Engineers' Training on T&D in low-income countries: a case study in Africa

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Introduction

A plurality of human resources has been committed to provide capacity building and training services to many low-income African countries in the last two decades. The efforts in addressing arguments of different natures and complexities have often common goals in terms of awareness and efficacy.

In this context, the authors depict their recent experience in preparing several technical lectures tailored to a training course for electrical engineers' employees of two national public ministries, namely the Ministries of Energy and Water Resources of Gabon and Congo (here referred to as the Client).

The course was aimed at responding to specific needs of the two utilities, namely:

- providing engineering tools for easy assessment of main parameters ruling the design of major infrastructures, e.g. extremely high voltage (EHV) transmission lines;
- highlighting interconnected grids operation criticalities on a large scale, such as black-outs;
- emphasizing low cost, attractive technical solutions for rural electrification tailored to hydropower projects.

In its request for proposals, the client specified some subjects pertaining to the design of transmission and distribution systems (T&D) as well as EHV transmission lines and substations in cross-boundary projects. The topics of the training course covered, among others:

- line conductor optimal assessment as a function of hydropower plant development;
- protections of double circuit high voltage lines;
- network studies stability analysis;
- large disturbances of electric systems (black-outs).

In addition to those subjects, two other interesting topics were proposed and delivered:

- energy tariff features definition from the legal and commercial point of view;
- the application of the Insulated Shield Wire Scheme for rural electrification.

This paper provides an overview on the key features of the lectures and relevant audience feedback.

Key words: Africa, Gabon, Congo, cross-border project, European Union Delegation, training, electrical engineering, transmission system

1. Background

Design, management and operation of high voltage grids requires building-up of a widely experienced and skilled engineering team, with technical capabilities in several fields and disciplines such as insulation coordination of electrical lines and substation, overall expertise in large electrical machines such transformers, autotransformers, shunt reactors, etc., "PCMS" (protection, control and monitoring systems), coordination with unit commitment plans and generation machinery management, among the others.

In the framework of the "Programme d'Appui au Commerce et à l'Intégration Économique" funded by the European Development Fund (Fonds Européen de Développement, FED), the contract required the preparation of a comprehensive program of training. SP has therefore proposed to the Client a wide horizon of themes so to convene and agree on a robust and multidisciplinary set of topics, to be addressed within the contractual task of the capacity building.

Fig. 1. Engineers' attendance taking notes and drafting questions while training in progress

A well-balanced genders representative's participation has been assured thanks to the coordination of both ministries.

The following paragraphs provides an overview on the agreed topics.

2. The programme

As already favourably experienced in recent training sessions, the activities were based on a classical in-room lessons with bi-directional communication aimed at fully involving participants in each topic and promoting troubleshooting with answers and questions exchanges.

The in-room training covered the following modules:

- software-based network studies and grid operation planning
- extremely high voltage overhead lines electric protection schemes

- rural electrification based on the Insulated Shield Wire Scheme (ISWS), theory and applications
- determination of the best (economic) phase conductor cross-section as a function of the utilisation factor and plant factor
- concepts of tariffs application in trans-boundaries high voltage interconnectors, legal and commercial aspects
- large electric grids black-out events survey, defence plans and remedies

The following paragraphs describe some of the above topics.

2.1 Software-based network studies

This topic was one of the contractual ones demanded by the Client.

Specifically tailored to the contract's core task, i.e. the design and operation stability assessment of the 400kV interconnector between Gabon and Congo, this module offered an overlook on the main aims of this kind of software-based investigation and studies, together with an in-depth exhaustive dissertation on the grid stability definitions and aspects.

The module depicted in details topological representation of network components (generation, transformers, lines, compensation equipment, etc. with active and passive components), steady-state and transient regimes behaviours as well as load flow theory based on the well-known numerical algorithms for matrix calculus resolutions.

The module closed with the discussion of the results of the case study, (the "INTGACO" network studies), highlighting the stability limits of the system in the two cases of import to Congo and export towards Gabon in the target year.

2.2 EHV (300 – 750kV class) overhead lines protection schemes criteria

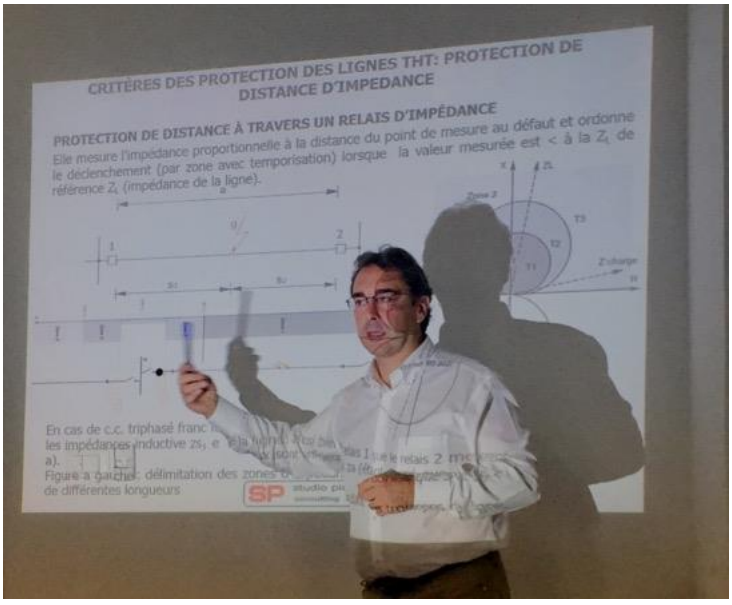

Fig. 2. Impedance-based distance relaying type criteria explanation

This topic was as well among the ones stipulated in the contract.

The module provided an ample portrait of the most developed distance protection applications in EHV overhead (OHL) lines of rather importance length such as the INTGACO (about 350km), zooming into the main aspects leading the most suitable scheme selection in respect to several characteristics of the line to be protected.

In particular, the discussion with the participants was stimulated by interest in teleprotection signals uses and the application of a differential protection for the specific case of HV double circuit OHL, crossing high lightning density levels zones (such as the INTGACO).

2.3 Insulated Shield Wire Scheme (ISWS)

The proposal of including this topic within the training program was warmly welcomed by both ministries. Indeed, the argument was already introduced in a seminar held by Professor Iliceto (long-term SP consultant, the inventor of the scheme) in Libreville, Gabon, in 2012.

The module was intended to provide a quick but complete ready-to-use tool for the application of the scheme for power supply to rural areas and villages located along planned or already built HV overhead lines (up to 330kV), generally exploited at low power flows.

At the beginning, a description of the concept and aims of the Iliceto shield wire scheme, which is applicable for minimum cost power supply from the grid to villages, small towns, farms, factories, and water pumping stations located near or at some distance from the route of the HV, 110 to 330 kV, transmission lines (TLs), was provided. The ISWS is a solution for rural electrification that is not economically justifiable with conventional systems, i.e. long medium-voltage (MV) lines routed along the HV TLs or dedicated HV/MV transformer stations.

ISWS mainly consists of the following:

- insulating the shield wires (SWs) from the towers of the HV TL for MV operation (20 to 34.5 kV)
- energizing the SWs at MV from the HV/MV transformer station at one end of the HV TL
- using the earth return of current as an MV distribution conductor
- supplying the loads by means of medium-voltage/low-voltage (MV/LV) distribution transformers connected between the SWs and the ground.

The majority of the engineers involved in the training course was significantly stimulated by discovering the contribution of the earth carrying capacity in the 3-phase scheme of the ISWS, as curiosity inspired questions about fault-related management topics.

The Ministry of Energy of Gabon enquired about the possibility of retrofitting existing 225kV OHLs thus enabling the shield wires to be isolated and energised for the purpose of implementing the ISWS. Positive response excited interest and attention.

In conclusion, the engineers have been invited to consider the ISWS Manual, commissioned and coordinated by the Africa Electrification Initiative (AEI) of the World Bank, funded through the Africa Renewable Energy Access program (AFREA) of The World Bank's Energy Sector Management Assistance Program (ESMAP).

The late Professor Francesco Iliceto, Emeritus Professor at the University of Rome "La Sapienza" and the inventor of the Shield Wire Scheme technology, acted as the consultant and author for this manual.

2.4 EHV OHL's conductor optimal selection

Users' load demand profiling with peak and average trend, load factor, generating features such as plant factor, installed capacity, transmission connection distance to the grid and more other parameters influence the selection of the interconnecting line conductor economic cross-section.

All these parameters lead the engineers in determining their choice at design stage, which usually could be misjudged as mainly dictated by thermal rating or stability limits of the line.

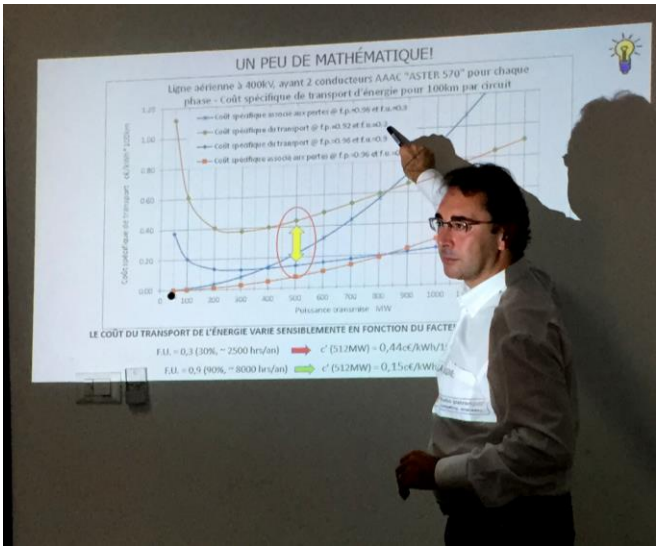

Fig. 3. Doing maths in best conductor cross-section sizing!

Notwithstanding the need of an overall understanding of the economics' role, engineers should be sensitized in acquiring knowledge of the system wherein the power plant will operate in terms of generation/demand balance and unit commitment.

This module, one of the most appreciated by the engineers of both ministries, zoomed into the methodology for investigating the OHL phase conductors sizing, while achieving a trade-off among those parameters by adopting coherent algorithms based on the driving variable such as price and cost of the infrastructures (line components and generating plant procurement), plant factor, utilisation factors, etc.

2.5 Energy tariff set up criteria in bilateral agreements

This topic was specifically required by the Ministry of Energy of Congo, taking into consideration the complexity of future power grid interconnection systems and the institutional and economic arrangements needed.

The in-room session was supplemented by and supported with a dedicated document driving the participants through the main aspects of the topic, outlined by the following subjects:

- among the legal aspects
  - definition of the involved institutions, agencies, public and private enterprises
  - identification of the international funding banks
  - definition of the agreements related to energy selling/buying modalities, responsibilities for interconnector exploitation and environmental and social aspects management, etc.
  - harmonization of different legal frameworks between the two countries
- among the commercial aspects
  - methodologies for tariff (energy price) establishment with relevant penalties mechanism
  - tariff threshold subject to interconnector exploitation
  - etc.
- the need for harmonising the grid code on the basis of the new to come technical requirements and market structures

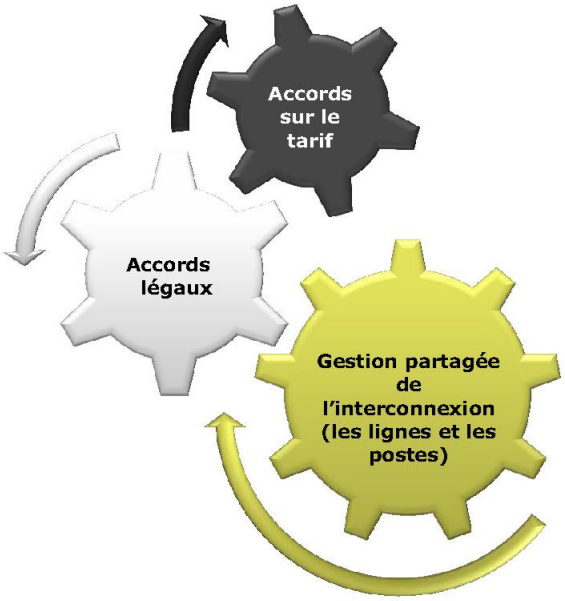

Fig. 5. Legal and commercial gearing based on shared management of the interconnector's infrastructure

Some of the identified criticalities of these aspects were discussed during the "Table Ronde" organised in Libreville, at the end of the engineering mission, at the presence of the General Directors of Energy of Gabon and Congo, A.

Ngari and J.M. Iwandza, the IRP Coordinator of the Central African Economic and Monetary Community (CEMAC), R. Zogo Ekassi, the Energy Consultant of the Economic Community of Central African States (CEAC), J. Koutele, the Technical Assistant of the Central Africa Power Pool (PEAC), A. Azarak Mogro, and the Electricity Director of Gabon, P. Yalis Ongalla.

3. Acknowledgments and benefits

The paper intends to bring a contribution in considering general topics while preparing training programme of emerging economies public authorities in Africa, in the framework of a European Union funded contract for the design of sensitive grid interconnector projects such as the 400kV Gabon – Congo (INTGACO).

It is worthwhile mentioning that the INTGACO interconnector will serve the two countries wheeling power generated by existing and planned hydropower projects, some of which of large size (Chutes Booué and Tsengué-Lélédi in Gabon, the hydropower cascade of Louéssé and Chute Chollet in Congo) and meshing a growing up grid of large size spanning more than 2500km. In this light, besides investment in skills and training assets is of paramount importance, SP has also focused the training topics on design and planning themes that could have boosted knowledge, interest and motivation among the involved engineers.

The enthusiastic feedback from the participants collected during the course has been the main indicator of the successful achievement of the activities.

A well-balanced genders representative's participation has been also recorded, a significant sign of women increased participation in engineering designing and planning.

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Stefano Galantino received his degree in Electrical Engineering from the University of Rome "*La Sapienza*", Italy. He works as power systems expert and hydropower development specialist for Studio Pietrangeli (SP), Rome, Italy. His 16 years of professional experience include the planning, design coordination and construction supervision of numerous hydropower Projects and HV/EHV transmission systems projects mainly located in Africa, most of which with cross-border features. He is currently responsible for the electromechanical engineering department in SP and his field of expertise includes planning, static and dynamic stability studies, voltage collapse in power systems.

Ilaria Colucci obtained her degree in Electrical Engineering from the University of Rome *"La Sapienza"*, Italy before joining Studio Pietrangeli (SP), Rome, Italy. Her professional experience includes the design coordination of HV/MV T&D systems located in several African countries such as Congo, Gabon, RDC/Rwanda/Burundi, Zambia, Zimbabwe, Ethiopia, and others. She followed and coordinated the Gabon – Congo interconnection project since the beginning of tendering phase, prior to the awarding of the contract in October 2016.

Riccardo Vignoli, obtained his master's degree in Electrical Engineering from the University of Rome "*La Sapienza*" in 2016. He works for Studio Pietrangeli as hydropower & transmission system engineer gaining important experience in the feasibility, design and construction of hydropower plants and T&D systems. His expertise ranges from electromechanical equipment to overhead transmission lines and substations.