needs.

6.2.3.3 NELSAP scope in Gitega substation for a 220 kV substation

110 kV switchgear
Extension of the existing 110 kV switchgear is proposed.
• One transformer bay for the interbus transformer 220/110 kV
• One 110 kV bay for the OHL to RN1 Bujumbura
The busbar should be extended to accommodate one interbus transformer feeder bay for the 220 kV substations.

A rehabilitation and extension of the 110 kV substations is recommended. This should be included in the ongoing project or in the rehabilitation project of the REGIDESO grid. For the economical analysis we have considered that the rehabilitation and extension of the 110 kV substation is included in the project of Rusumo Falls.

**220 kV switchgear**

The new substation will be as follows:
- 220 kV busbar
- 1 OHL bays for Rusumo falls
- 4 spare bays not equipped for future extension
- 1 transformer bays
- 1 transformer bay not equipped
- 1 reactor bays with one reactor
- 1 reactor bay not equipped
- 1 transformer 220/110 kV 25 MVA

**220 kV switchgear as variant**

The new substation will be as follows:
- 220 kV busbar
- 1 OHL bays for Rusumo falls
- 2 spare bays not equipped for future extension
- 2 transformer bays
- 1 reactor bays with one reactor
- 1 reactor bay not equipped
- 2 transformer 220/110 kV 25 MVA

**Auxiliary system**

Complete, new auxiliary systems are needed for the substation facilities.

**Control Building**

A new, air conditioned control building for the switchgear secondary and auxiliary systems shall be provided. Space reservations for future extensions shall be considered.

**Control/Protection/SCADA systems**

A new digital Control and command system (SCADA) is foreseen for the substation Gitega with an interconnection to a future Load Dispatch Centre.

**Protection System**

**Transformer Protection**

For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.
Shunt Reactor Protection
For the new reactors a complete protection cubicle shall be installed with
differential protection (87T), Over excitation (24), Restricted Earth fault
Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz,
Winding Temperature, Oil level, Oil temperature etc.

OHTL Feeder Protection
When applying the n-1 system planning principle for important cross border
interconnection system, two independent main protection systems fed from
different DC sources and connected to different CT cores will be required.
Suitable communication and back-up facilities need to be provided as well.

The two main protection systems could be based on similar measuring
principles (e.g. two distance relays), however more secure arrangement -in
order to reliably detect different types of faults- would be systems based on
different measuring principles.

Therefore, the following OHTL feeder protection facilities are proposed:

- Main 1 Protection, consisting of:
  - Full scheme distance protection with minimum four independent
    impedance measuring zones and with six independent measuring loops
    (ph to ph and ph to earth).
  - The first zone shall be complemented with teleprotection scheme
    (permissive underreach) over multiplexed communication link to cover
    the complete length of the protected line. The second zone would act as
    back-up for the first zone, the third zone as for back-up in busbar faults at
    remote station and the fourth zone could be a reverse zone and act as
    back-up for busbar faults at local station
  - The distance protection would be backed-up with directional earth fault
    protection (intended for high resistance faults) also complemented with
    teleprotection scheme (directional comparison) over multiplexed
    communication link.

- Main 2 Protection, consisting of:
  - Longitudinal differential protection over multiplexed communication
    link to cover the complete length of the protected line.
  - To cover the possible failures in communication link, the line
differential protection should be backed up with directional over
current and directional earth fault protection functions, however,
without teleprotection schemes. These functions may be integrated in
the line differential relay.

For network stability reasons it is necessary to complement the protection
system with single phase rapid auto-reclosing (SPAR) as well as with three
phase delayed auto-reclosing facilities.
For circuit breaker faults, breaker failure protection system with direct intertrip (DIT) to remote end over dedicated teleprotection channel in MUX equipment should be planned.

Under voltage tripping facility should also be provided and over voltage protection should be considered due to possible future non-switched shunt reactors on line side.

**Busbar Protection**

There is no busbar protection foreseen, because in the first stage only one 220 kV feeder will be realized. If the 220 kV substation will be completed, than a 220 kV busbar protection will be installed.

Busbar faults will be cleared by distance protection second zones at remote stations as well as by reverse zone at local station.

### 6.2.4 Muyinga substation

The substation Muyinga shall be located as discussed with REGIDESO near of the existing 30 kV distribution centre (S02°52,185’; E30°19,594’)

### 6.2.4.1 Substation Muyinga with 220 kV

The new substation Muyinga can be designed as a T-Off substation with only one transformer bay. This substation is important for the rural electrification in the region.

- One (1) set of 220 kV transformer feeder bay for single busbar system for the new transformer

**Transformers**

- One new transformer 25 MVA 220/30 kV

**Reactive Power compensation equipment**

None

**30 KV switchgear**

30 kV switchgear with 6 cubicles is required

**Auxiliary Systems**

A new auxiliary system is foreseen

**Control Building**

A new control building is foreseen

**Control/Protection/SCADA systems**

A new digital Control and command system (SCADA) is foreseen for the substation Muyinga with an interconnection to a future Load Dispatch Centre.
Substation Area
The substation area shall be built with enough space for an extension and a future 220 kV substation.
The necessary area (environ 12m x 60 m) for the actual substation and environ 50m x 60 m for a future extension is given in Annex 6.4. This area is available at the existing 30 kV substation.

Transformer Protection
For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50,51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

Busbar Protection
There is no busbar protection foreseen, because in the first stage only one 220 kV feeder will be realized. If the 220 kV substation will be completed, than a 220 kV busbar protection will be installed.
Busbar faults will be cleared by distance protection second zones at remote stations as well as by reverse zone at local station.

6.3 Rwanda

6.3.1 Environmental characteristics in Rwanda

Ambient air temperature

<table>
<thead>
<tr>
<th>Indoor</th>
<th>Outdoor</th>
</tr>
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<tbody>
<tr>
<td>Maximum</td>
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<td>Minimum</td>
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<td>Humidity</td>
<td>90 %</td>
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<td>Seismic Acceleration</td>
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<td>Isoceraunic Level</td>
<td>150</td>
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<tr>
<td>Rainfall average annual</td>
<td>1100 mm</td>
</tr>
</tbody>
</table>

6.3.2 Electrical characteristics at Rwanda substations

Stations Characteristics

Existing 110 (123) kV system:

- Maximum operating voltage: 123 kV, 3-phase, 50 Hz
- Neutral earthing: solidly earthed
- Impulse withstand voltage: 550/650 kV peak (internal/external)
- Rated power-frequency short: 230/275 kV (internal/external)
- Duration withstand voltage
- Short-circuit withstand ability: 31.5 kA, 1 s/ 80 kA
- Creepage distance: 16 mm/kV
Future 220 (245) kV system:

- Maximum operating voltage: 245 kV, 3-phase, 50 Hz
- Neutral earthing: solidly earthed
- Impulse withstand voltage: 950/1050 kV peak (internal/external)
- Rated power-frequency short duration withstand voltage: 395/460 kV (internal/external)
- Short-circuit withstand ability: 31.5 kA, 1 s/ 80 kA
- Creepage distance: 16 mm/kV

6.3.3 BIREMBO substation

6.3.3.1 General

The Birembo substation is a new substation that will be built by Electrogaz at the outskirts of Kigali. At final stage, it will become one of the main 220 kV substations of the Electrogaz grid and one of the main feeder substations for the Kigali distribution system. Altitude of the substation is 1 600 m.

The administration of Rwanda will decide in the near future of an eventually relocation of the end point of the Rusumo falls line, because the area around Birembo is now heavy populated and in the next years an additional increase of the population is expected.

The 220 kV substation Birembo will be needed in the near future. Because there are different ongoing projects, it should be decided by the Rwandan authorities and the financing institutions which project shall handle which part of the Birembo 220 kV substation.

6.3.3.2 ELECTROGAZ scope

The Birembo substation will be operating for a certain period of time before the construction of future interconnection. The following items will be provided by Electrogaz.

**110 kV switchgear**

- One single busbar system, AIS switchgear, with provision for a second busbar system;
- One line bay, from Jabana substation;
- One line bay, to Gasogi substation, complete with the Installation of 110/70 kV transformer previously installed at Jabana; or with a 110 kV operation for the Gasogi line
- One transformer bay 110/15 kV
- Two future transformer bay 110/15 kV
- One future line coupler;
- Future bays for reactive power compensation.
Transformers
- One 110/70 kV, 10 MVA autotransformer, Ynyno with solidly grounded neutral; if needed
- One 110/15 kV, 20 MVA transformer, YNynod11, with high voltage and low voltage neutral solidity grounded;
- Two 110/15 kV, 20 MVA future transformers.

Reactive Power Compensation Equipment
There is no power compensation equipment presently planned at the substation. All required reactive compensation must be added by Electrogaz.

Auxiliary Systems
All required auxiliary system will be provided by Electrogaz.

Control Building
There will be enough space in the substation control building for any additional control boards, relay panels, and telecommunication equipments required for the new 110 kV interconnection. Space should also be planned for the future.

Interconnections
- double circuit 220 kV interconnection between Rwanda and Uganda
- Double circuit 220 kV interconnection between Rwanda and Tanzania (Rusumo Falls).
- double circuit 220 kV interconnection between Rwanda and DR Congo(Gisenyi,Kibuye)
- Two Interbus transformers 220/110 kV

Substation Area
Substation area will be obtained by Electrogaz.

6.3.3.3 NELSAP scope in Birembo substation

110 kV switchgear
Extension of the planned and in 2012 existing 110 kV switchgear is assumed to be realized by other projects (Line Kibuye-Gisenyi-Birembo) including

- 2 transformer bay for the interbus transformers 220/110 kV

For the ongoing project no extension of the 110 kV busbar is foreseen.

220 kV switchgear
Extension of the planned (in 2012 existing) substation:

- 1 OHL bays for Rusumo falls
- 1 OHL bays for Rusumo falls not equipped
- 1 reactor bay
- 1 reactor 220 kV

Auxiliary system
Extension of the auxiliary systems.
Control Building
Extension of the equipment.

Control/Protection/SCADA systems
Extension of the equipment.

Protection System

Transformer Protection
For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc

Shunt Reactor Protection
For the new reactors a complete protection cubicle shall be installed with differential protection (87T), Over excitation (24), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

OHTL Feeder Protection
When applying the n-1 system planning principle for important cross border interconnection system, two independent main protection systems fed from different DC sources and connected to different CT cores will be required. Suitable communication and back-up facilities need to be provided as well.

The two main protection systems could be based on similar measuring principles (e.g. two distance relays), however more secure arrangement -in order to reliably detect different types of faults- would be systems based on different measuring principles. Therefore, the following OHTL feeder protection facilities are proposed:

- Main 1 Protection, consisting of:
  - Full scheme distance protection with minimum four independent impedance measuring zones and with six independent measuring loops (ph to ph and ph to earth).
  - The first zone shall be complemented with teleprotection scheme (permissive underreach) over multiplexed communication link to cover the complete length of the protected line. The second zone would act as back-up for the first zone, the third zone as for back-up in busbar faults at remote station and the fourth zone could be a reverse zone and act as back-up for busbar faults at local station.
  - The distance protection would be backed-up with directional earth fault protection (intended for high resistance faults) also complemented with teleprotection scheme (directional comparison) over multiplexed communication link.
- Main 2 Protection, consisting of:
Longitudinal differential protection over multiplexed communication link to cover the complete length of the protected line.

To cover the possible failures in communication link, the line differential protection should be backed up with directional over current and directional earth fault protection functions, however, without teleprotection schemes. These functions may be integrated in to the line differential relay.

For network stability reasons it is necessary to complement the protection system with single phase rapid auto-reclosing (SPAR) as well as with three phase delayed auto-reclosing facilities.

For circuit breaker faults, breaker failure protection system with direct intertrip (DIT) to remote end over dedicated teleprotection channel in MUX equipment should be planned.

Under voltage tripping facility should also be provided and over voltage protection should be considered due to possible future non-switched shunt reactors on line side.

**Busbar Protection**
A busbar protection is needed to fulfill a SPAR (Single pole auto reclosing) dead time under 450 ms (see system calculation).

### 6.3.4 Substation Kigali Airport

The new substation Kigali Airport will be located either directly along the line Rusumo Falls to Kigali north of the river Nyabarongo near Gatare and Samuduha or about 5 km south of the river Nyabarongo near at the new Airport.

The new substation Kigali Airport will be as follows:

- 220 kV busbar
- 2 OHL bays for Rusumo falls and Birembo (Kigali)
- 6 spare bays not equipped for future extension
- 1 transformer bays
- 1 transformer bay not equipped
- 1 reactor bays with one reactor 10 MVAr
- 3 reactor bays not equipped
- 1 transformer 220/15(30) kV 20 MVA
- MV switchgear

The new substation Kigali Airport with 2 transformers will be as follows:

- 220 kV busbar
- 2 OHL bays for Rusumo falls and Birembo (Kigali)
• 6 spare bays not equipped for future extension
• 2 transformer bays
• 1 bus coupler bay
• 2 reactor bays with one reactor 10 MVAr
• 3 reactor bays not equipped
• 2 transformer 220/15(30) kV 20 MVA
• MV switchgear

**Auxiliary system**
Complete, new auxiliary systems are needed for the substation facilities.

**Control Building**
A new, air conditioned control building for the switchgear secondary and auxiliary systems shall be provided.
Space reservations for future extensions shall be considered.

**Control/Protection/SCADA systems**

**Protection System**

**Transformer Protection**
For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50,51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

**220 kV Protection Systems**

**Transformer Protection**
For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50,51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

**Shunt Reactor Protection**
For the new reactors a complete protection cubicle shall be installed with differential protection (87T), Over excitation (24), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

**OHTL Feeder Protection**
When applying the n-1 system planning principle for important cross border interconnection system, two independent main protection systems fed from different DC sources and connected to different CT cores will be required. Suitable communication and back-up facilities need to be provided as well.

The two main protection systems could be based on similar measuring principles (e.g. two distance relays), however more secure arrangement -in order to reliably detect different types of faults- would be systems based on
different measuring principles. Therefore, the following OHTL feeder protection facilities are proposed:

- **Main 1 Protection**, consisting of:
  - Full scheme distance protection with minimum four independent impedance measuring zones and with six independent measuring loops (ph to ph and ph to earth).
  - The first zone shall be complemented with teleprotection scheme (permissive underreach) over multiplexed communication link to cover the complete length of the protected line. The second zone would act as back-up for the first zone, the third zone as for back-up in busbar faults at remote station and the fourth zone could be a reverse zone and act as back-up for busbar faults at local station.
  - The distance protection would be backed-up with directional earth fault protection (intended for high resistance faults) also complemented with teleprotection scheme (directional comparison) over multiplexed communication link.

- **Main 2 Protection**, consisting of:
  - Longitudinal differential protection over multiplexed communication link to cover the complete length of the protected line.
  - To cover the possible failures in communication link, the line differential protection should be backed up with directional over current and directional earth fault protection functions, however, without teleprotection schemes. These functions may be integrated into the line differential relay.

For network stability reasons it is necessary to complement the protection system with single phase rapid auto-reclosing (SPAR) as well as with three phase delayed auto-reclosing facilities.

For circuit breaker faults, breaker failure protection system with direct intertrip (DIT) to remote end over dedicated teleprotection channel in MUX equipment should be planned.

Under voltage tripping facility should also be provided and over voltage protection should be considered due to possible future non-switched shunt reactors on line side.

**Busbar Protection**
A busbar protection is needed to fulfill a SPAR dead time under 450 ms (see system calculation).
6.4 Tanzania

6.4.1 Environmental characteristics in Tanzania

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Indoor</th>
<th>Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ambient air temperature</strong></td>
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<td></td>
</tr>
<tr>
<td>Maximum</td>
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<td>+ 35°C</td>
</tr>
<tr>
<td>24 hour average, max</td>
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<td>+ 35°C</td>
</tr>
<tr>
<td>Minimum</td>
<td>+5°C</td>
<td>+5°C</td>
</tr>
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<td>Humidity</td>
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<td>100 %</td>
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<td>Seismic Acceleration</td>
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<td>Isoceraunic Level</td>
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<td></td>
</tr>
<tr>
<td>Rainfall average annual</td>
<td>1100 mm</td>
<td></td>
</tr>
</tbody>
</table>

6.4.2 Electrical characteristics at Tanzania substations

**STATIONS CHARACTERISTICS**

Existing 132 kV system:
- Maximum operating voltage: 145 kV, 3-phase, 50 Hz
- Neutral earthing: solidly earthed
- Impulse withstand voltage: 650/750 kV peak (internal/external)
- Rated power-frequency short duration withstand voltage: 275/325 kV (internal/external)
- Short-circuit withstand ability: 31.5 kA, 1 s / 80 kA
- Creepage distance: 16 mm/kV

Existing 220 (245) kV system:
- Maximum operating voltage: 245 kV, 3-phase, 50 Hz
- Neutral earthing: Solidly earthed
- Impulse withstand voltage: 950/1050 kV peak (internal/external)
- Rated power-frequency short withstand voltage: 395/460 kV (internal/external) duration
- Short-circuit withstand ability: 31.5 kA, 1 s / 80 kA
- Creepage distance: 16 mm/kV
6.4.3 Substations in Tanzania

All substations in Tanzania related to the project do not yet exist. The endpoint of the OHL from Rusumo Falls is Nyakanazi/Biharamulo.

The new substation Nyakanazi/Biharamulo will be as follows:

- 220 kV double busbar
  - (1) 220 kV OHL bays for Rusumo Falls
  - (1) 220 kV OHL bays for Rusumo Falls not equipped
  - (4) 220 kV OHL bays for Geita, Kigoma (lake Tanganika) not equipped
  - (2) 220 kV OHL bays spare not equipped
  - (1) Transformer bay 220/33 kV 25 MVA
  - (1) Transformer bay 220/33 kV spare not equipped
  - (1) One bay for Reactive power compensation with a 10 MVAr shunt reactor
  - (6) Bays for Reactive power compensation not equipped
  - (1) MV substation 33 kV with 5 feeders and possibilities for an extension

The new substation Nyakanazi/Biharamulo with more equipment will be as follows:

- 220 kV double busbar
  - (1) 220 kV OHL bays for Rusumo Falls
  - (1) 220 kV OHL bays for Rusumo Falls not equipped
  - (2) 220 kV OHL bays for Geita, Kigoma (lake Tanganika)
  - (2) 220 kV OHL bays spare not equipped
  - (2) Transformer bay 220/33 kV 25 MVA
  - (1) One bay for Reactive power compensation with a 10 MVAr shunt reactor
  - (4) Bays for Reactive power compensation not equipped
  - (1) MV substation 33 kV with 5 feeders and possibilities for an extension

Auxiliary system
Complete, new auxiliary systems are needed for the substation facilities including AC/DC supply, UPS system etc.

Control Building
A new, air conditioned control building for the switchgear secondary and auxiliary systems shall be provided.
Space reservations for future extensions shall be considered.

Control/Protection/SCADA systems
Control
SCADA

Protection System

Transformer Protection
For the new transformer a complete protection cubicle shall be installed with differential protection (87T), Restricted Earth fault Protection (87N),
negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

**Shunt Reactor Protection**
For the new reactors a complete protection cubicle shall be installed with differential protection (87T), Over excitation (24), Restricted Earth fault Protection (87N), negative sequence (46), Over current (50, 51), Buchholtz, Winding Temperature, Oil level, Oil temperature etc.

**OHTL Feeder Protection**
When applying the n-1 system planning principle for important cross border interconnection system, two independent main protection systems fed from different DC sources and connected to different CT cores will be required. Suitable communication and back-up facilities need to be provided as well.

The two main protection systems could be based on similar measuring principles (e.g. two distance relays), however more secure arrangement - in order to reliably detect different types of faults - would be systems based on different measuring principles.

Therefore, the following OHTL feeder protection facilities are proposed:

- **Main 1 Protection, consisting of:**
  - Full scheme distance protection with minimum four independent impedance measuring zones and with six independent measuring loops (ph to ph and ph to earth).
  - The first zone shall be complemented with teleprotection scheme (permissive under reach) over multiplexed communication link to cover the complete length of the protected line. The second zone would act as back-up for the first zone, the third zone as for back-up in busbar faults at remote station and the fourth zone could be a reverse zone and act as back-up for busbar faults at local station.
  - The distance protection would be backed-up with directional earth fault protection (intended for high resistance faults) also complemented with teleprotection scheme (directional comparison) over multiplexed communication link.

- **Main 2 Protection, consisting of:**
  - Longitudinal differential protection over multiplexed communication link to cover the complete length of the protected line.
  - To cover the possible failures in communication link, the line differential protection should be backed up with directional over current and directional earth fault protection functions, however, without teleprotection schemes. These functions may be integrated in to the line differential relay.
  - For network stability reasons it is necessary to complement the protection system with single phase rapid auto-reclosing (SPAR) as well as with three phase delayed auto-reclosing facilities.
For circuit breaker faults, breaker failure protection system with direct intertrip (DIT) to remote end over dedicated teleprotection channel in MUX equipment should be planned.

Under voltage tripping facility should also be provided and over voltage protection should be considered due to possible future non-switched shunt reactors on line side.

**Busbar Protection**
A busbar protection is needed to fulfill a SPAR dead time under 450 ms (see system calculation).

The new substation for Kabanga Nickel as well as the related 220 kV OHLs from the new OHL Rusumo Falls to Nyakanazi/Biharamulo (NELSAP scope) is in the scope of the mine KabangaNickel

### 6.5 Substation Control and Monitoring System

#### 6.5.1 General Requirements

The control system of the new 220 kV for the Rusumo Falls Project shall be a digital control and monitoring system (SCS) and shall be designed to provide full redundancy, i.e. failure of any component in the control system must not at all cause failure of the entire digital control and monitoring system.

The design and arrangement of the system shall follow the latest engineering practice, ensure optimum continuity and reliability of supply, and ensure the safety of equipment and the operating staff.

The highest degree of uniformity and interchangeability shall be provided.

The control and monitoring system shall be of "open" architecture, based on the standard protocol IEC 61850 for hardware and software

The system shall permit extension, upgrading and replacement, and allow the use of equipment from different manufacturers.

All components shall be suitable for the local climatic conditions.

Storage of equipment shall be possible in closed rooms without air conditioning at a maximum ambient temperature of 60°C.

The system shall also be suitable for operation under the electrical conditions (including electrical discharge and disturbance level) prevailing in high voltage substations.
The equipment shall be installed in steelclad cubicles with hinged frames and glass door, having a protection degree of IP 52 as a minimum.

The SCMS shall be designed for easy modification of hardware and software and for easy extension of the substations. Maintenance, modification or extension of components may not force shut-off of the whole SCMS.

Self-monitoring of individual components, modules and data transfer channels shall increase the availability and the reliability of the equipment and minimize maintenance.

Failure of any component of the system may not force a total system failure.

6.5.2 System Control Operations and Supervision Levels

The following system control operations and supervision levels, including monitoring of status indications, alarms and measurements, shall be possible and implemented:

- **Level 3 (local and/or equipment control level):**
  local control and supervision from the Bay Control Units (through monitor screens). Closing of the circuit breaker shall only be possible if the circuit breaker is isolated for maintenance purposes.

  Should the Bay Control Units be out of service, control shall be direct from the conventional control cubicles of the new 220 kV HV equipment. This level serves as emergency level only. Operation shall be without electrical interlocks, except manufacturers’ standard mechanical interlocks. Each item of apparatus shall be equipped with local/remote switches to allow switching only with the switch in local position. Means shall be provided of padlocking the motor drives in such a way that no unauthorized operation is possible.

- **Level 2 (remote control level):**
  remote control and supervision from the Substation Control and Monitoring System (SCMS) for all switchgears and relevant auxiliary systems through the operator workstations located in the power station central control room.

  Remote control shall be realized via the station computer. All interlocks shall be programmed. The interlocks shall be programmed as close as possible to the field. Bay interlocks shall be implemented in the bay controllers and station interlocks in the station controller. Control shall be provided via the computer workstations. Control shall only be possible if all local/remote switches of the respective HV equipment and the respective local control panels are in the “remote” position. A soft-key on the station control shall be implemented to switch control between the substation and the supervisory level (National Control Center – NCC).

- **Level 1 (supervisory level):**
  This level is a remote control and supervision from the National Control Centre (NCC). Control shall be enabled only if the soft-key on the substation control system is in the “supervisory” position.
All control and monitoring functions have to be provided for secure and reliable operation of the entire new substation.

**It shall not be possible to initiate control actions at the same time from different control levels!!**

Under normal conditions, the 220 kV substations shall be remotely controlled and monitored from the National Control Center (NCC).

Two (2) operator consoles (with workstations) for control and monitoring (level 2) of the switchgears shall be conveniently located in the power station central control room.

SCADA data from the new 220 kV substation to the NCC shall be transmitted via fibre optic cables.

The SCMS shall also transmit the data of the HPP (generators) und 220kV S/S to the NCC.

For monitoring and control of all switchgear equipment, the existing Client SCADA regulations and tools shall be taken into consideration.

The bay units as well as the conventional control panels shall be integrated into the Bay Level Control and Protection System of the new stations to be located in the control building independently of each other, and their operation shall not be affected by any fault occurring at the station level or in other bay units of the substation.

### 6.5.3 Main Parts of SCMS

The substation control system will consist of the following main parts:

- Man Machine Communication (MMC)
- Substation Control Computer (SCC)
- Data Communication Interfaces (DCI) to the NCC and, in the near future, Gateway on international (EAPP) Control Center.
- Operator Workstations (with two displays and one event printer for each operator station):
  - Two placed in existing HPP Control Room
  - One placed in new Control Building (stand by), shall also be used as service and analysis system stations
- Operation and Display system (with one display and one hardcopy printer) for:
  - Director
  - Chef Engineer
  - Protection Engineer
- Bay Control Units (BU) for local control and supervision of each 220 kV bay as well as all auxiliaries
Note: Bay Control Unit and Bay Protection Unit can be carried out in one common device

- Serial high-speed bus (IEC 61850-8) for data transmission from bay units via fiber-optical links; recommended are separate FO rings for each voltage level and a redundant link for the auxiliary systems
- Diameter related conventional type control panels.

6.5.4 Function Requirements

All control and monitoring functions have to be provided for secure and reliable operation of the entire substation in compliance with the client guidelines for substation control and monitoring systems.

The following are the minimum functions required:

- Input of digital and analog values
- Control, interlocking and supervision of the bays and the substation
- Alarm handling in the bay computer units and in the station computer
- Analogue value acquisition and processing
- Bay and substation status indications
- Indication of measured and processed analogue values
- Station control via video display system
- Automatic chronological control of standard switching routines
- All hardware, software and telecommunication facilities for remote control and supervision of the substations from the SCADA system at the National Control Center
- Emergency control of each bay from the related bay control units and conventional control panels
- Synchrocheck function for all breakers
- Display of trend values
- Fault and alarm indication
- Events and alarms recording
- Evaluation and archiving of historical data.

All performance requirements shall be based on the definitions given in the international regulations:

IEC 60870 – 4 for reliability (MTBF),
Availability of the complete system ≥ 99.95%, Maintainability (class RT4),

Security,
Data integrity (class I3 for a residual information error probability of IE ≤ 10-14), time parameters (indications, control and measurements, etc) and
User interface performance for display response time, display update rate, alarm and event response time, display hardcopy response time, etc.
6.5.5 Fibre Optic Equipment

The following fiber optic equipment shall be installed at each end of the fiber optic cables:

- optical distribution frame (ODF) for connection of at least 24-coe OPGW and fiber optic cable
- patch cables connecting ODF with the multiplexer
- SDF STM-1 (155 Mbits/s) add/drop multiplexer with multi-channels of 2 Mbits/s interfaces
- Access multiplexer with multi-channels (interfaces) each for 64 kbit/s to connect SCADA equipment and telephone subscribers.

6.6 Costs for the substations

The costs are calculated for the HV (110 kV and 220 kV) including control building, auxiliary systems, control and protection. The costs for the MV switchgear is extra indicated.

**Burundi**

Gitega 220 kV substation: 4.0 Mill US $

Muyinga 220 kV substation 1.7 Mill US $

Muyinga 30 kV switchgear 0.4 Mill US $

**Total Burundi:** 6.1 Mill US $

**Rwanda**

Birembo substation: part of the 220 KV 2.4 Mill. US $

Kigali Airport: complete substation 3.5 Mill. US $
(2x 220 kV OHL bays, one 220 kV reactor bay, one 220 kV transformer bay one new transformers and control building etc.)

Kigali Airport 30 kV switchgear 0.4 Mill US $

**Total Rwanda:** 6.3 Mill US $

**Tanzania**

Nyakanazi/Biharamulo substation: complete substation: 3.4 Mill. US $
(2x 220 kV bays, one (1) 220 kV OHL bays
For Rusumo Falls, one (1) 220 kV transformer bay
One new transformers and control building etc.)

Nyakanazi/Biharamulo 30 kV switchgear 0.4 Mill US $

**Total Tanzania:** 3.8 Mill US $
The maximum costs are calculated for the HV (110 kV and 220 kV) including control building, auxiliary systems, control and protection. The costs for the MV switchgear is extra indicated.

**Burundi**

Gitega 220 kV substation: 4.7 Mill US $

Muyinga 220 kV substation 1.7 Mill US $

Muyinga 30 kV switchgear 0.4 Mill US $

**Total Burundi:** 6.8 Mill US $

**Rwanda**

Birembo substation: part of the 220 KV 2.4 Mill. US $

Kigali Airport: complete substation 5.3 Mill. US $

(2x 220 kV OHL bays, one 220 kV reactor bay, one 220 kV transformer bay one new transformers and control building etc.)

Kigali Airport 30 kV switchgear 0.4 Mill US $

**Total Rwanda:** 8.1 Mill US $

**Tanzania**

Nyakanazi/Biharamulo substation: complete substation: 5.8 Mill. US $

(2x 220 kV bays, one (1) 220 kV OHL bays For Rusumo Falls, one (1) 220 kV transformer bay One new transformers and control building etc.)

Nyakanazi/Biharamulo 30 kV switchgear 0.4 Mill US $

**Total Tanzania:** 6.2 Mill US $
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Annex 6-1a Single line substation Gitega with 2 transformers
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