| | |
|---|---|
| Appendix I | Tower Outlines and Accessories |
| Appendix II | Conductor, Overhead Groundwire and OPGW Hardware Fittings and Accessories |
| Appendix III | Typical Foundations and Tower Grounding |
| Appendix IV | Electric Clearances |
| Appendix V | General Geological and Lithological Structure for the Region of Three Lines |
| Appendix VI | Geotechnical Investigation |
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# 7. Overhead Transmission Line Design

## 7.1 General characteristics of the line

### 7.1.1 Introduction

This section contains all technical necessary information for the evaluation of the costs of electrical transmission lines connected to the Rusumo Falls power station.

The main purpose of this section is to establish the basic parameters, design criteria and characteristics to be used for the preparation of the technical specifications for the design, supply and construction of 220 kV transmission line associated to Rusumo Falls.

### 7.1.2 Mechanical design of the lines

Project related lines will be erected after an international invitation to tender is issued «ICB». It is intended that the 60826-1, 2, 3 and 4 of the International Electronic Commission (IEC) standards of security a class 1 line (return period of a 50 year ultimate conditions) will be used by project.

The loading of the power transmission line is calculated on the basis of IEC 60826-2 and 3. Special loads will be applied without wind at minimum temperature (broken cables, conductors and/or ground wire) and loads of cables will be calculated on basis of IEC. Overloads factors of 1.2 for steel structure design taking into account steel supply fluctuations and of 1.5 for the foundation design taking into account the soil structure related unpredictability will be applied to the calculated loads. Earthquake related loads are calculated with a horizontal acceleration of 0.1 g and a vertical of 0.05g. The seismic level of the region is of 0.1 g.

The mechanical tension limits of conductors will be of:

- 20% of the rated tensile strength (RTS) at 25°C without wind, initial state;
- 50% of the rated tensile strength (RTS) for maximum wind at minimum temperature, final state;
- 25 % of the rated tensile strength (RTS), at 10°C and initial state.

Insulators as well as accessories are designed in such away that their security factors are not less than 2.0 under the most unfavorable conditions for insulators and 2.5 for accessories.

### 7.1.3 Electric characteristics of the lines

#### 7.1.3.1 High altitude

The influence of high altitudes on both the thermal rating and the insulation coordination due to the change in air density is considered. Accordingly, a correction factor is assumed for the thermal rating and the impulse withstand voltages at altitudes above sea level. As for the project, the maximum lines' altitude is between 1000 m and 2000 m above sea level.

#### 7.1.3.2 Pollution

The route of the transmission lines is considered slightly polluted, according to level II of IEC 60815, with a minimum creepage distance of 20 mm/kV.

#### 7.1.3.3 Thunderstorm

The keraunic levels are high throughout all equatorial lake regions and hit 110 Td/year in the area of the lines.

#### 7.1.3.4 Earth resistance

Given a high keraunic level, the ground resistance should be placed between 10 and 20 , except for the three first and three last kilometers from the/up to the substation, where the resistance must be 10 . For the above to be achieved, two counterpoises are therefore required over the full length of the line.

## 7.2 Summary of electrical and mechanical characteristics of a 220 kV transmission line

Electrical and mechanical characteristics are summarized as follows:

| | | |
|---|---|---|
| Nominal voltage of a three phase system | 220 | kV |
| Highest voltage of the three phase system | 245 | kV |
| Minimal distance between arcing horns | 2.45 | m |
| 1 mn power frequency withstand voltage | 815 | kV |
| Lighting impulse positive withstand voltage (peak) | 1 250 | kV |
| Lighting impulse negative withstand voltage (peak) | 1 715 | kV |
| Nominal frequency | 50 | Hz |
| Minimal length of the leakage path of the insulators | 20 | mm/kV |
| Maximum shielding angle to outer phase conductor in towers | 10 | $^{o}$ |
| Maximum air temperature | 35 | $^{o}$C |
| Average air temperature | 25 | $^{o}$C |
| Minimum air temperature | 10 | $^{o}$C |
| Humidity | 90 - 100 | % |
| Reference gust wind speed (3 sec.) at 10 m high | 36 | m/s |
| Conductor per phase | 1 ASTER 570 | |
| Optical ground wire (OPWG) | DNO-7515 | |
| Ground wire | 10.6 mm GSW70 | |
| Number of insulators units :<br>• Suspension towers :<br>• Tension towers : | 18 (with arcing horns)<br>19 (with arcing horns) | |
| Maximum conductor temperature | 75 | $^{o}$C |
| Maximum ground wire temperature | 50 | $^{o}$C |
| Ruling span (P.E.) | 350 | m |
| Wind span (1.2 P.E.) | 420 | m |
| Weight span (2.0 P.E.) | 700 | m |
| Starting angle of conductors | -5 to +20 | $^{o}$ |
| Limit wind on cables at 10$^{o}$C | 760 Pa | |
| Clearance to tower :<br>• every day:<br>• reduced wind of 450 Pa :<br>• maximum wind of 760 Pa : | <br>2.91<br>1.60<br>0.89 | <br>m<br>m<br>m |
| Clearance to ground | 8.0 | m |

## 7.3 Phase conductors

In general, the supply and installation of the conductors represents 30 to 40 % of the transmission line cost. The conductor size has major influence on the loads transmitted to the towers and thus their cost. For these reasons, it is important to carry out a conductor optimization study. Eight different conductor arrangements consisting of both ACSR and AAAC conductor types have been studied. These are described in the following table and consist of three single conductor optimization and five more are composed of a bundle with two conductors optimization. The conductor properties along with mass of the suspension tower associated with each one and the number of conductors per bundle are shown in the table below.

| **Conductor Type** | **Size (kcmil)** | **% Acier** | **Diameter (mm)** | **Weight per Conductor (kg/km)** | **Tower (kg)** |
|---|---|---|---|---|---|
| 2-Ostrich | 300 | 14 | 17.27 | 614 | 6781 |
| 2-Aster 182 | 358 | - | 17.50 | 500 | 6723 |
| 2-Wolf | 311 | 19 | 18.13 | 726 | 6825 |
| 2-Aster 228 | 449 | - | 19.60 | 627 | 7037 |
| 2-Hawk | 477 | 14 | 21.79 | 975 | 7571 |
| Cardinal | 954 | 16 | 30.38 | 1.828 | 7019 |
| Aster 570 | 1,125 | - | 31.00 | 1.569 | 6689 |
| Bluejay | 1,113 | 6 | 31.98 | 1.868 | 7330 |

The optimization considers the capital cost per kilometer of transmission line associated with each conductor combined with the electrical losses to find the overall lowest cost for each scenario. This optimization has been done for single circuit transmission lines and double circuit transmission lines respectively.

Our estimates show for the three interconnections that one conductor ASTER 570 (AAAC) per phase or an equivalent conductor will be the most economical solution.

In addition, these are some advantages in homogenous conductor (AAAC) compared with an ACSR conductor:

- Corrosion problems are not encountered since corrosion affects mainly steel;
- Joints are simple and easy to workout.

The AAAC conductor characteristics selected are described below:

| | | |
|---|---|---|
| • Type of conductor: | | AAAC |
| • Name: | | Aster 570 |
| • Standard : | | NF C34-125 |
| • Number of conductors per phase : | | 1 |
| • Section: | mm2 | 570.22 |
| • Overall diameter: | mm | 31.05 |
| • Stranding : | no x mm | 61 x 3.45 |
| • Unit weight: | kg/m | 1.574 |
| • Minimum breaking load: | kN | 183.6 |
| • DC Resistance at 20oC : | Ώ/km | 0.0583 |

## 7.4 Overhead ground wires

According to electrical requirements, especially for earth fault current, one steel cable with a cross-section of 70 mm2 would be enough.

Given a high keraunic level for the region, the shielding angle of the ground wire will be around 10 degrees.

If only one shield (ground) wire is used, the overhead ground wire peak would become very high to be able to meet the requirements of the protection angle of 10 degrees

If two ground cables are used, the ground wire peak will be reduced, the weight of the tower decreases, and the total line cost as well, including the ground wires, it will turnout to be less costly than one higher tower with one ground wire. Thus, the two ground wires solution is recommended. In this case, one of the ground wire is an optical ground wire (OPGW) and the other, a conventional galvanized steel ground wire (GSW).

### 7.4.1 Galvanized steel ground wire

The galvanized steel ground wire selected has the following characteristics:

| | | |
|---|---|---|
| • Type of ground cable : | | GSW 70 |
| • Construction : | | 7 x 3.52 |
| • Standard : | IEC | 60 888 |
| • Section : | mm2 | 68.1 |
| • Overall diameter : | mm | 10.6 |
| • Weight : | kg/m | 0.540 |
| • Minimum breaking load : | kN | 89.5 |

## 7.4.2 Optical ground wire

The optical ground wire selected has the following characteristics:

a. Cable properties:

| | | |
|---|---|---|
| • Type of cable : | | ACS (Aluminum clad steel) |
| • Construction : | | 8ACS/3.15 |
| • Standard : | | IEC, IEEE, ASTM and ITU-T |
| • Suspension of optical fibers : | | Aluminum pipe and stainless steel tube |
| • Section : | mm2 | 77.55 |
| • Overall diameter : | mm | 11.5 |
| • Weight : | kg/m | 0.472 |
| • Minimum breaking load : | kN | 87 |
| • DC Resistance at 20oC : | Ώ /km | 0.8471 |

b. Optic fiber properties:

| | | |
|---|---|---|
| • Optical fiber type : | | Single mode |
| • Standard : | | ITU-T-G652 |
| • No of fibers : | | 24 |
| • External diameter : | µm | 250±15 |
| • Concentricity : | | ≥≥ 0.7 |
| • Attenuation | | |
| At 1310 nm | db/km | ≤ 0.35 |
| At 1550 nm | db/km | ≤ 0.22 |
| • Lifetime expected | years | 40 |

The OPGW will be designed and manufactured in accordance with the following standards:

| | |
|---|---|
| • Cable: | EEE 1138, IEC 60794-4 |
| • Fiber: | EC 60793,ITU-T G. 65x Series |
| • Color Code : | NSI/EIA 359-A, 598-A, IEC 60304 |
| • Aluminum Pipes : | STM B483 |
| • Stainless Steel Tubes : | STM A240, ASTM A632 |
| • Aluminum Clad Steel Wire: | EC 61232 |

## 7.5 Aeolian vibration protection of conductor, overhead groundwire and OPGW

### 7.5.1 General

To ensure the longevity of phase conductors and ground wires and avoid damage at suspension and strain supports, adequate protection must be provided against aeolian vibration. Particular attention must be paid to aeolian protection measures on lines located in flat open land and all long-span river crossings.

### 7.5.2 Damping

For single conductors, steel ground wire and OPGW aeolian vibration protection shall be provided by stockbridge type vibration dampers, or equivalent proven system.

Additionally, for OPGW, the use of armoured grip suspension clamps (AGS) is prescribed. Equivalent new designs can be considered when their performance has been demonstrated.

For single cable, the typical minimum requirements are as follows:

| **Span Length** | **Suspension Towers** | **Strain Towers** |
|---|---|---|
| 365 m or less | 2 dampers per span | 2 dampers per span |
| 365 m to 670 m | 2 dampers per span | 4 dampers per span |
| 670 m and above | 4 dampers per span | 6 dampers per span |

Vibration dampers shall be designed to restrict aeolian vibration to such levels, as determined by the method IEEE STD 1368-2006, “IEEE Guide for Aeolian Vibration Field Measurements of Overhead Conductors”, IEEE Power Engineering Society, 6 June 2007.

### 7.5.3 Tension limits

In addition to having adequate vibration control protection (suitable to the environmental conditions of the line), conductors and ground wires shall be strung so as not to exceed the following limits:

| **Conductor Type** | **Unloaded (no wind)** | | **Loaded** |
|---|---|---|---|
| | <u>Initial at 10°C Normal Terrain</u> | <u>Initial at 25°C Normal Terrain</u> | <u>Final at 10°C Max. Wind</u> |
| Conductor (AAAC) | 25 | 20 | 50 |
| Ground Wire - Steel | 19 | 14 | 50 |
| OPGW | 17 | 12 | 50 |
| Tension Limits are expressed in percent (%) of rated tensile strength (RTS) | | | |

For major river crossings, tension limits, vibration, protection measures and actual ambient conditions (wind, temperature, exposure) shall be verified for the specific site.

Also, the sag of the overhead steel ground wire at 25°C unloaded shall not exceed 90% of the conductor sag. For the optical ground wire (OPGW), the sagging at 25°C shall correspond to the sagging of the overhead steel ground wire.

## 7.6 Insulators and insulators strings

### 7.6.1 General

The insulation system is one of the line components where standardization is of outmost importance. This is because:

- Insulator string configuration and total length affects the design of the towers and safe climbing clearances;
- Insulators must be compatible not only with respect to established mechanical and geometrical characteristics, but also meet specified electrical values;
- Maintenance work is done regularly on insulator strings requiring specialized equipment and tools. Tools and equipment, as well as work procedures must be as uniform as possible.

All of the above elements underscore the importance of having a standardized insulation system, with known components, modular, and easily inspectable and maintainable throughout the life-span of the line.

Based on the above elements we recommend that the type of insulators to be used on this line will be cap and pin toughened glass type or porcelain type.

Insulator quality is highly variable from many suppliers.

Because of the importance of the insulator element in an HV system, for its very demanding electrical and mechanical performance and the high cost of outages, only high quality insulators from proven manufacturers should be used.

Also, wide-spread use of composites is not recommended for this project because of the yet unproven longevity, the unavailability of standard models in the industry today, the lack of modularity, more complex and expensive long-term storage and the high costs of inspection.

Composite insulators are generally longer than glass or porcelain insulator strings and generally require longer tower cross arms. The towers in this study have been optimized with glass or porcelain insulator strings.

Considering inspection and maintenance, toughened glass insulators offer the lowest life cycle cost of all insulating solutions.

### 7.6.2 Insulator characteristics

We recommend for this project that all insulators units are the cap and pin type toughened glass. The insulators will be in accordance with the following requirements :

| **Insulator Type** | **U70BL** |
|---|---|
| Nominal diameter of the insulator part | 255 mm |
| Nominal spacing | 146 mm |
| Minimal nominal creepage distance | 280 mm |
| Standard coupling size | 16A IEC 60120 |
| Internal height of socket end size | 16A IEC 60120 |
| Hole for split pin size | 16A IEC 60372 |
| Split pin size | 16A IEC 60372 |
| Dry lightning impulse withstand voltage | IEC 60383 |
| • positive | 100 kV |
| • negative | 100 kV |
| Power frequency withstand voltage | IEC60383 |
| • dry | 70 kVrms |
| • Wet | 40 kVrms |
| Min. (puncture in oil) | 130 kVrms |
| Max. RIV at 1 Mhz | 50 µV |
| Related electro-mechanical strength | 70 kN |
| Mechanical strength | 70 kN |

### 7.6.3 Insulators strings characteristics

To ensure satisfactory operation under normal, conditions, the number and type of insulators units are recommended as follows :

- Single suspension string with arcing horns: 1* 18 “U70BL” units
- Double suspension string with arcing horns: 2* 18 “U70BL” units
- Single tension string with arcing horns: 1* 19 “U70BL” units
- Double tension string with arcing horns: 2* 19 “U70BL” units

18 (19) insulators per string will be provide adequate electrical strength even for the highest altitudes expected (2000 m).

The appendix shows typical outlines of suspension and tension strings.

In all the suspension towers, phases will be supported by “I” strings. In general “I” strings will be single strings. Double “I” strings will be used in connection with the crossing of railroads, principal roads with an asphalt topcoat and for extra long spans.

Tension towers will be equipped with double tension strings. All tension strings (strain) will have one additional disk insulator and then will have additional electrical strength to reduce the probability of lighting flash-over at strain towers. Single tension string will be used for slack span for the connection with the substation.

All fittings subject to tension loads will be such that under the most unfavourable loading conditions, the factor of safety will not be less than 2.5; for the insulator itself, the safety factor will not be less than 2.0.

## 7.7 Transmission line towers

### 7.7.1 General

Throughout the line, the same towers (i.e. the identical “tower family”) will be used.

Conventional lattice self-supported steel towers with double vertical configuration for double circuit line or with delta configuration for single circuit line will be used. The ruling span would be approximately 350 m giving tower height (from top of the foundation to the bottom cross-arm) varying between 20.0 to 31.0 m for the suspension tower.

Although monopod tubular towers are less susceptible to vandalism, these tower types are only used where the visual aspect is of high importance and right of way is very restricted, this because of their very high cost which can be three (3) times higher than an equivalent lattice tower. The transport of monopod towers as well as their foundations is also very expensive.

### 7.7.2 Standard towers

The family of towers comprise four (4) standard structure types. The designation, utilization and principal characteristics of each tower type are summarized in the following table. However, their use on any specific line project depends on actual line profile and routing. Where overall cost of a line can be optimized with less than four (4) towers types, then some types can be omitted. In general, whenever for a given project there is less than three angle towers of a given type, it is worth considering omitting such tower and use the next stronger tower in the family compatible with the utilization.

The angle tower type "B" will be used for line derivations as well as anticascading tower. Anticascading tower will be installed every 10 kilometer.

- Type A: suspension tower $0^o$-$2^o$;
- Type B: tension tower angle of $0^o$-$15^o$;
- Type C: tension tower angle of $15^o$-$60^o$ and dead-end tower $0^o$-$15^o$;
- Type D: tension tower $60^o$-$90^o$.

### 7.7.3 Tower design standard

The tower design will be in accordance with the ASCE standards in design of latticed steel transmission structures ANSI/ASCE 10-97, 1997. In addition due consideration shall be given to IEC60826 which provides standard for the structural loading of transmission lines.

The wind load on the wires, insulators and on the superstructure will be calculated as stated in IEC 60826 standard.

The utilization factors for tower design shall be 0.80 for intact loading conditions, 0.9 for broken cable conditions and 0.50 for construction and maintenance.

# 220 kV TRANSMISSION LINE - BASIC TOWER PARAMETERS AND UTILISATION LIMITS FOR SPOTTING

<table>
<tr><td colspan="3">TOWER TYPE</td><td>A</td><td>B</td><td>C</td><td colspan="2">D</td></tr>
<tr><td colspan="3">UTILISATION</td><td>Suspension</td><td>Tension</td><td>Tension</td><td colspan="2">Tension</td></tr>
<tr><td colspan="3">Utilization Limits</td><td>Tangent (0° - 2°)</td><td>Angle (0° -15°)<br>Anticascading (0°)</td><td>Angle (15° - 60°)<br>Dead-end (0°-15°)</td><td colspan="2">Angle (60° -90°)<br>Dead-End (15° -45°)</td></tr>
<tr><td colspan="2" rowspan="2">Insulator<br>Strings</td><td>Type</td><td>Suspension<br>I –String</td><td colspan="4">Tension</td></tr>
<tr><td>Rating</td><td>1 x 70 kN</td><td colspan="4">2 x 70 kN</td></tr>
<tr><td colspan="3">Ground-wire attachment</td><td>Suspension</td><td colspan="4">Strain</td></tr>
<tr><td colspan="2" rowspan="2">Height to bottom<br>Phase (m)</td><td>Min.</td><td>16.50</td><td>16.5</td><td>16.5</td><td>16.5</td><td>17.0</td></tr>
<tr><td>Max.</td><td>27.50</td><td>38.2</td><td>33.5</td><td>27.5</td><td>27.5</td></tr>
<tr><td colspan="3">Body extension (m)</td><td>6.0</td><td>6.0, 12.0</td><td>6.0, 12.0</td><td colspan="2">6.0</td></tr>
<tr><td colspan="3">Legs extension</td><td>0, 1, 2, 3, 4, 5</td><td>0, 1, 2, 3, 4, 5</td><td>0, 1, 2, 3, 4, 5</td><td colspan="2">0, 1, 2, 3, 4, 5</td></tr>
<tr><td colspan="3">Max. difference in leg extension</td><td>3.0</td><td>4.0</td><td>4.0</td><td colspan="2">4.0</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="5">SPAN LIMITS</td><td colspan="2">Wind span (m) - Max</td><td>420</td><td>420 @ Max Angle</td><td>420 @ Max Angle</td><td colspan="2">420 @ Max. Angle</td></tr>
<tr><td colspan="2">Weight span (m) - Max</td><td>850</td><td>850</td><td>850</td><td colspan="2">850</td></tr>
<tr><td colspan="2">Weight span (m) – Min</td><td>50</td><td>-800</td><td>-800</td><td colspan="2">-800</td></tr>
<tr><td colspan="2">Weight/Wind span ratio-Min</td><td>0.83 at $0^o$</td><td>-</td><td>-</td><td colspan="2">-</td></tr>
<tr><td colspan="2">Max single span (m)</td><td>700</td><td>900</td><td>900</td><td colspan="2">900</td></tr>
</table>

### 7.7.4 Loads on towers

The loads given in the following two (2) tables will be assumed to be acting on the towers simultaneously and in their most stringent conditions.

a) Transverse Loads:

- These shall be the forces resulting from the limit wind pressure applied to the conductors and ground wires at a temperature of 10°C. These loads shall be combined with the limit wind pressure applied to the tower and insulators.
- The limit wind pressure is assumed perpendicular to the line and also at 45° to the line (oblique).
- In the case of angle structures, the transverse loads due to line deviation shall also be included.

b) Longitudinal Loads:

- Suspension tangent tower: the longitudinal forces due to broken conductors shall be equal to the residual tension of the one phase or one ground wire (at minimum temperature) with no wind. The residual tension is the static equilibrium load reached after the rupture of the conductor in the middle of a series of six spans suspension. In the case of ground wire, the residual tension is 100% of the tension without wind. The residual tension can be estimated as 70% of the tension for one phase conductor.
- Tension angle tower: Shall be designed for the condition of one broken phase and one groundwire simultaneously for the limit wind speed at every day temperature.
- All tension angle towers shall be designed for the unbalanced tension resulting from unequal ruling spans of 100 m and 400 m on each side of the tower in addition to all other loading.
- All tension angle towers that are allowed to be used as a temporary dead-end during construction shall be designed for the tension of all cables on one side of the tower with 50% of the limit wind on cables, tower and insulators. In this case, the spans shall be considered similar to those of failed system conditions.
- The dead-end tower shall be designed for the maximum tension of all cables on one side.
- The dead-end tower shall also be designed for another loading case where the conductors are attached to the terminal station with the worst case of deviation angles.

c) Vertical Loads:

- Normal case: The vertical load due to conductors and ground wires shall be based on appropriate weight spans (maximum and minimum). These loads are in addition to the dead weight of the structure, insulators and fittings.
- Construction and maintenance: Towers shall be designed for all conductor and ground wire attachment points with 50% increase of weight span at all points except at one point where the increase shall be 100%. This loading shall be combined with the appropriate longitudinal and transverse loads applicable if the tower is used as a temporary dead-end during construction.
- In addition to the above loads, compression struts of the cross arms shall be designed for a concentric load of 4.0 kN applied at the center of its unsupported length while all other horizontal members (all members with an angle less than 15° with the horizontal) including redundant shall withstand vertical load of 1.5 kN at their center in addition to everyday compression load of the members they support..

## 220 kV TRANSMISSION LINE - LOADING CASES FOR SUSPENSION TOWERS

| | Loading Case | Vertical Loads* | Transverse | Longitudinal | Strength factors |
|---|---|---|---|---|---|
| **Intact System** | Every day | Weight of all cables with max. weight span | Component of the tension at 25°C with no wind | - | 0.80 |
| | Construction and Maintenance | 1.5 times the every day load in all but one point where it is 2.0, combined with concentric loads in horizontal members | 1.5 times or 2.0 times above mentioned component of tension (see vertical load) | - | 0.50 |
| | Limit wind - Transversal | Identical to every day load (for uplift calculations another loading case shall be used with minimum weight span) | Limit wind pressure on all cables with max. wind span at 10°C + wind on tower + component of the tension | - | 0.80 |
| | Limit wind - oblique | Identical to every day load (for uplift calculations another loading case shall be used with minimum weight span) | Limit wind pressure on all cables with max. wind span at 10°C + wind on tower at 45° angle + component of the tension | Limit wind pressure on all cables with max. wind span at 10°C + wind on tower at 45° angle | 0.80 |
| **Failed System** | Rupture of one phase or one ground wire | 70% of every day load for the broken cables and 100% for others | Component of 70% of the tension without wind for the conductors or 100% of the tension for the groundwires | Component of 70% of the tension without wind for the conductors and 100% of the tension without wind for the groundwires | 0.90 |
| | Fall of one phase in an adjacent tower | 1.5 time the every day load for the dropped phase and the every day load for all other phases and groundwires | | 20% of the vertical load of the fallen phase only | 0.90 |

* These loads are in addition to the weight of tower, insulators and hardware, which are constant.

## 220 kV TRANSMISSION LINE - LOADING CASES FOR ANGLE TENSION TOWERS

| | **Loading Case** | **Vertical Loads *** | **Transverse** | **Longitudinal** | **Strength factors** |
|---|---|---|---|---|---|
| **Intact System** | Every day | Weight of all cables with the most stringent weight span combination | Component of the tension in cables at 25°C with no wind | - | 0.80 |
| | Dead-end during construction (with 50% limit wind pressure) | 1. Same as every day loading | Component of cable tension at min. temperature plus reduced wind on cables, towers & insulators | Component of cable tension at min. temperature | 0.80 |
| | Maintenance (no wind) | 150% of every day loading plus concentric loads | Same as every day load | - | 0.50 |
| | Limit wind – transversal | Same as every day load (for uplift calculations, minimum weight span shall be used) | Component of cable tension plus limit wind pressure on all cables at 10°C plus wind on tower and insulators | Unbalanced tension due to unequal ruling spans at 10°C | 0.80 |
| | Limit wind - oblique | Same as every day load (for uplift calculations, minimum weight span shall be used) | Component of cable tension plus limit wind pressure on all cables at 10°C plus wind on tower and insulators at 45° angle | Unbalanced tension due to unequal ruling spans at 45° at 10°C | 0.80 |
| **Failed System** | Rupture of one phase or one ground wire | 100% of weight span for all cables | Component of tension + limit wind on all spans and towers (70% on broken phase only) at 10°C | Same as limit wind+ longitudinal component of broken phase | 0.90 |

* These loads are in addition to the weight of tower, insulators and hardware, which are constant.

## 7.8 Conductor spacing, clearances and transpositions

### 7.8.1 Live metal-structure clearances

Air gap between earthed tower steelwork and line conductors or live metal string components are as follows:

a) Net clearance of 2.910 m for insulator or jumper swing, without wind at every day temperature (25°C).

b) Net clearance of 1.600 m for insulator or jumper swing corresponding to a wind (wind pressure of 450 Pa) speed of 60% of the maximum wind at every day temperature (25°C).

c) Net clearance of 0.890 m for insulator or jumper swing corresponding to the maximum wind speed (wind pressure of 760 Pa) at every day temperature (25°C).

### 7.8.2 Ground clearances and phase to phase distance

The following minimum vertical clearances should be maintained at a maximum conductor temperature of (75$^{o}$C) at the final state without wind:

| | **Vertical clearances (m)** |
|---|---|
| Roads | 9.0 |
| Pedestrian zone only, ground in general | 8.0 |
| Overhead lines | 5.0 |
| Telecommunication lines | 4.6 |

The phase to phase distance (dm) should not be less than:

$$d_m \geq 0.9\sqrt{(F+L)}+C$$

Where:

F = Sag of Conductor (m) at maximum temperature (75$^{o}$C)

L = Length of the insulator string (m), L = 0 for tension string

C = Constant for 220 kV = 1.5 m

Special requirements in connection with crossing may be ordered by the client. Where construction of other types are met, the clearances shall be reviewed and approved.

### 7.8.3 Conductor – Overhead shieldwire spacings

The minimum vertical distance between the phase conductor and the overhead shield wire at the tower will be not less than 3.0 m for 220 kV lines. To limit the probability of flashover, the minimal spacing between conductor and groundwire at the tower must be increased (in the span) in proportion to the span, this in addition to the above:

- The overhead shieldwire sag at 25°C will not be more than 90% of the conductor sag at 25°.

### 7.8.4 Shielding angle

Given a high keraunic level for the region, the shielding angle to the outside phases will be limited to 10°.

### 7.8.5 Transposition

For the 220 kV lines, it is recommended that these lines be fully transposed in order to minimize the coupling between phases and to improve the performance of single-pole reclosing.

The lines may be transposed at two locations (1/3 and 2/3 along the line length) with equal lengths of each phase arrangement. This will however result in different phase arrangements at each end of the line requiring additional care when making the line termination.

## 7.9 Tower signs and accessories

Latticed towers are to be equipped with following signs and accessories.

### 7.9.1 Tower accessories

| Accessories | Purpose/Type | Tower Type |
|---|---|---|
| • Step-Bolts<br>• Anticlimbing device | Maintenance<br>Barbed wire type | All towers<br>All towers |
| • Antitheft bolts and nuts | Protection | Up to the level of anticlimbing devices of all towers |

Appropriate anti-theft fasteners, for example huck-bolting, shall be applied on all the towers up to the level of anti climbing devices, to prevent theft of tower members. Specifications will be included in Tender Documents.

### 7.9.2 Tower signs

| Sign | Location | Tower |
|---|---|---|
| • Tower and circuit No. sign<br><br>• Danger sign<br>• Phase identification sign | Lower part of tower, above anticlimbing device | All towers<br><br><br>All towers<br>All towers |
| • Aerial tower No. sign | Top of tower | Every $10^{th}$ tower and angle towers |

## 7.10 Foundations

This chapter briefly describes the anticipated geotechnical conditions, the planned geotechnical investigation program and the considered foundation types. It is composed of six sections. The first section lists the reference documents. The second section summarizes the planned geotechnical investigation program. The third section describes the estimated geotechnical conditions. The fourth section describes the proposed foundation types. The fifth section presents the estimated frequency of the various geotechnical conditions and of their corresponding foundation types and finally the sixth section is the foundation design criteria.

### 7.10.1 Reference documents

The geotechnical conditions were estimated based on the following reference documents:

- Satellite images from "Google Earth";
- Topographic maps (1 : 50 000);
- Geological maps of Rwanda (1 : 250 000 and 1: 100 000);
- Mineral map of Rwanda (1: 250 000);
- Geological maps of Burundi (1 : 250 000 and 1: 100 000);
- Mineral map of Burundi (1: 250 000);
- Geological maps of Tanzania (1: 2 000 000 and 1: 125 000);
- Soil map of Tanzania (1: 2 000 000).

### 7.10.2 Geotechnical Investigation Program

A summary geotechnical investigation program is planned in order to collect basic data concerning the following elements:

- Nature, stratigraphy and distribution of soils and paleosoils;
- Soils granulometry, color, consistency, in place and reworked density resistance;
- Nature of underlying rock formations, when visible;
- Nature and intensity of rock fissuration;
- Rock weathering level;
- Surficial and underground water conditions;
- Some complementary information (local topography, hydrography, access, vegetation, man made structures, etc.).

A detailed description of the geotechnical investigation program is given in Appendix VI. This appendix also contains the topographical and geological maps, which show the position of the planned geotechnical exploration sites.

These sites, considered representative of the transmission line geotechnical conditions, will be fully explored. For each one of these sites, the following field work will be realized:

- General description and photographies of the studied area (topography, access, vegetation, man made structures, site representativity, special features, etc.);
- Man made exploration pit with sampling an description of main soil types;
- In situ density measurement of surficial soils;
- Light weight dynamic penetration testing;
- Laboratory testing of samples, including natural water content, Atterberg limits and particle size analysis (sieving and hydrometer methods).

### 7.10.3 Geotechnical conditions

Four main geotechnical conditions are anticipated along the transmission lines: brownish organic sands, laterites, alluviums and bedrock. These settings are described in the following paragraphs.

### 7.10.3.1 Brownish organic sands

These usually silty brownish sands are mainly encountered in cultivated areas and probably come from the long-term reworking of more or less underlying ferruginuous sands or laterites for agricultural purposes. Thicknesses are usually small, less than 1.5 m, and extension limited to cultivated fields. They are better developed in low lying and flatter areas than on hill slopes or tops. Best sightings are to be found in the northwest part of the Rwanda line. Consistency of these sands ranges from soft to firm. Thicknesses are usually smaller than planned depths of footings, so that most of the time they will be excavated so that footings can rest on stiffer underlying soils.

### 7.10.3.2 Laterites

This is by far the most frequent soil type encountered along the three lines. They have been produced by the slow weathering and disintegration of underlying rock formations. They are usually argillaceous on pelitic and granitic rock types and gravely to cobbly on more competent rock formations like quartzite, sandstone and conglomerates.

They are found on hill slopes and tops, thicknesses tending to be smaller on hill tops and larger at the base of hill slopes. Thicknesses tend also to be greater on granitic roks and, to a lesser extent, on pelitic rocks. Thicknesses are smallest on quartzitic crests. They are extensively developed along the line connecting Rusumo Falls to Nyakanazi.

Consistency usually ranges from firm to very stiff with, from place to place, an overlying thin layer of softer lateritic materials.

### 7.10.3.3 Alluvium

These deposits have been formed by fluvial processes and are to be found along river beds. Extension and thickness are usually small along short and steeper water courses where agricultural activities have often completely reworked valley bottoms and transformed river beds into small straighter ditches.

Larger valleys show flat bottoms of various widths with usually quite sharp contacts between the river bed alluviums and the hill slope laterites. Thickness of alluviums in these larger valleys tend to be important and increases from valley slopes to valley center. Alluviums usually consists of yellow-brown or greyish silty to clayey sands, the grey color being produced by a higher organic content. Consistency, on dry samples, varies from soft to stiff. Usual bed load of encountered rivers range from clay to very fine sands and many rivers are now meandering within much larger valley flat bottoms.

In wetter parts of these larger valleys, organic matters have accumulated to, sometime, significant thicknesses with very low bearing capacities.

Most of the transmission line sections will cross these rivers with large alluviums deposits at high angles so that it will not be of a great concern. A few exceptions are however known in Rwanda (points 64 to 106, lake Mugesera crossing (points 168 – 174), points 265-268), in Burundi (Ruvuvu river, Karuzi area) and in Tanzania (downstream Ruvubu river).

There are also large older alluviums deposits in the southeast part of the Rusumo Falls – Nyakanazi transmission line, found far away from the original rivers that have formed them. Most show a firm to stiff consistency with little to no associated organic matters.

#### 7.10.3.4 Bedrock

The area is underlined by metasedimentary rocks of Mesoproterozoic age, by granitic intrusions and by some mafic rocks, especially in the Rusumo Falls area. These formations composed mainly of metamorphosed pelitic and quartzitic rocks are mainly oriented N.N.E.-S.S.O. and form sets of usually tight folds that have had a great influence on the area hydrography forming sets of valleys (politic rocks) and ridges (quartzitic rocks).

Rock outcrops are usually seen on the crest or upper slopes of quartzitic crest and, to a lesser extent, along crests of mixed quartzitic and pelitic rocks. Depth of rock formations is usually small in the upper half of elongated crests. Elsewhere it can vary significantly over short distances.

Most of these rock formations can be easily be excavated without using explosives or percussion tools. Rock formations of low to medium quality can be more easily encountered along quartzitic crests (Kibungo and Rusumo Falls areas in Rwanda, Ngara crest, Nyabugombe and Nyakahura in Tanzania) or in some granitic areas (Burundi).

#### 7.10.3.5 Foundation types

Four types of foundation are considered : spread foundations, short belled piles, long piles and rock sockets. These foundations types are shown on Plate xx and described in the flowing paragraphs.

#### 7.10.3.6 Spread foundations (concrete pad and pier foundation)

The considered spread foundations consist of a concrete slab placed about two meters below the surface, at each tower leg. The required excavation is backfilled with the original inorganic soil. This foundation type is appropriate for firm or stiff laterite, for medium or coarse grains alluviums above the water table and for very weathered or fractured bedrock, when it can be excavated to at least 2.0 m deep without explosives or percussion tools.

### 7.10.3.7 Short belled piles (pyramidal pad and chimney foundation)

The considered belled piles consist of reinforced concrete placed in an auger hole with an enlarged base, produced with a special tool, at each tower leg. This foundation type is appropriate for stiff laterites, as an alternative to spread foundation.

### 7.10.3.8 Long piles (pile foundation or raft foundation)

The considered pile foundations consist of driven circular steel section or cast in place reinforced concrete, at each tower leg. The latter may require drilling mud to maintain the auger hole stability. For circular steel piles, the included soils are replaced by concrete on the entire depth or only to a depth sufficient to properly embed each leg. Pile foundations are appropriate for soft alluviums below water table and fine grains loose alluviums.

In a very soft soil requiring piling, it may not be economic to install piles if only a few foundations are required on a given project. Instead, the Contractor may find it more convenient to install "raft" type foundations, which do not require the mobilization of expensive and specialized pile driving equipment.

### 7.10.3.9 Rock sockets (rock foundations)

The considered rock sockets consist of a short reinforced concrete shaft embedded into bedrock at each tower leg. This type of foundation is appropriate where bedrock is at less than 2,0 m deep and cannot be excavated without explosives or percussion tools.

### 7.10.3.10 Frequency

The estimated frequency of the various geotechnical conditions and corresponding foundation types for the three (3) lines are presented in the following four (4) tables.

## TANZANIA, RUSUMO FALLS TO NYAKANAZI, 220 KV TRANSMISSION LINE
## FOUNDATION CONDITIONS AND TYPES

| Foundation materials | | % | Conditions | % | Foundation type | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Spread** | **Belled piles** | **Long piles** | **Rock sockets** |
| | | | | | | | | |
| Laterites | From thin to very thick, with some ferruginuous soft sands | 70 | Soft (usually thin) | 10 | 10 | | | |
| | | | Firm | 30 | 30 | | | |
| | | | Stiff | 30 | | 30 | | |
| Alluvium | Fine to medium soft to firm silty sands | 10 | Water table more than 2 m deep | 8 | 8 | | | |
| | | | Water table less than 2 m deep | 2 | | | 2 | |
| | Fine silty and clayey firm sands | 5 | Water table more than 2 m deep | 4 | 4 | | | |
| | | | Water table less than 2 m deep | 1 | | | 1 | |
| Bedrock | Can be excavated without explosives or percussion tools | 5 | Less than 2 m deep | 5 | 5 | | | |
| | Low quality | 5 | Less than 2 m deep | 5 | | | | 5 |
| | Medium quality | 5 | Less than 2 m deep | 5 | | | | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Total :** | **100** | **------** | **100** | **57** | **30** | **3** | **10** |

**TANZANIA, RUSUMO FALLS TO BURUNDI BORDER, 220 KV TRANSMISSION LINE**
**FOUNDATION CONDITIONS AND TYPES**

| Foundation materials | | % | Conditions | % | Foundation type | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Spread** | **Belled piles** | **Long piles** | **Rock sockets** |
| | | | | | | | | |
| Laterites | From thin to very thick, with some ferruginuous soft sands | 66 | Soft (usually thin) | 5 | 5 | | | |
| | | | Firm | 30 | 30 | | | |
| | | | Stiff | 31 | | 31 | | |
| Alluvium | Fine to medium soft to firm silty sands | 1 | Water table more than 2 m deep | 1 | 1 | | | |
| | | | Water table less than 2 m deep | 0 | | | | |
| Bedrock | Can be excavated without explosives or percussion tools | 21 | Less than 2 m deep | 21 | 21 | | | |
| | Low quality | 10 | Less than 2 m deep | 8 | | | | 8 |
| | Medium quality | 2 | Less than 2 m deep | 4 | | | | 4 |
| **Total :** | | **100** | **------** | **100** | **57** | **31** | **0** | **12** |

**BURUNDI, GITEGA TO TANZANIA BORDER, 220 KV TRANSMISSION LINE**
**FOUNDATION CONDITIONS AND TYPES**

| **Foundation materials** | | **%** | **Conditions** | **%** | **Foundation type** | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Spread** | **Belled piles** | **Long piles** | **Rock sockets** |
| | | | | | | | | |
| Laterites | From thin to very thick, with some ferruginuous soft sands | 62 | Soft (usually thin) | 7 | 7 | | | |
| | | | Firm | 25 | 25 | | | |
| | | | Stiff | 30 | | 30 | | |
| Alluvium | Fine to medium soft to firm silty sands | 3 | Water table more than 2 m deep | 2 | 2 | | | |
| | | | Water table less than 2 m deep | 1 | | | 1 | |
| | Fine silty and clayey firm sands | 2 | Water table more than 2 m deep | 1 | 1 | | | |
| | | | Water table less than 2 m deep | 1 | | | 1 | |
| Bedrock | Can be excavated without explosives or percussion tools | 29 | Less than 2 m deep | 29 | 29 | | | |
| | Low quality | 2 | Less than 2 m deep | 2 | | | | 2 |
| | Medium quality | 2 | Less than 2 m deep | 2 | | | | 2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Total :** | **100** | **------** | **100** | **64** | **30** | **2** | **4** |

## RWANDA, BIREMBO TO RUSUMO FALLS, 220 KV TRANSMISSION LINE, FOUNDATION CONDITIONS AND TYPES

| Foundation materials | | % | Conditions | % | Foundation type | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Spread | Belled piles | Long piles | Rock sockets |
| | | | | | | | | |
| Brown sands | Less than 2 m thick, in cultivated low-lying areas | 2 | Soft (usually thin) | 2 | 2 | | | |
| | | | Firm | 0 | | | | |
| | | | Stiff | 0 | | | | |
| Laterites | From thin to very thick, with some ferruginuous soft sands | 64 | Soft (usually thin) | 4 | 4 | | | |
| | | | Firm | 35 | 35 | | | |
| | | | Stiff | 25 | | 25 | | |
| Alluvium | Fine to medium soft to firm silty sands | 8 | Water table more than 2 m deep | 5 | 5 | | | |
| | | | Water table less than 2 m deep | 3 | | | 3 | |
| | Fine silty and clayey firm sands | 4 | Water table more than 2 m deep | 1 | 1 | | | |
| | | | Water table less than 2 m deep | 3 | | | 3 | |
| Bedrock | Can be excavated without explosives or percussion tools | 15 | Less than 2 m deep | 15 | 15 | | | |
| | Low quality | 5 | Less than 2 m deep | 5 | | | | 5 |
| | Medium quality | 2 | Less than 2 m deep | 2 | | | | 2 |
| **Total :** | | **100** | **------** | **100** | **62** | **25** | **6** | **7** |

### 7.10.3.11 Foundations design criteria

Tower foundations shall be designed to ultimate loads derived from the tower loading and accordingly to the basic soil parameters. A safety factor of 1.5 will be applied.

Basic design parameters are shown in the following table.

The structural design of foundation should be made to ACI 318, BS 8110 and IEEE 691.

The design of foundation should take account of all recommendations and methodology described in CIGRE brochure No. 206.

## 7.11 Earthing of towers

All towers will be permanently and effectively earthed. The required tower ground resistance shall be 12 ohms or less for all types of soil except where rock is encountered at shallow depths for which the requirements shall be 20 ohm, or less.

The Contractor shall measure the ground resistance of individual towers with the measuring instruments and methods approved by the Engineer. The records of these measurements shall be submitted to the Engineer who will determine the necessity for additional grounding. Date, temperature, resistance and soil condition will be recorded whenever ground resistance is measured.

All towers shall be grounded in accordance with the drawing and materials to be installed include ground rods, counterpoise and necessary fittings, as shown in appendix III. Grounding shall be installed in steps to attain the necessary resistance. Readings of tower resistance shall be furnished to Engineer after each step.

Copper-clad steel rods for the 220 kV line earthing shall be made from a high-strength steel. Pure electrolytic copper shall be uniformly molecularly bonded onto the core to ensure corrosion resistance and eliminate electrolytic action. The steel core shall have sufficient rigidity for easy driving with hammer or mechanical drivers.

Counterpoise and ground connecting cable (earthing conductors) for lattice steel towers, fences and metal objects grounding shall be a copper-clad steel conductor 19 No. 7 AWG grade 40 HS and shall meet all the requirements of Specifications ASTM B227 and ASTM B228.

## 220 kV TRANSMISSION LINE – PRELIMINARY DESIGN PARAMETERS FOR SPECIFIED SOIL TYPES

| Soil description | Maximum allowable bearing capacity (1) | Dry unit weight (2) (3) | Cu Undrained shear strength | SPT N Index (4) | Uplift frustum angle (cohesive soil) | | Uplift frustum angle (cohesive less soil) | |
|---|---|---|---|---|---|---|---|---|
| | **(kPa)** | **(kg/m$^3$)** | **(kPa)** | | **With undercut (0,3 min.)** | **Without undercut** | **With undercut (0,3 min.)** | **Without undercut** |
| Sound rock | > 1 000 | 2 000 | --- | --- | 45$^o$ | | --- | |
| Soft rock (can be excavated) | 400 | 1 800 | > 200 | > 30 | 30$^o$ | 25$^o$ | 30$^o$ | 25$^o$ |
| Very stiff cohesive soils or laterites | 300 | 1 800 | 100 - 200 | 20 – 30 | 30$^o$ | 25$^o$ | 25$^o$ | 20$^o$ |
| Stiff cohesive soils or laterites | 200 | 1 600 | 50 - 100 | 10 -20 | 25$^o$ | 20$^o$ | 15$^o$ | 10$^o$ |
| Firm cohesive soils or laterites | 100 | 1 600 | 25 - 50 | 5 - 10 | --- | 10$^o$ | ---- | 5$^o$ |
| Loose sands, soft soils | 50 | 1 400 | 10 - 5 | 3 - 5 | --- | 0$^o$ | --- | 0$^o$ |

***(1) Based on allowable soil pressure or 25 mm settlement criteria.***
***(2) Natural soil and well compacted backfill to 95 % Proctor.***
***(3) Submerged unit weight of soil is to be taken as 1 000 kg/m$^3$.***
***(4) Blows per 0.3 m.***

## 7.12 Maintenance of the 220 kV transmission line

### 7.12.1 General

It is important to take into consideration the structure and hardware at the design stage in order to facilitate maintenance, ensure personnel safety and lower the cost of the operation.

### 7.12.2 Hardware

The hardware design should also consider the ease with which individual parts of a suspension or strain assembly could be replaced without having to dismantle the whole assembly.

The insulator chain assembly should comprise as few components as possible, which will facilitate and accelerate part replacement. Single suspension insulator chains ("I" type) are preferable to the "V" type suspension assemblies for maintenance purposes.

Modern power line design should insist on the possibility to execute live maintenance work on transmission lines in order to reduce transmission line down time in cases of minor repair or maintenance.

#### 7.12.2.1 Structures

One of the most important requirements concerning power line maintenance is the provision of adequate working clearance.

#### 7.12.2.2 Maintenance Schedule

A 220 kV transmission line will require at least one (1) yearly visit by pick-up. Furthermore every ten (10) years the line will need to be climbed and thoroughly inspected for maintenance purposes.

See "220 kV Transmission Line Maintenance Program" at the end of this section.

This Maintenance Program indicates the frequency and type of line inspection to perform. It also identifies and lists components to be inspected and corrective actions to be taken by the maintenance crew.

#### 7.12.2.3 Yearly Visit

Each line will need to be inspected from the ground at least once a year. A crew of two (2) or three (3) experienced linemen can perform this inspection using two (2) pick-up trucks.

This inspection should be at the beginning of the dry season.

#### 7.12.2.4 Ten Year Visit

In addition to the yearly inspection, a thorough inspection of the lines will be required every ten (10) years by experienced linemen climbing and inspecting each structure.

A crew of three (3) linemen and three (3) ground men will perform this inspection.

#### 7.12.2.5 Maintenance Crew

A maintenance crew of three (3) linemen, and three (3) ground men should be available for inspection, systematic maintenance and corrective maintenance of the transmission line.

This crew will use two (2) pick-up trucks to perform their inspection and to reach the areas where maintenance is needed.

#### 7.12.2.6 Vegetation Control

This issue is also to be considered and the inspection crews will be in a position to evaluate the need for vegetation control in the ROW.

#### 7.12.2.7 Maintenance Cost

The cost of maintaining a transmission line may significantly differ from one line to another.

But considering that the lines under consideration are newly built we estimate the approximate maintenance time as follows:

| ***Systematic Maintenance Planned*** | ***Corrective Maintenance Conditional*** |
|---|---|
| *20 days per 100 km per year* | *15 days per 100 km per year* |

The annual maintenance cost for a 100 km of the new 220 kV line in 2009 dollars is estimated at approximately fifty (50) thousand US dollars.

### 7.12.3 Spare Parts

It is suggested to store three (3) suspension and two (2) 15° structures, three (3) reels of conductor and  reel of overhead ground wire as well as an inventory of dampers, insulators  and hardware at the Rusumo Falls substation for each of the three (3) transmission lines.

Accessibility of maintenance and repair material is the key to a quick transmission line return to service.

**Remark**: Please note that it is very important to keep all structure drawings. Shop drawings are particularly very useful in the event of a major structure incident on the lines if the manufacturing of damaged components is required.

| 220 kV Transmission Line Maintenance Program | | | | |
|---|---|---|---|---|
| **Description** | **Type of Inspection** | | **Activities** | **Corrective Actions** |
| | **Visit** | **Climbing Visit** | | |
| | **Frequency** | | | |
| | **Yearly** | **10 years** | | |
| | **Items to Inspect According to the Type of Inspection** | | | |
| **Footing** | | | | |
| - Ground Line | X | X | Check back filling around footings | Replace backfill |
| - Corrosion | X | X | Check for rust or corrosion on footings | Apply zinc based paint |
| - Diagonal Braces | X | X | Check for damaged or missing members | Replace missing members |
| - Concrete | X | X | Eroded or cracked concrete footings | Repair or replace concrete |
| - Anchor Bolts & Nuts | X | X | Check for missing or loose bolts | Tighten or replace bolts or nuts |
| - Depth & Alignment | X | X | Check to see if tower plumb or if footings have shifted | Re-plumb or reset tower |
| **Counterpoise & Grounding** | | | | |
| - Connections | X | X | Check all counterpoise & ground connections | Tighten connections |
| - Continuity | X | X | Check counterpoise continuity | Repair |
| **Right-of-Way** | | | | |
| - Vegetation | X | X | Check amount & height of vegetation on right-of-way | Cut vegetation |
| - Roads, Bridges, Culverts | X | X | Check conditions of access roads & roads on right-of-way | Repair |
| **Structures (Metal)** | | | | |
| - Bolts | | X | Check for missing or loose bolts | Replace or tighten |
| - Step Pins | | X | Check for loose or missing step pins | Replace or tighten |
| - Protective Coating | X | X | Check for rust spots on steel | Brush & paint with zinc based paint |
| - Bent or Missing Members | X | X | Check for bent or missing steel members on legs, cross-arms | Replace |
| - Number & Danger Signs | X | X | Check for bent or missing signs | Tighten or replace |
| - Warning Markers | X | X | Check for loose or missing line markers | Tighten or replace |
| **Conductors & Hardware** | | | | |
| - Conductors | | | | |
| - Sag | X | X | Check for loose sag | Re-sag |
| - Strands | X | X | Check for damaged or broken strands | Install repair rods or sleeves |
| - Clearance | X | X | Check conductor clearance on low spans | Re-sag |
| - Joints | | X | Check sleeves for discoloration, spot-check with infra-red | Replace sleeves |
| - Clamps | | X | Check all clamps for signs of wear & looseness | Tighten or replace |
| - Dampers | X | X | Check for loose or broken dampers | Replace |
| - Dead-End Assemblies | | X | Check for loose or missing bolts, nuts and cotter pins | Tighten or replace |
| - Jumpers & Terminals | | X | Check for loose or missing bolts, nuts and cotter pins | Tighten or replace |
| - Grading Rings | | X | Check for loose or missing bolts, nuts and cotter pins | Tighten or replace |
| **Overhead Ground Wire & OPGW** | | | | |
| - Sag | X | X | Check to see if OHGW or OPGW has slipped through clamp | Re-sag |
| - Strands | X | X | Check for worn or broken strands | Install repair sleeve or repair rods |
| - Clamps | | X | Check U-bolts & jumpers | Tighten or replace |
| - Dead-End Assemblies | | X | Check for loose or missing bolts, nuts and cotter pins | Tighten or replace |
| - Vibration Dampers | | X | Check for loose or missing vibration dampers | Tighten or replace |
| - Fusion Boxes | X | X | Check the condition of the fusion box | Repair or replace |

## 7.13 Cost estimation and schedule

### 7.13.1 General

Based on electric and mechanical characteristics described in the previous paragraphs, the cost estimates for the three lines of the Rusumo Falls Project have been prepared based on the proposed transmission line route and the preliminary tower spotting. The preliminary tower spotting for each line is presented in appendix VIII.

The time basis of all costs is beginning of 2009, no escalation. The cost estimates include taxes and locally purchased items. All imported materials and equipments have been assumed free of import duty.

### 7.13.2 Rusumo Falls-Birembo Transmission Line

A detailed analysis of cost has been done for the line connecting Rusumo Falls to Birembo substation in Rwanda. The following two tables present the cost of different items, the first table for a double circuit 220 kV transmission line with only one circuit strung and the second table for a double circuit 220 kV transmission line with both circuits installed.

**Rwanda – Double Circuit with Single Circuit Strung**

| Description | Cost/km ($) | Total Cost ($) | % Foreign Currency | Foreign USD ($) |
|---|---|---|---|---|
| 1. General works | 3 525 | 371 215 | 70 % | 259 851 |
| 2. Foundations | 36 244 | 3 816 528 | 33 % | 1 259 454 |
| 3. Tower Grounding | 472 | 49 651 | 85 % | 42 203 |
| 4. Steel Towers | 63 351 | 6 670 872 | 85 % | 5 670 241 |
| 5. Tower Load Tests | 3 561 | 375 000 | 98 % | 367 500 |
| 6. Line Conductor insulators and fittings | 8 171 | 860 420 | 97 % | 834 607 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 595 | 273 256 | 89 % | 243 197 |
| 8. Conductor and shield wire | 34 889 | 3 673 781 | 94 % | 3 453 354 |
| 9. Spares | 2 520 | 265 400 | 96 % | 254 784 |
| 10. Transport and Services | 11 231 | 1 182 595 | 50 % | 591 297 |
| **SUB-TOTAL** | **166 560** | **17 538 716** | **74 %** | **12 976 488** |
| 11. Engineering (5 %) | 8 328 | 876 936 | 95 % | 833 089 |
| 12. Site Supervision and quality control (5 %) | 8 328 | 876 936 | 80 % | 701 549 |
| 13. Contengencies (10 %) | 16 656 | 1 753 872 | 74 % | 1 297 649 |
| **TOTAL** | **183 215** | **19 292 587** | **82 %** | **15 808 775** |

**Rwanda – Double Circuit with Both circuits installed**

| Description | Cost/km ($) | Total Cost ($) | % Foreign Currency | Foreign USD ($) |
|---|---|---|---|---|
| 1. General works | 3 525 | 371 215 | 70 % | 259 851 |
| 2. Foundations | 36 244 | 3 816 528 | 33 % | 1 259 454 |
| 3. Tower Grounding | 472 | 49 651 | 85 % | 42 203 |
| 4. Steel Towers | 63 351 | 6 670 872 | 85 % | 5 670 241 |
| 5. Tower Load Tests | 3 561 | 375 000 | 98 % | 367 500 |
| 6. Line Conductor insulators and fittings | 15 716 | 1 654 851 | 97 % | 1 605 205 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 595 | 273 256 | 89 % | 243 197 |
| 8. Conductor and shield wire | 60 319 | 6 351 544 | 94 % | 5 970 451 |
| 9. Spares | 3 082 | 324 513 | 96 % | 311 532 |
| 10. Transport and Services | 11 231 | 1 182 595 | 50 % | 591 297 |
| **SUB-TOTAL** | **200 095** | **21 070 023** | **77 %** | **16 320 932** |
| 11. Engineering (5 %) | 10 005 | 1 053 501 | 95 % | 1 000 826 |
| 12. Site Supervision and quality control (5 %) | 10 005 | 1 053 501 | 80 % | 842 801 |
| 13. Contengencies (10 %) | 20 010 | 2 107 002 | 77 % | 1 632 093 |
| **TOTAL** | **220 105** | **23 177 025** | **85 %** | **19 796 653** |

More detailed tables are presented in appendix VII.

The distance between the new Kigali airport substation and the main line is about 10 km (the location is not yet finally fixed). A double circuit line will be installed. For this purposes the costs of the main line were used and the total costs are evaluated at 2,2 Mill. US $.

### 7.13.3 Rusumo Falls- Nyakanazi Transmission Line

A detailed analysis of cost has been done for the line connecting Rusumo Falls to Nyakanazi substation in Tanzania. The following two tables present the cost of different items, the first table for a double circuit 220 kV transmission line with only one circuit strung and the second table for a double circuit 220 kV transmission line with both circuits installed.

**Tanzania – Double Circuit with Single Circuit Strung**

| Description | Cost/km ($) | Total Cost ($) | % Foreign Currency | Foreign USD ($) |
|---|---|---|---|---|
| 1. General works | 3 667 | 357 573 | 70 % | 250 301 |
| 2. Foundations | 29 511 | 2 877 341 | 33 % | 949 522 |
| 3. Tower Grounding | 485 | 47 297 | 85 % | 40 202 |
| 4. Steel Towers | 58 668 | 5 720 110 | 85 % | 4 862 093 |
| 5. Tower Load Tests | 3 846 | 375 000 | 98 % | 367 500 |
| 6. Line Conductor insulators and fittings | 6 783 | 661 309 | 97 % | 641 470 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 561 | 249 671 | 89 % | 222 207 |
| 8. Conductor and shield wire | 34 780 | 3 391 016 | 94 % | 3 187 555 |
| 9. Spares | 2 722 | 265 400 | 96 % | 254 784 |
| 10. Transport and Services | 12 088 | 1 178 587 | 50 % | 589 294 |
| **SUB-TOTAL** | **155 111** | **15 123 303** | **75 %** | **11 364 928** |
| 11. Engineering (5 %) | 7 756 | 756 165 | 95 % | 718 357 |

| | | | | |
|---|---|---|---|---|
| 12. Site Supervision and quality control (5 %) | 7 756 | 756 165 | 80 % | 604 932 |
| 13. Contengencies (10 %) | 15 511 | 1 512 330 | 75 % | 1 136 493 |
| **TOTAL** | **170 622** | **16 635 633** | **83** % | **13 824 710** |

**Tanzania – Double Circuit with both circuits installed**

| Description | Cost/km ($) | Total Cost ($) | % Foreign Currency | Foreign USD ($) |
|---|---|---|---|---|
| 1. General works | 3 667 | 357 573 | 70 % | 250 301 |
| 2. Foundations | 29 511 | 2 877 341 | 33 % | 949 522 |
| 3. Tower Grounding | 485 | 47 297 | 85 % | 40 202 |
| 4. Steel Towers | 58 668 | 5 720 110 | 85 % | 4 862 093 |
| 5. Tower Load Tests | 3 846 | 375 000 | 98 % | 367 500 |
| 6. Line Conductor insulators and fittings | 12 951 | 1 262 688 | 97 % | 1 224 807 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 561 | 249 671 | 89 % | 222 207 |
| 8. Conductor and shield wire | 60 312 | 5 880 403 | 94 % | 5 527 579 |
| 9. Spares | 2 722 | 265 400 | 96 % | 254 784 |
| 10. Transport and Services | 12 088 | 1 178 587 | 50 % | 589 294 |
| **SUB-TOTAL** | **186 811** | **18 214 069** | **78** % | **14 288 290** |
| 11. Engineering (5 %) | 9 341 | 910 703 | 95 % | 865 168 |
| 12. Site Supervision and quality control (5 %) | 9 341 | 910 703 | 80 % | 728 563 |
| 13. Contengencies (10 %) | 18 681 | 1 821 407 | 78 % | 1 428 829 |
| **TOTAL** | **205 492** | **20 035 476** | **86** % | **17 310 850** |

More detailed tables are presented in appendix VII.

**400 kV Variante for Tanzania**
To implement the request of replacing the 220 kV line in Tanzania with 400 kV structures operating at 220 kV as originally proposed, the consultant needs more time and costs to fulfill the task in an adequate form.

For this modification, the following assumptions have to be done:

- The conductor will be chosen to meet electromagnetic field requirements with a ROW of 40m. No further load and network studies will be done.
- The line route will be the same as the 220 kV route already chosen with no modification to substation locations.
- Substations will remain at 220 kV with no modification.
- 400 kV towers will be self-supporting double circuit structures of similar configuration to the proposed 220 kV structures.
- Only one 220 kV single circuit will be initially installed with conductors and insulation already proposed for 220 kV line.

From our experience the additional costs for the Overheadline will be in the range of 20 %.

### 7.13.4 Rusumo Falls – Gitega Transmission Line

A detailed analysis of cost has been done for the line connecting Rusumo Falls to Gitega substation in Burundi. The following table presents the cost for different items. A more detailed table is presented in appendix VII.

**Burundi – Single Circuit – Section Rusumo Falls to Tanzanian Border**

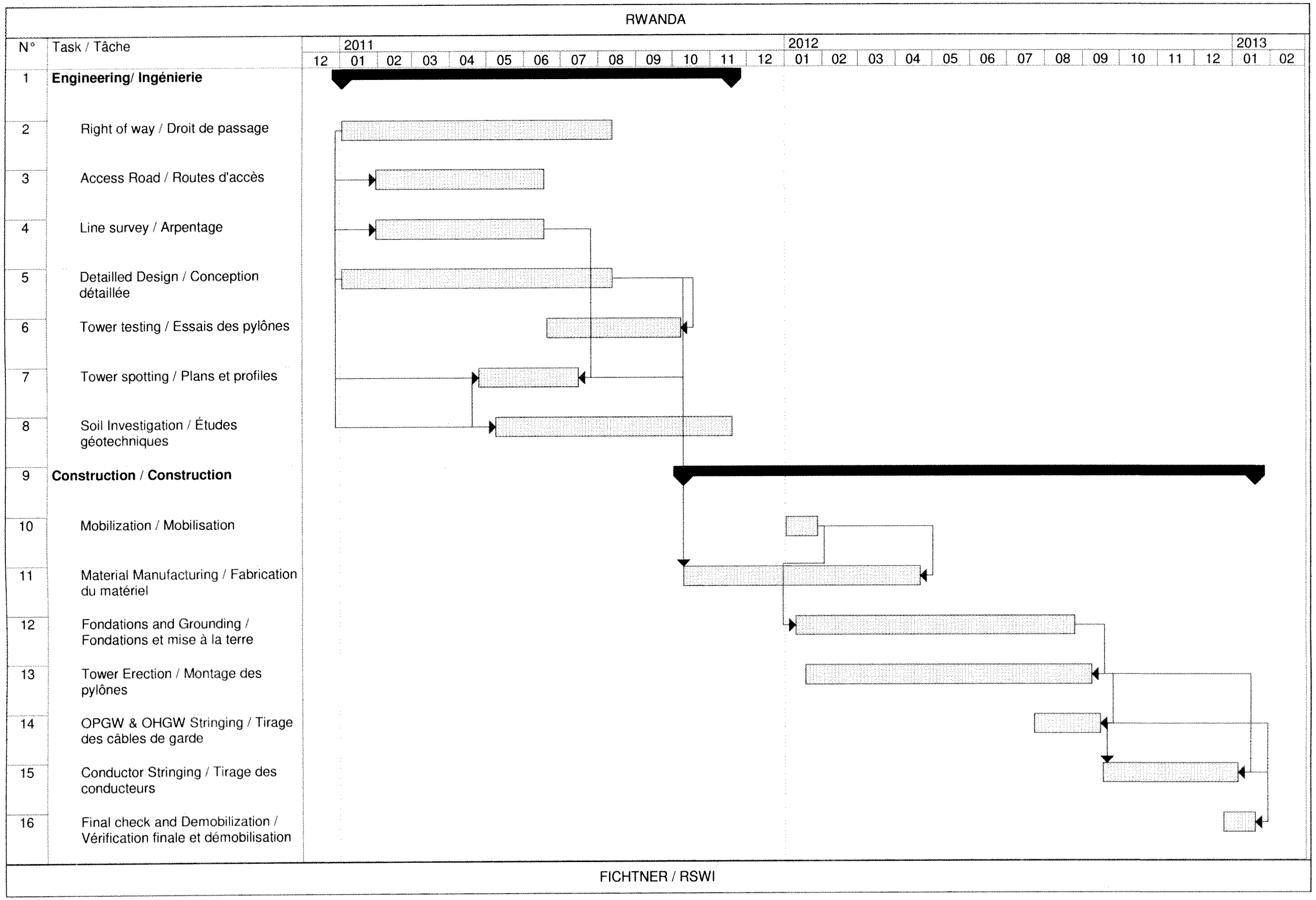
| Description | Cost/km ($) | Total Cost ($) | % Foreign Currency | Foreign USD ($) |
|---|---|---|---|---|
| 1. General works | 9 154 | 512 650 | 70 % | 358 855 |
| 2. Foundations | 25 171 | 1 409 593 | 33 % | 465 166 |
| 3. Tower Grounding | 457 | 25 570 | 85 % | 21 734 |
| 4. Steel Towers | 49 144 | 2 752 039 | 85 % | 2 339 233 |
| 5. Tower Load Tests | 2 214 | 124 000 | 98 % | 121 520 |
| 6. Line Conductor insulators and fittings | 8 001 | 448 051 | 97 % | 434 609 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 577 | 144 302 | 89 % | 128 429 |
| 8. Conductor and shield wire | 33 469 | 1 874 244 | 94 % | 1 761 790 |
| 9. Spares | 1 854 | 103 825 | 96 % | 99 672 |
| 10. Transport and Services | 15 136 | 847 616 | 50 % | 423 808 |
| **SUB-TOTAL** | **147 177** | **8 241 890** | **75 %** | **6 154 816** |
| 11. Engineering (5 %) | 7 359 | 412 095 | 95 % | 391 490 |
| 12. Site Supervision and quality control (5 %) | 7 359 | 412 095 | 80 % | 329 676 |
| 13. Contengencies (10 %) | 14 718 | 824 189 | 75 % | 615 482 |
| | **161 894** | **9 066 079** | **83 %** | **7 491 463** |

**Burundi – Single Circuit – Section Burundi Border To Gitega**

| **Description** | **Cost/km ($)** | **Total Cost ($)** | **% Foreign Currency** | **Foreign USD ($)** |
|---|---|---|---|---|
| 1. General works | 6 868 | 722 526 | 70 % | 505 768 |
| 2. Foundations | 25 189 | 2 649 890 | 33 % | 874 464 |
| 3. Tower Grounding | 470 | 49 418 | 85 % | 42 005 |
| 4. Steel Towers | 47 050 | 4 949 612 | 85 % | 4 207 170 |
| 5. Tower Load Tests | 2 386 | 251 000 | 98 % | 245 980 |
| 6. Line Conductor insulators and fittings | 7 162 | 753 437 | 97 % | 730 834 |
| 7.OPGW fittings and accessories, Steel groundwire accessories | 2 556 | 268 898 | 89 % | 239 319 |
| 8. Conductor and shield wire | 34 670 | 3 647 310 | 94 % | 3 428 472 |
| 9. Spares | 1 995 | 209 886 | 96 % | 201 490 |
| 10. Transport and Services | 10 264 | 1 079 736 | 50 % | 539 868 |
| **SUB-TOTAL** | **138 609** | **14 581 712** | **76 %** | **11 015 370** |
| 11. Engineering (5 %) | 6 930 | 729 086 | 95 % | 692 631 |
| 12. Site Supervision and quality control (5 %) | 6 930 | 729 086 | 80 % | 583 268 |
| 13. Contengencies (10 %) | 13 861 | 1 458 171 | 76 % | 1 101 537 |
| | **152 470** | **16 039 884** | **83 %** | **13 392 807** |

### 7.13.5 Schedule

The project schedule for the three lines are presented in the following figures. The transmission lines will not be the critical path of the project. From the award of the contract to the commissioning of three lines, the total time will be between 24 to 28 months depending of the lines; in comparison, the generation plant will take between 50 to 60 months.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Task / Tâche
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2013
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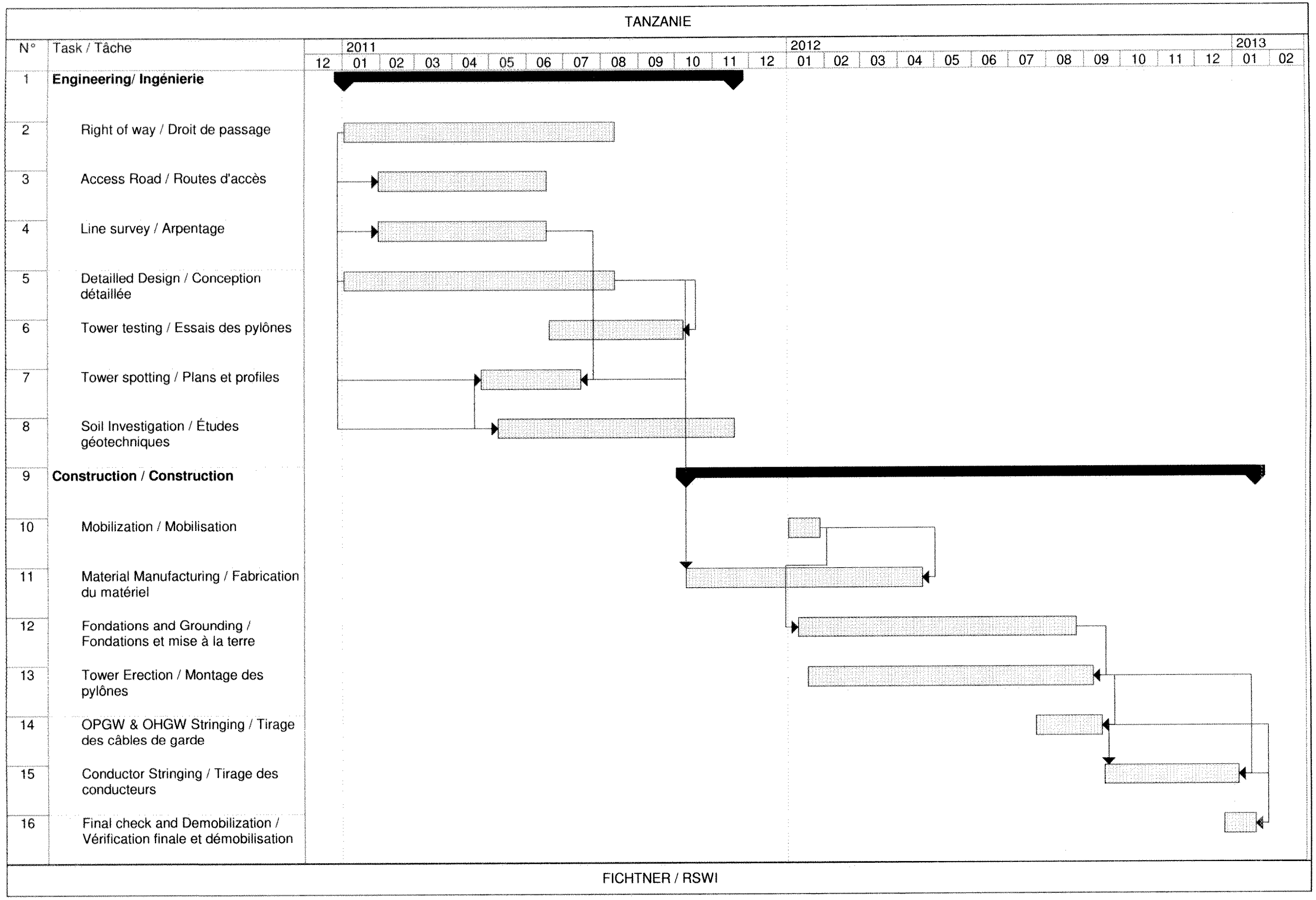
12
01
02
1 Engineering/ Ingénierie
2 Right of way / Droit de passage
3 Access Road / Routes d'accès
4 Line survey / Arpentage
5 Detailled Design / Conception détaillée
6 Tower testing / Essais des pylônes
7 Tower spotting / Plans et profiles
8 Soil Investigation / Études géotechniques
9 Construction / Construction
10 Mobilization / Mobilisation
11 Material Manufacturing / Fabrication du matériel
12 Fondations and Grounding / Fondations et mise à la terre
13 Tower Erection / Montage des pylônes
14 OPGW & OHGW Stringing / Tirage des câbles de garde
15 Conductor Stringing / Tirage des conducteurs
16 Final check and Demobilization / Vérification finale et démobilisation
FICHTNER / RSWI


TANZANIE
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Task / Tâche
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1 Engineering/ Ingénierie
2 Right of way / Droit de passage
3 Access Road / Routes d'accès
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8 Soil Investigation / Études géotechniques
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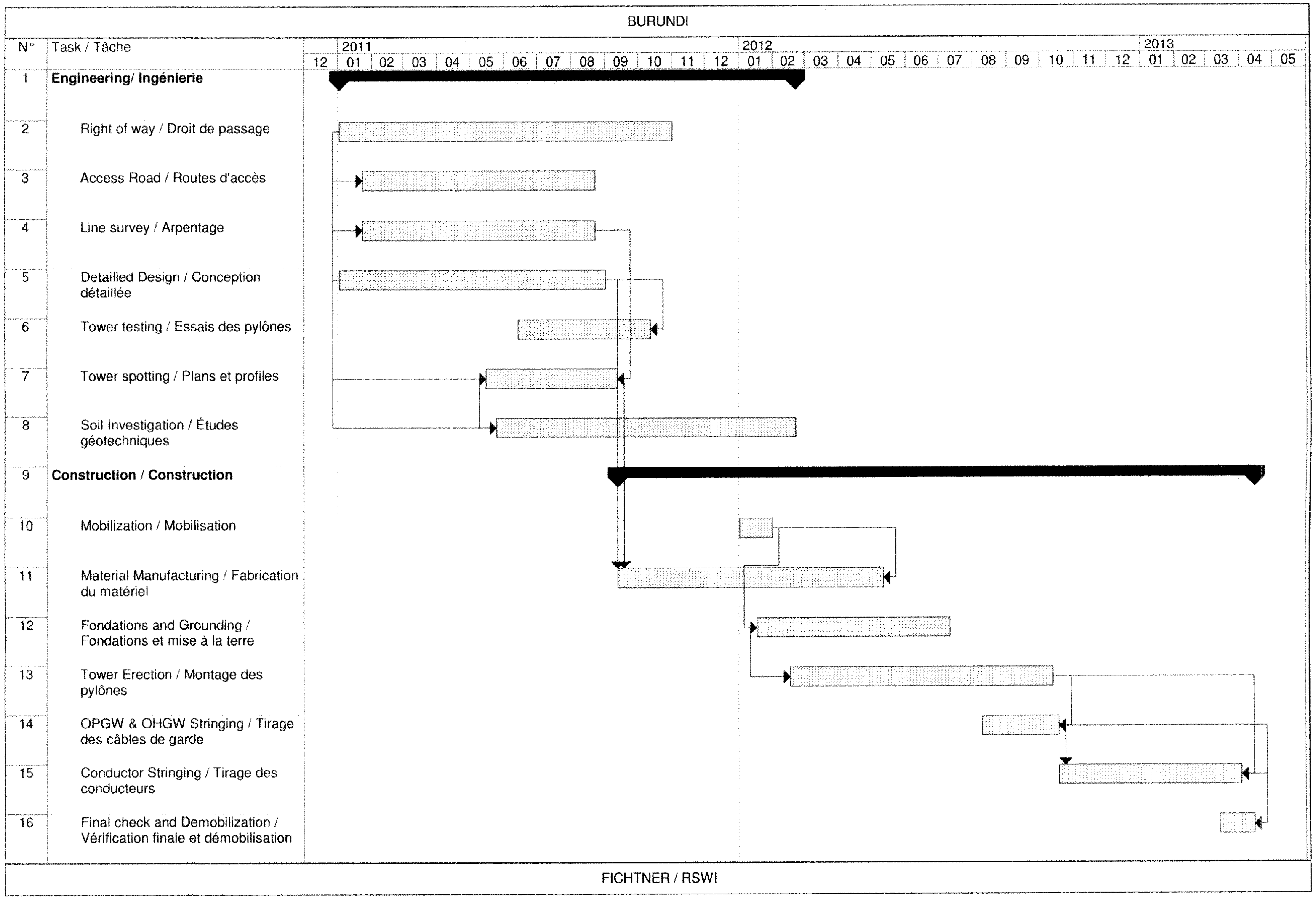
15 Conductor Stringing / Tirage des conducteurs
16 Final check and Demobilization / Vérification finale et démobilisation
FICHTNER / RSWI


BURUNDI
N°
Task / Tâche
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2013
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1 Engineering/ Ingénierie
2 Right of way / Droit de passage
3 Access Road / Routes d'accès
4 Line survey / Arpentage
5 Detailled Design / Conception détaillée
6 Tower testing / Essais des pylônes
7 Tower spotting / Plans et profiles
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FICHTNER / RSWI