The Gabon-Congo interconnection project: Infrastructures development and planning strategies under PEAC's aegis

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Introduction

In the framework of the PEAC (CAPP) strategic view, based on the identification of the “Projets d’Intégration Prioritaires – PIP” and “Projets du Programme d’Électrification Transfrontalière – PPET”, the 400kV Gabon – Congo interconnection project aims at improving the population living conditions as well as the quality of the socio-economic environment, boosting both availability of affordable electric energy and electricity access. This will be achieved by increasing cross-border electric power trade.

The interconnection represents a section of a much longer backbone that extends from Angola, crossing Congo towards Brazzaville, already linked with the RDC, then in Gabon, where the backbone will extend northwards to Cameroun. In 2016, the Delegation of the European Union (DUE) awarded Studio Pietrangeli (SP) the contract for the feasibility studies and bidding documents of the HV transmission system interconnection.

The paper describes the main design features of the project, linking the existing substation of Moanda (Gabon) and Djambala (Congo), conceived for enhancing the transmission capacity of the two countries and relevant power trade promotion.

The 400 kV double circuit, 350km long transmission line will link two countries with different generating sources: Gabon has a total installed capacity of 440MW, 60% of which is hydropower, meanwhile Congo power generation has a predominantly thermal component. The Gabon – Congo interconnection will ensure not only an improvement in fulfilling of the energy demand of the two countries, but also a better utilization of the generation park.

Key words: Gabon, Congo, PEAC, CAPP, transmission, interconnection, power corridor, cross-border project, 400kV, European Union Delegation, FED, high voltage

1. Background and PEAC’S role

The Republic of Gabon and the Republic of Congo are located in Central Africa and are part of two communities, the Communauté Économique et Monétaire de l’Afrique Centrale (CEMAC) and the Communauté des États de l’Afrique Centrale (CEEAC) respectively. CEEAC covers ten (10) countries while the CEMAC covers six (6). The two communities have adopted long-term visions that favour energy development as a priority in the fight against poverty.

According to their mandates, CEMAC and CEEAC developed, with the support of the UNDP-LOAN, the "*White paper of the CEEAC and the CEMAC - Regional Politics for a universal access to the modern energy services and the economic and social development*" (April, 2014), which was jointly adopted by the authorities of both communities.

Foundation and implementation of the development policies of the states of Central Africa are among the pillars of regional integration. In doing that, appraisal of the enormous energy potential of the region, as well as the development in an effective and environmental-friendly manner of the electricity access for populations and industrial players, awaiting a long time, are key aspects of the CEEAC strategic vision at the 2025-2035 horizon.

This vision passes through strengthening of infrastructures such as generating power plants, as well as the development of cross-border exchanges and new high voltage interconnections. The aim of this process is to make possible the establishment of a regional market of reliable electricity, with competitive costs.
With the objective of transforming this vision into reality, the ten member states of the CEEAC created the Central Africa Power Pool (CAPP – PEAC, Pool Énergétique de l'Afrique Centrale) in 2003, as a specialised body responsible for implementing this energy mission.

The continuous role of PEAC in coordinating, at high level, the regional cross-borders interconnections, is of paramount importance, as evidenced in particular by the recent experience of SP in interfacing with the PEAC and its Secrétariat Permanent during the feasibility studies of the 400kV interconnector of the grids of Gabon and Congo, under the European Union Delegation FED accomplished in 2017.

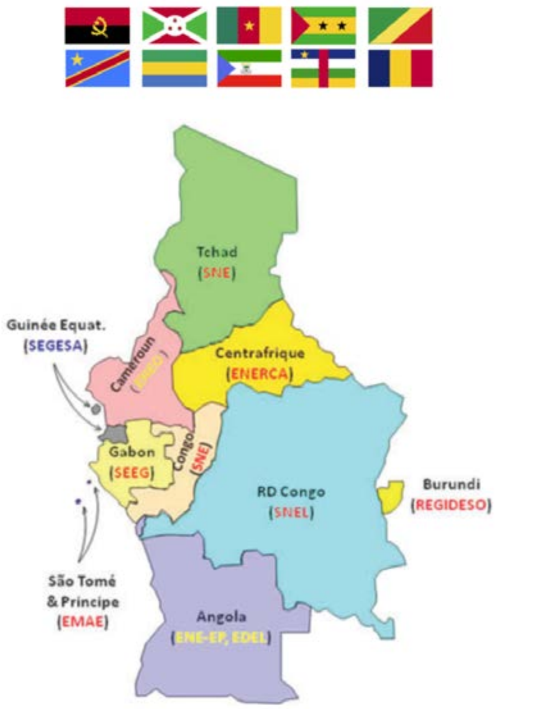

Fig. 1. PEAC's member countries with associated national utilities

Located on a community space with an area of 6,640,000 km^2, with more than 140 million inhabitants, the Central Africa Power Pool (PEAC) is a specialized agency of the Economic Community of the States of the Central African States (ECCAS) responsible for the implementation of the energy policy, monitoring studies and construction of community infrastructure and organization of trade in electric energy and related services in ECCAS region.

The electric interconnection between Gabon and Congo has been studied for almost 25 years, as grounded back in the 90s and resumed in 2009 with pre-feasibility design studies concerning this matter.

The "interconnector" finds its justification in a number of key benefits, tailored to the future expansion of an integrated grid under the need of developing feasible and low-cost power corridors, such as the Inga – Boma – Cabinda – Pointe Noire – Brazzaville, of whom this project is part. On top of that, Inga hydropower site development (Inga 3 Basses Chutes, Inga 3 Hautes Chutes and the long term Inga 4 to Inga 8) would boost the implementation of the transmission infrastructures needed for wheeling associated power production.

The short term carrying capacity of the proposed interconnector was 400MW, according to the previous pre-feasibility studies. However, its full rating should have reflected not only load demand growing rates but also stability operating conditions and (n-1) contingency situations.

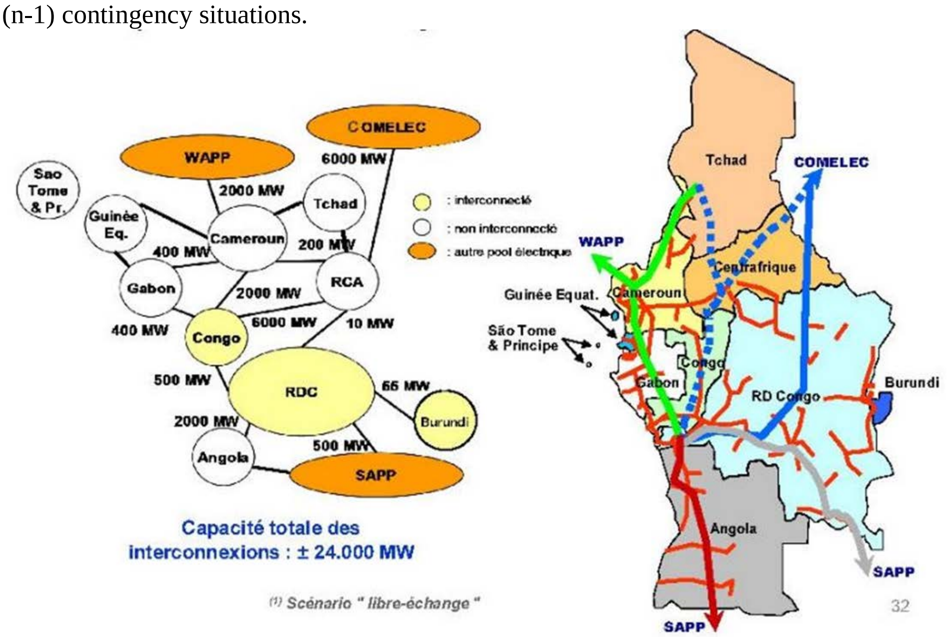

Fig. 2. Priority Integration Projects in PEAC's region and cross-border interconnections prospected capacity (source: PEAC, 2012)

This is the overall scenario wherein SP has undertaken the design of the HV interconnector between Gabon and Congo. The following paragraphs depicts the project main features and ratings.

2. Project’s benefits and target year scenario

While assessing the basic conditions in designing the interconnector, the consultant has further interpreted and updated the collected data, provided by the two ministries of Energy of Gabon and Congo (the Client) picturing the target year of operation of the interconnector, i.e. 2035, in terms of balancing of load demand and generation (either planned and existing).

The project viability has been evaluated onto two main features:

- the utilisation factor of the interconnector based on the mismatch between generated power and loads of the two countries;
- the neighbour countries contribution in dispatching and wheeling power over the two linked grids while facing considerable load or generation variation avoiding stability problems.

In particular, the interconnection project is aimed at optimizing the generation plan of the two countries. It allows to exchange power and plan the generating contribution of each plant (the so-called unit commitment) in order to increase the global efficiency of the generating and transmission systems. Benefits will be brought to the local communities in terms of access to highly-secured electrification, as stepped down from 400/225kV/MV main substations in Moanda, Okoyo and Djambala.

Fig. 3. Prospected connection project between Inga (Congo) and Calabar (Nigeria) via Gabon (source: PEAC website, 2018, http://www.peac-ac.org/index.php/projets/projets-pip)

Moreover, among the key parameters of the project viability, the conduction of a network study for static and dynamic stability assessment was of dominant importance so as to further confirm the project implementation feasibility within a credible future panorama.

In fact, in the target year 2035 both networks (Congolese and Gabonese) differ rather substantially from the present ones:

- in Congo, presently exists an East-West 225kV backbone connecting the Pointe Noire economic hub and Brazzaville, the capital city, integrated by a 225kV line towards the Centre-North of the country and another 400kV line (presently operated at 225kV) which supplies Brazzaville via Kinshasa from the large Inga hydroelectric power plant (HPP) located in the DRC; in the target year 2035, substantial expansion is foreseen by doubling all the 225kV backbones, extending the 225kV system towards the Northeast of the country (the Brazzaville – Djambala backbone), implementing new 225kV system in Central Congo for the power evacuation of the planned Cascade de la Louéssé HPP complex, a new 400kV line connecting the Inga HPP and Pointe Noire (this new 400kV backbone will also connect Djambala and Brazzaville); and, the subject of the present study, i.e. the planned 400kV Gabon-Congo interconnection line between the Djambala (Congo) and Moanda (Gabon) substations.

- in Gabon, presently there are two isolated sub-systems, the "Estuaire" serving Libreville and the industrial pole, and the Franceville province where Grand Poubara HPP supplies the mining pole in Moanda; the future expansion plan foresees a consistent strengthening of the system with a north-south backbone up to Cameroun, passing through the future hydropower sites of Chutes Booué and Tsengué-Lélédi, and transmission lines meshing towards other hydropower sites in the south-western part of the country; moreover, HV connection will also be established to Cameroun and Equatorial Guinea.

Thought the planned 400kV Congo-Gabon interconnection will be operated at 225kV for several years following its commissioning, the present study has dealt with its "final" operation at 400kV.

The implementation of the project will allow the two nations a coordinated and sound management of the respective generating parks and hence an efficient industrial and commercial development ramping. Indeed, 60% of the Gabon generating park is composed by hydroelectric power plants which are useful for regulating purpose, while Congo has a predominantly thermal power component which should be used for base load.

3. The Project of the Interconnector

The interconnector project foresees 350km of 400kV double circuit transmission line, departing from Moanda substation in Gabon and ending in Djambala substation in Congo. An intermediate substation in Okoyo (Congo) is foreseen.

The two ending stations are already existing in Moanda and Djambala.

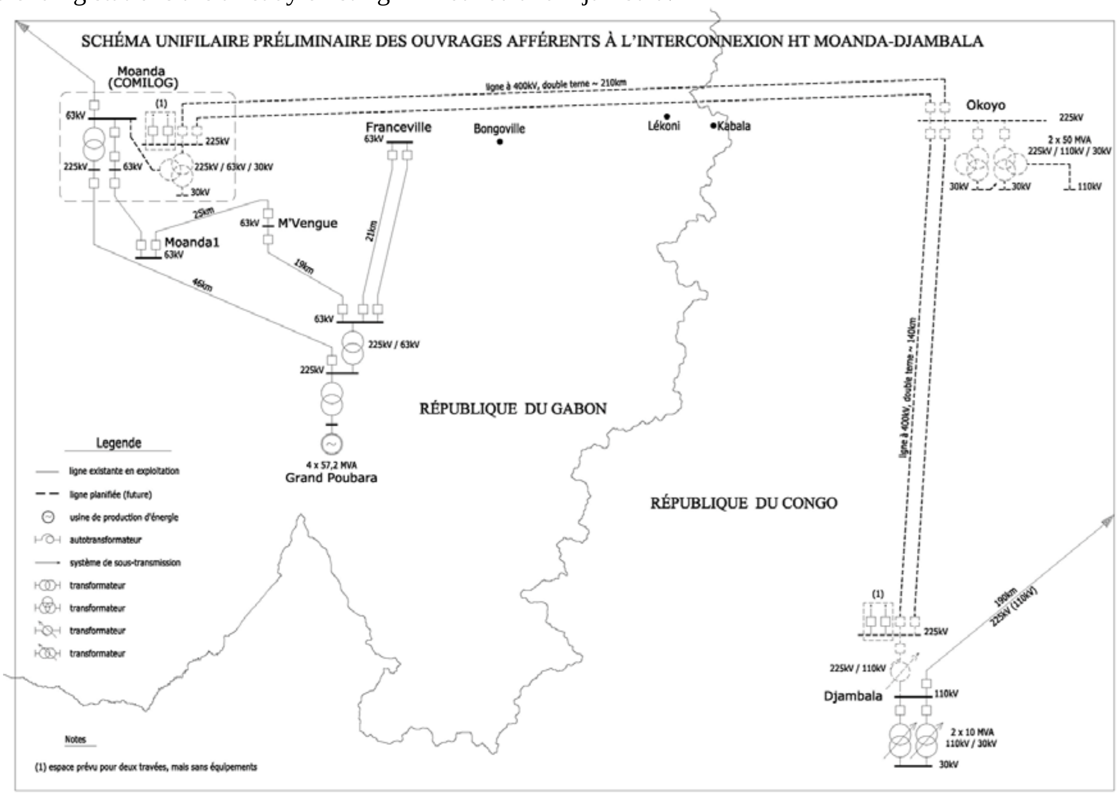

Fig. 4. Gabon-Congo Interconnector Project – topology of the design infrastructures

Multidisciplinary field's activities supported the design task with electrical and mechanical engineering, environmental and social impact assessment studies (ESIA) with resettlement action plan (RAP). Several site visits and an extensive survey of the possible line routes for topographic, geotechnical, ESIA and, in general, engineering purposed were conducted jointly with representatives from the Ministry of each country in 2016 and 2017.

The selected design is a compromise achieved by investigating several alternatives, pertaining not only to the route of the 400kV line, but also to the extension works of the two terminal (existing) substations in Moanda and Djambala, as required by the contractual terms of reference. In this case, the Moanda substation has been selected due to the following reasons:

- its existing 225kV connection from Gran Poubara power plant (4x57.2MW), which entails considerable switching capabilities
- its sub-transmission installation, due to the connections with other 63kV substations;
- its geographical position.

Djambala substation is selected for its position and its voltage level, both favourable to exchange electrical power with the Gabon network. It is provided with an existing 110kV substation and allows, due to its voltage level, to distributing power incoming from the interconnector project. Moreover, an upgrade to the 225kV voltage level is foreseen for this substation for the interconnector early operation.

Fig. 5. Existing Moanda 225kV substation with the incoming line from Grand Poubara (SP survey, 2016)

The intermediate substation of Okoyo is conceived to for the following reasons:

- interposing a substation in the middle of a long line allows the installation of reactive power compensation elements, with an increase of line operation performances that turns in benefits to voltage profile;
- it allows ease of power spillage benefitting local communities development;
- increasing the connection nodes of a HV grid allows to transfer the power onto the minimum impedance path, thus reducing power losses and voltage drop, providing multi-vectoring power wheeling over long distances

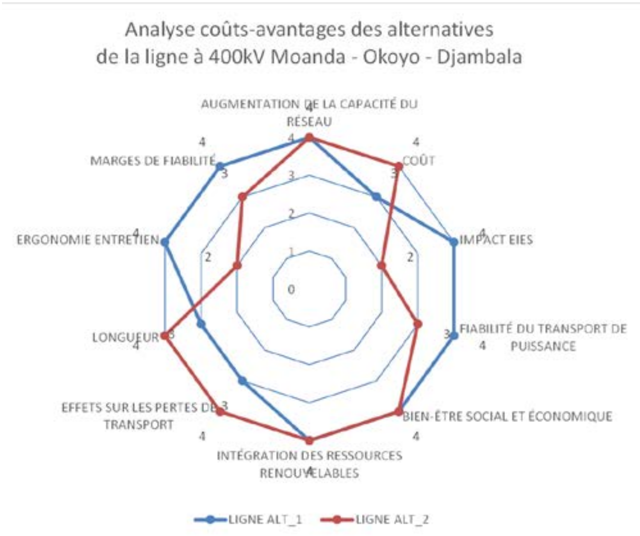

Fig. 6. Radar chart for route alternatives ranking

Once the substations of the project has been selected and confirmed, the line route alternatives assessment has taken place, as it consisted in selecting a feasible route taking care of many aspects, such as:

- minimization of the line length, directly impacting on investment costs;
- obeying national and international standards related to environmental impact and utilisation of the soil;
- compliance with right-of-way (wayleave) determination criteria;
- interference with existing installations and infrastructure (e.g. the existing railway, mining and industrial sites), villages, cities, airports, military zones;
- rivers, lakes, swamp areas, mountains, gorges
- consideration to planned high voltage lines crossing the project zones

An excellent way for visualising multi-options analysis results, based on multi-variable structure as the ones performed, is offered by a typical radar chart. By assigning a ranking point (worst = 0, best = 4) to the decision-making parameters and aspects, the magnitude of each area is proportional to the ranking (the greater the area, the best the option). The alternatives of the line route have been then scored accordingly.

The minimization of the length is strictly connected to the cost of the line so that, unless particular conditions have to be considered, it should not exceed 10% ÷ 15% of the point-to-point distance.

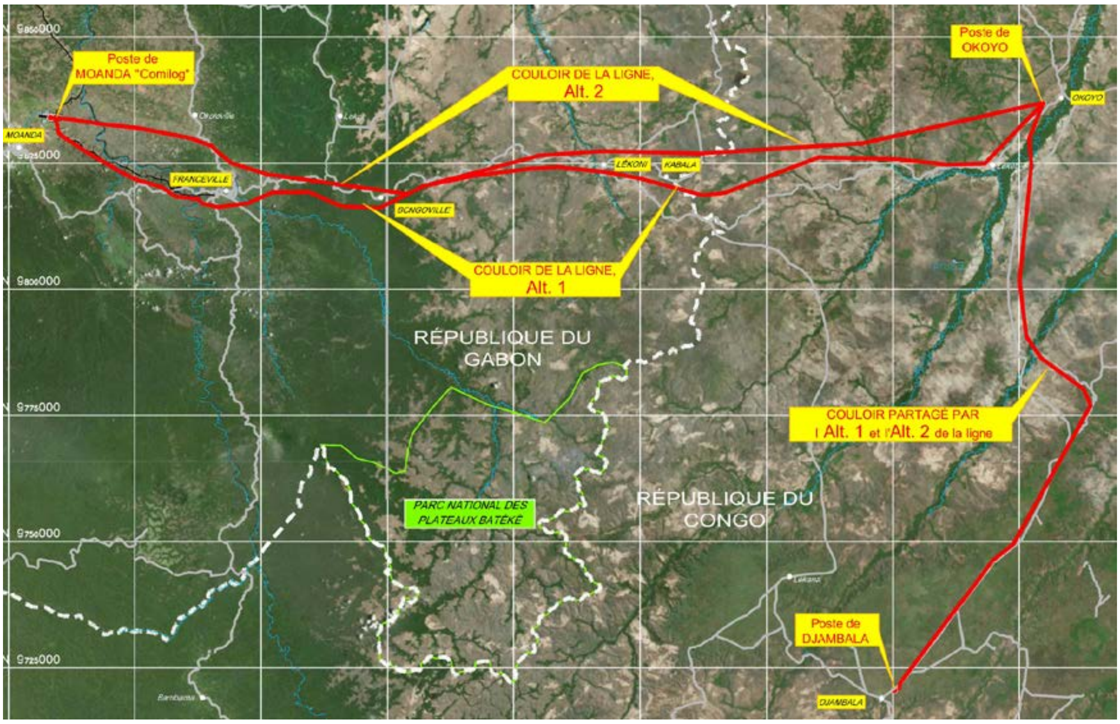

Fig. 7. Alternative line routes – design documentation excerpt

4. Conductor cross-section optimization

One of the most important design activities of a transmission line feasibility study is the conductor selection and justification, since its mechanical and electrical characteristic heavily impact the financial viability of the project.

The conductor, with its resistance and geometrical configuration, determines the electrical constant per unit length which are considered in the calculations relevant to the voltage drop and the power losses of the line and hence to its performances. Moreover, the conductor current rating and relevant thermal expansion factor are utilized together with the tower configuration to determine the thermal limit of the transmission line.

The conductor weight and admissible load are the input data for the mechanical design, as together with the weather conditions, it is possible to calculate and determine the most suitable tower and span length.

If the national utilities have standards relevant to the transmission line voltage level of the project, it is useful to follow them. Indeed, for a national utility, it is easier operating and maintaining well known conductors. The costs for spare quantities will be reduced too. However it is necessary to verify that the conductor indicated by the national standard is suitable to the project' specific circumstances.

For the 400kV double circuit transmission line on the Gabon-Congo Interconnector project, the All Aluminium Alloy Conductor (AAAC) ASTER 570 in twin bundle configuration has been selected, against other choices (including Aluminium Conductor Steel Reinforced, ACSRs). Its main characteristics are the following:

$A = 570.22\text{mm}^2$; $d = 31.05\text{mm}$; Tensile Strength = 18360daN; Linear weight 1574kg/km; $r_{DC20°C} = 0.115\Omega/\text{km}$

The analysis carried out with the mentioned conductor leads to acceptable results, as shown in the following chart.

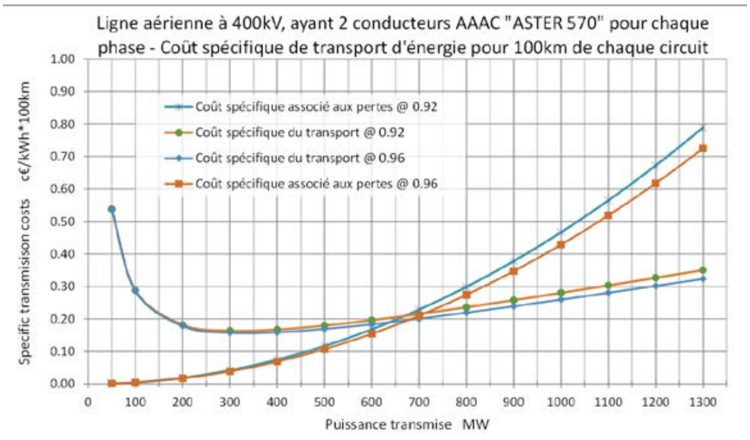

Fig. 8. Specific transmission costs (c€) per circuit length of 100km

The specific transmission costs for the rated power flow transmitted via the interconnector project, i.e. approximately 1050MW (say 525MW per circuit) are around 0.18c€/kWh*100km.

The line rating capability is about 1000MW per circuit.

Line steel lattice tower geometry and layout comply with the most stringent international requirements in terms of electromagnetic compatibility (as per the Commission Internationale de Protection contre les Rayonnements Non Ionisants).

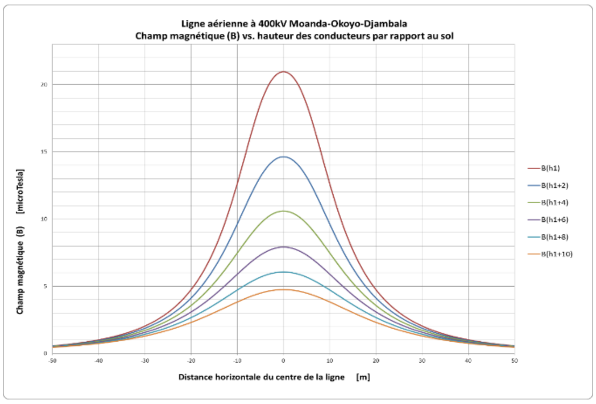

Fig. 9. Magnetic field at 1.5m from ground on the line axis at 721 A

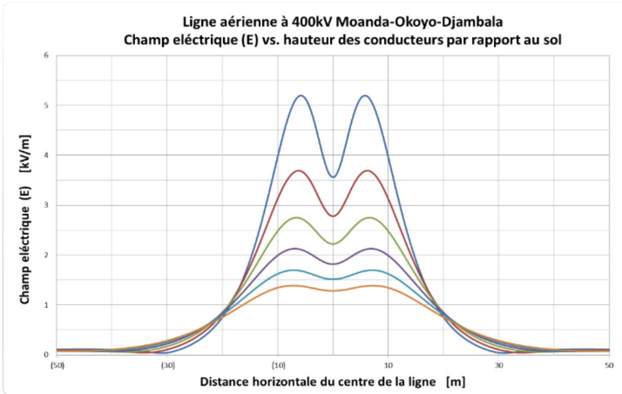

Fig. 10. Electric field at 1.5m above ground under line axis at 721 A

5. Expansion of existing substations

The HV interconnector is conceived as a 400kV double circuit line, but it will be operated at 225kV for the first years. This strategy, while allowing grid exploitation at low loads during the inception of operation, implies precautions and expedients to be accounted for at the design stage, affecting procurement of the substations equipment, which will be replaced at the time of upgrading from 225kV to 400kV, even though detailed diversification has been considered for cost reduction.

Reactive power flow has also been duly investigated as the balance between the line consumption and generation reactive power operation can be supported by compensative installation (usually capacitor banks and shunt reactors) in the departing and ending stations. If the approximate load of the line is known, some strategies can be applied to increase the line reactive power balance.

The optimization of the mentioned voltage upgrading strategy and the interface between the existing substations and their expansion translates in the fact that the majority of the substation equipment will be procured and operated according to the 400kV insulation requirements while some equipment, i.e. circuit breakers, surge arresters, current and voltage transformers are specified for 225kV to preserve their performances.

Two out of three substations of the project are already existing, namely Moanda and Djambala.

For sakes of case study interest, it is worthwhile mentioning some of the technical features and issues managed during the design of the expansion of the existing 225/63kV Moanda SS, composed by:

- one 225kV incoming line bay;
- one bus coupler bay;
- two 225/63kV transformer bay;
- on 63kV outgoing line bay;
- one longitudinal sectionalizer bay;
- one 63kV line spare bay.

The existing 225kV section will be provided with two new autotransformer bays and a new 400kV section will be built. As mentioned above, the new section will be operated during the first years at 225kV voltage level, nevertheless the layout of the busbars and bays is already designed for housing the final 400kV equipment.

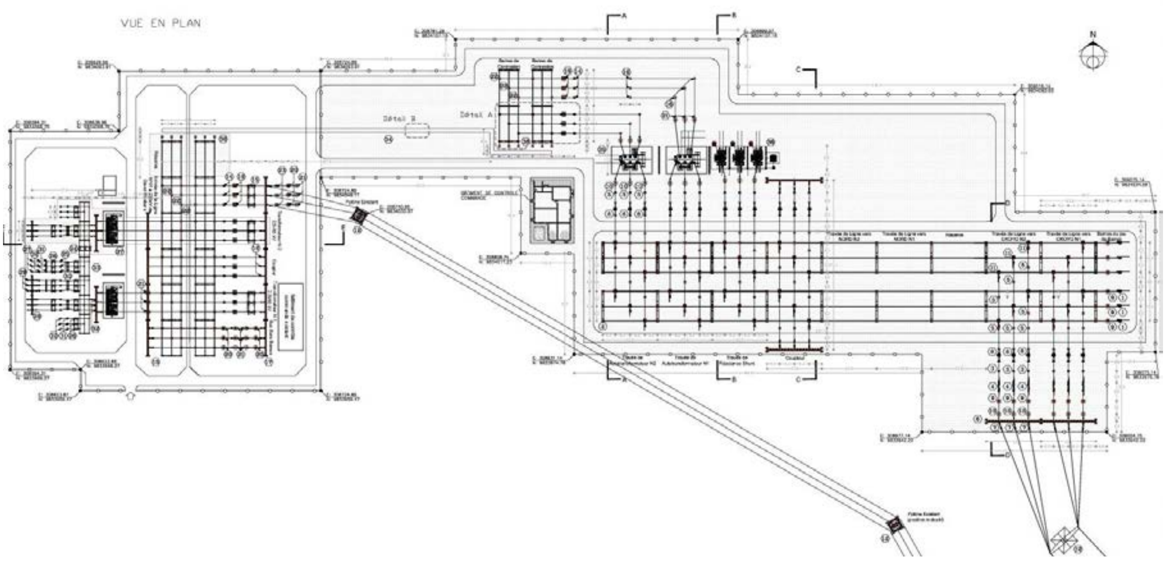

Fig. 11. Planned 400/225/63kV Moanda substation expansion (existing section on the left) – design documentation extract

The design has faced many constraints to reach the optimal layout: the presence of a railway contouring the northern side, the existing 225kV incoming line from Grand Poubara and its future 2nd addition required a customized solution. The existing 225kV section is connected to the new one via insulated cables connection, while the busbars voltage transformers and earthing switches will be re-located to allow the incoming of the future 225kV line.

The other existing facility, i.e. Djambala 110/63kV substation, will also be subject to future expansion under the project, where the present 110kV section will be updated to 225kV and a new 400kV section will be added.

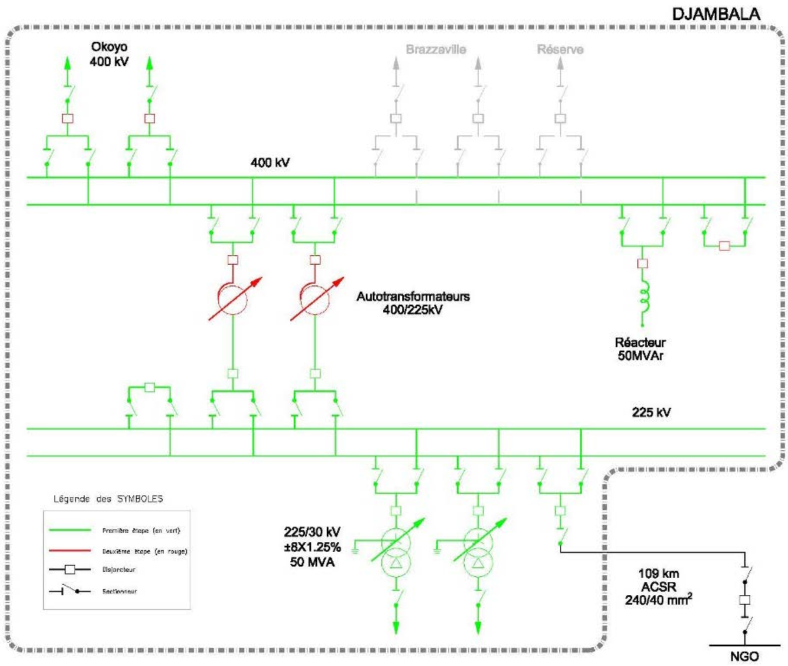

Fig. 12. Djambala future substation scheme – extract from design documents

The 110kV section presents one outgoing line bay and two 110/33 kV bay. Two medium voltage transformer bays contribute to feed the distribution grid.

The existing substation will be provided with:

- two 400kV three phase busbars systems;
- two 225kV autotransformer bays;
- two 400kV autotransformer bays;
- one shunt reactor bay;
- one bus coupler bay;
- two incoming lines from Okoyo;
- two spare bays for the two future lines from Brazzaville;
- one spare bay.

6. New substation design

The intermediate substation, selected in the nearby of the city of Okoyo (Congo), will be a newly built facility.

The location has been selected for manifold reasons as it is approximately in the middle of the line route (thus offering advantages in reactive compensation and power flow vectoring, as the more the barycentric the position, the greater the advantages), and being the surrounding areas developed for electricity access boosting.

The positioning of a substation has to comply with a lot of requirements. Among the others, Okoyo is rather free from infrastructures interferences and presents favourable topographical configuration with easy incoming and outgoing of the lines routes, the installation of heavy and voluminous electrical machines and future expansions at different voltage levels, etc.

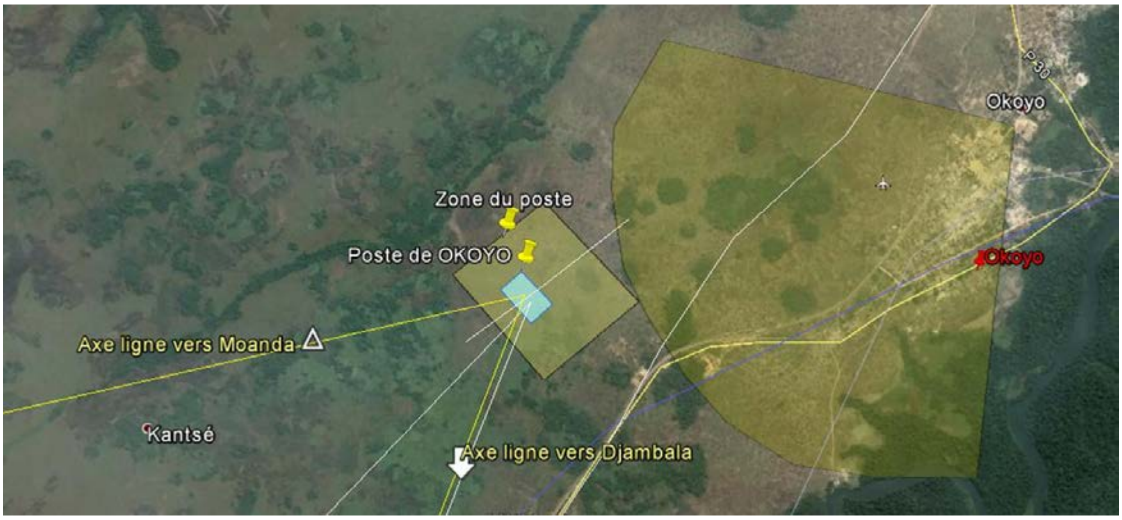

Fig. 13. Okoyo substation area selection study

In the figure above the white blue rectangular identifies the area destined to the Okoyo substation. The green painted area around the station needs to be kept free from installations such as to favour future expansions and the incoming of new lines. As it can be seen, the line from Moanda and the one to Djambala find no obstacles to reach the station. The expansion area foreseen for Okoyo is highlighted in green and is preserved by the installation of high voltage equipment.

Maintenance operations within the station are facilitated by roads that round the high voltage equipment and allow to quickly reach every electromechanical installation.

7. Project costs estimate

Complementing the design package with investment costs estimate and financial analysis provides key indicators for project's viability.

The Project total costs, including transmission line and substations works, is approx. 146M€, associated implementation of environmental impacts mitigation implementation and resettlement issues are estimated in 1.4M€. These figures have been tested by financial analysis resulting in effective bankable parameters.

8. Conclusions

The paper presents an overview on the Gabon – Congo Interconnector project design carried out by Studio Pietrangeli (SP), promoted by PEAC, financed by the European Union FED

The study has highlighted the benefits related to its implementation targeting the interconnected grid operation and load demand scenario in 2030 based on the generation and transmission development plans set up by Gabon and Congo, the technical and financial viability as well as a limited impact of ESIA and RAP results on the line route.

The project will be a key path for wheeling power in both direction, boosting trading between PEAC's country members and contributing significantly to the increase of the electrification access in the region interested by the project.

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