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5. **Power System Design (Summary)**

5.1 **Introduction**

Chapter 5 of Volume II describes power system studies carried out to assess the performance of each interconnector. It also describes all studies that were carried out in order to select conductors, insulation and type of tower for each interconnector of this project.

The power system studies define the required performance of each interconnector, and specified the location and configuration of line compensation reactors ensuring satisfactory operation of the system following implementation of the interconnections.

EMTP (Electromagnetic Transients Program) model analysis was not performed during this stage of the project. The selection of equipment was performed by using empirical equations that are well accepted. All recommended additional studies are clearly identified in this report and mainly concern transposition requirements and circuit breakers recovery voltage.

This volume comprises 13 sections along with tables and figures. Following this section, the present volume is structured as follows:

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Detailed Calculations and Design Brief are included in appendix at the end of this report.
5.2 Conclusions and Recommendations

5.2.1 Load Flow Analysis and Reactive Compensation Requirements

Load flow studies, contingency analyses and PV analysis were carried out for 2015 and 2025. Only one scenario was studied for 2015. For 2025, a comprehensive study was carried out on two Load Flow Cases and following TAC and PIC meetings held in July 2009 at Kigali, NELSAP requested a brief study on an additional Load Flow Case proposed by Rwanda and DRC. Main conclusions and recommendations are summarized below for 2015 and 2025.

5.2.2 High Voltage Line

Selection of conductors, conductor type, conductor size and electrical characteristics of the proposed 220 kV lines are summarized below. Lightning performance analysis and environmental studies that were carried out are also summarized.

5.2.2.1 Lightning performance

Lightning performance of new 220 kV lines were studied with the “flash 1.7” software included in IEEE Standard 1243.

Based on information included in isokeraunic maps from Rwanda, one can see that the maximum keraunic level is of 110 thunderstorm days per year for the area covered by this study. This level was also compared with data provided by optical transient detectors published by EPRI. The keraunic level providing from these two sources are very similar and proved that a level of 110 thunderstorm days per year is acceptable.

Following detailed lightning performance analyses on the new 220 kV lines, it is recommended that 18 standard insulators string be installed on 220 kV lines. The installation of two arcing horns is also recommended on each insulator string. These arcing horns reduced the lightning impulse withstand voltage by reducing the air gap distance but they also help protecting the line and more specifically the insulator strings.

The calculated flashover rate is less than 6 flashover per 100 km-years for the proposed 220 kV single circuit lines and is less than 9 flashover per 100 km-years for the proposed 220 kV double circuit lines.

To improve reliability and availability, single phase auto reclose (SPAR) is recommended on all line. For double circuits lines, in addition to (SPAR) and the (N-1),criterion, it is recommended to select “ABC-CBA” phasing to minimise the predominant critical stroke current on only one phase at a time.
5.2.2.2 Conductor selection

Following capital cost estimate and electrical losses comparison a single ASTER 570, AAAC conductor was selected.

5.2.2.3 Environmental studies

The calculated value of the peak electrical field for the proposed 220 kV single circuit line is equal to 3,46 kV/m and is reduced to 1,21 kV/m at the edge of the row. These value are respectively of 3,28 kV/m and 0,86 kV/m for the proposed 220 kV double circuit line,. All these values are all under our design criteria included in section 5.2 and are acceptable.

Both 220 kV single and double circuit lines with single ASTER 570, AAAC conductor meet the 52,5 dB (A) criterion even if the right-of-way is reduced to 30 m. The 220 kV lines also easily meet all design criteria for corona performance, magnetic field, audible noise, radio interference (RI) and television interference (TVI).

5.2.3 Short-Circuit

Three phases short-circuit level are well under recommended initial symmetrical values of short-circuit rating of equipment.

To complete single phase-to-earth fault analysis and EMTP studies, KPLC, UETCL and TANESCO must provide negative and zero sequence impedance of all equipments.

5.2.4 Single Pole Auto Reclose (SPAR)

To increase reliability and availability of the integrated network and avoid the need for resynchronization of isolated network, independent pole switching should be installed on all 220 kV lines to allow single pole auto reclosure (SPAR). Delayed three phase auto reclose on double circuit lines should be prohibited.

Since shunt reactors are required as explained in section 5.3 of this volume on 220 kV double circuit line from Rusumo-Falls to Kigali’s airport and on 220 kV double circuit line from Rusumo-Falls to Nyakanazi to limit overvoltages at the open one end at an acceptable level, these must be complete with neutral reactor. Five limbs shunt reactors and neutral reactors must be installed in the following locations.

- At Nyakanazi substation, 10 MVAr shunt reactor complete with neutral reactor must be installed on the two circuits to Rusumo-Falls hydropower plant;

- At Kigali’s airport substation, 7,5 MVAr shunt reactor complete with neutral reactor must be installed on the two circuits to Rusumo-Falls hydropower plant.
For these two 220 kV double circuits lines two transpositions per section are required to achieve successful operation of (SPAR). Shunt reactor should not be installed on 220 kV double circuit line from Kigali’s airport to Birembo.

It is recommended that a surge reactor rated at 48 kV rms be connected at the reactor neutral voltage to limit the neutral voltage below the lightning withstand voltage of lightning withstand voltage of 170 kV peak in the event of lightning strike.

All required shunt reactor should not be switched, steady state voltage can be controlled within acceptable limit by switched shunt capacitors.

### 5.2.5 Transient Stability

#### 5.2.5.1 Stability criteria

System stability should be maintained following a permanent three phase fault on each interconnector. The fault is assumed to clear by tripping the line in less than 5 cycles at 220 kV.

System stability should also be maintained following temporary and permanent single phase-to-ground faults. A temporary single phase fault is assumed to be cleared by single pole tripping of the faulted phase in less than 5 cycles at 220 kV. The dead time before reclosing is selected at 450 ms to reduce disturbance on the network and limit the phase unbalance on the tripped line. If this criterion is fulfilled, reclosing should be successful on temporary single phase-to-ground faults. For any permanent three-phase fault, the fault will be re-established following circuit breaker reclosing and must be cleared by tripping the line in time specified above. A second reclosing attempt will not be allowed following single pole reclosure failure.

#### 5.2.5.2 Excitation system

All excitation systems for new units must be of static type, with positive ceiling voltage of 3.5 P.U. and with negative ceiling voltage of – 1.0 P.U. The static excitation systems must also be included with stabilizers and minimum and maximum excitation limiter must also be included.

#### 5.2.5.3 Dynamic simulation for 2015

Since we are only studying three interconnection lines between Rwanda, Burundi and Tanzania and that power master plan for any of these countries are not part of our scope of works, transient stability studies were not carried out for 2015. These studies require many details and information from power master plan and investment plan. Except for Tanzania which has a new power master plan all other power master plan are either in revision or obsolete. Any transient stability would be
meaningless in such a condition. A comprehensive transient stability study based on our two proposed arrangement cases has yet been carried out for 2025 and is detailed below.

5.2.5.4 Dynamic simulation for 2025

The two load flow cases that are described in section 5.3 have been further studied during transient stability.

The two proposed arrangement cases are generally stable and their stabilised voltages are within the design criteria limits. There is yet some concern while clearing a permanent three phase fault at Rusumo-Falls substation by opening the two circuits of the double circuit transmission line from Rusumo-Falls substation to Nyakanazi substation. A transient voltage of approximately 1.6 P.U. exists for a short period of time just after opening these two circuits at Nyakanazi substation. Additional studies would be required including EMTP for resolving this issue.

Yet without resolving all major issues on Ugandan, Tanzanian and Kenyan networks and without knowing the final configuration of the 400 kV network in Tanzania any additional study would be meaningless. For this reason we recommend using phase-to-earth and phase-to-phase temporary overvoltages of approximately 1.6 P.U. during insulation coordination. This might lead to over insulated equipments but also requires that this study to be revisited when interconnecting the Nyakanazi substation to the Tanzanian network.

5.2.6 Insulation Coordination

Preliminary insulation coordination studies were carried out on all new and modified 110 kV, 132 kV and 220 kV substations. These insulation coordination studies were based on procedure included in IEC Standards 60071-1 and 60071-2.

EMTP studies were not carried out at this stage of the project. The switching overvoltage values were estimated from figures included in IEC Standard 60071-2, but the slow-front switching overvoltages due to energization of capacitor banks could not be estimated. Since slow-front overvoltages values for this type of switching operation is excluded in this standard.

At a rated operating voltage of 220 kV, a standardized value of 460 kV for short-duration power frequency and a value of 1050 kV for lightning impulse withstand are required for all equipment with external insulation and also with internal insulation. Further studies including EMTP studies are required to define phase-to-phase insulation. These studies are required on all 220 kV substation but selection of accurate insulation withstand voltage is a major concern at new Nyakanazi substation.