

RUZIZI HYDROPOWER CASCADE COORDINATION OPTIMIZATION: A CASE STUDY

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Abstract

The paper describes functions, benefits and institutional framework of the **Cascade Coordination Centre (CCC)** designed for the Ruzizi River hydropower cascade.

The Ruzizi River represents the natural border between Rwanda, Burundi and the Democratic Republic of Congo. Along the river, at the moment, there are two hydropower plants, Ruzizi I and Ruzizi II. Two more hydropower plants are planned in the near future.

In 2012, the Delegation of the European Union awarded Studio Pietrangeli (SP) the contract for consultancy services relating to the feasibility, detailed design and bidding documents for the 220kV Kamanyola Station and transmission lines, the Regional Load Dispatching Centre (RLDC) and the Ruzizi CCC, placed in a common hub, strategically close to the future Ruzizi III HPP, at the boundary of the three countries.

The paper also describes SP' study findings, carried out for the definition of the RLDC/CCC institutional framework in the Economic Community of the Great Lakes Countries (ECGLC) context, by focusing on the following topics:

- the framing options
- the definition of institutional and commercial relations between the parties
- the analysis of the pros and cons of each option
- recommendations for the implementation of the chosen option.

Among the main results, the Consultant has proposed a coordinated management system of the Ruzizi hydropower cascade. The three ECGLC countries thus agreed that the functions of "coordination" will be performed by the new identified infrastructure, denominated Cascade Coordination Centre (CCC).

The overall objective of the assignment was to describe in detail a proposed operating organization of the Ruzizi cascade through a coordination centre, aimed at:

- to optimize the cascade electrical energy production;
- to adapt this production to all requests for each of the national electricity companies;
- to enable compliance with the concerns of investors by establishing an energy delivery mechanism produced fair and transparent (allocation keys);
- to submit a comprehensive organization by all, fair and equitable, positioning the Coordination Centre as Operator and unique contact Ruzizi Cascade vis-à-vis institutional actors in the region.

1 - Introduction

NELSAP, the Nile Equatorial Lakes Subsidiary Action Program falling within the Nile Basin Initiative (NBI), has recently issued the Multinational Electric Grid Interconnection project of the Nile Equatorial Lakes Countries aimed at coordinating the water resources and developing electric transmission grids strengthening of NELSAP countries of Burundi, Kenya, DRC, Rwanda and Uganda.

The project pursues to increase 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 shall be achieved by increasing cross-border electric power trade. The involved financial entities are, among the others, the African Development Bank – the leader financier, Japan International Cooperation Agency (JICA), the European Union, the Governments of Norway, of Germany through KfW and Netherlands.

Studio Pietrangeli's tasks associated to the Ruzizi Project included the study of the institutional restructuring of the regulatory framework and management of the Ruzizi river energy pricing, in respect to the wheeling feature of the Economic Community of the Great Lakes Countries (ECGLC), as part of the Technical and Organizational Studies on energy cooperation in the Great Lakes region. The study was coordinated by the Organization of the ECGLC for Energy of the Great Lakes Countries (EGL) and the European Investment Bank (EIB).

Among the main results, the Consultant has proposed a coordinated management system of the Ruzizi hydropower cascade. The three ECGLC countries thus agreed that the functions of "coordination" will be performed by the new platform, denominated **Cascade Coordination Centre (CCC) of Ruzizi**.

This paper focuses on the methodologies and results achieved by SP in performing the detailed study of the Ruzizi CCC and its implementation, based on the preliminary proposal made by SOFRECO Consultant.

2 – Background on the Great Lakes Region Electricity Sector

Rwanda, Democratic Republic of Congo (DRC) and Burundi are countries members of the ECGLC, an organization created with the purpose to promote regional cooperation and integration in the spheres of politic, economic and social life.



These countries are currently facing a power deficit that is increasing with time, as it was estimated around 40 to 50MW in 2005, then reached 60 to 80MW in 2011, with a current generation capacity unable to satisfy the demand, leading to outages and electricity supply interruptions.

According to the recent demand forecasts, with time horizon 2010-2040, the power demand will grow respectively by 7.4% in east of the DRC, 6.2% in Rwanda and almost 8% in Burundi. At Community level, the EGL is responsible for regional development of the energy sector, with the main objective of ensuring cooperation between countries members.

The most important projects identified by EGL in the region (figure on the left), to face present deficit, are placed along the Ruzizi river (Ruzizi III and Ruzizi IV), together with associated transmission infrastructures such as the 220kV Kamanyola station and relevant transmission lines, as part of the NIB for the interconnection of Burundi, Rwanda and DRC. The interconnection between Rwanda, Burundi and DRC is presently achieved through Ruzizi II that is operated by the International Society for Electricity in the Great Lakes Region (SINELAC), an international organization controlled by the ECGLC. The energy produced by the Ruzizi II hydroelectric plant is shared in a proportion of one third between REGIDESO, SNEL and EWSA, evacuated via 110 kV lines departing from Mururu II.

Fig.1 – Overview of the Ruzizi hydropower cascade

With the aim to increase the transmission capacity and to improve flexibility and the reliability of the supply, the existing network will be upgraded and complemented by new 220kV transmission lines, which will have a common hub in the 220kV Kamanyola Substation, a strategic location close to the forthcoming new Ruzizi III HPP and at the boundary of the three countries. By the forthcoming refurbishment of the existing Ruzizi I and Ruzizi II HPPs (built respectively in the 50s and 80s), two additional plants (Ruzizi III and IV) will step up the hydro cascade from the present 60MW to some 500MW. Accordingly, a new transmission grid will be realized at 220kV voltage level.

3 – Overview of the Ruzizi Hydropower Cascade

The Ruzizi River flows for 117km from Lake Kivu to Lake Tanganyika, forming the natural border between Rwanda and DRC, and the southern border between Burundi and the DRC. There are two existing hydropower projects (HPP) along the river, Ruzizi I HPP and Ruzizi II HPP. Two additional plants are planned, Ruzizi III HPP and Ruzizi IV HPP.

The 29.8MW rated Ruzizi I HPP, placed about 3 km downstream of the outlet of the Lake Kivu, was commissioned in 1959 and is owned and operated by the SNEL, the National Electricity Utility of the DRC. Nowadays, only 21.2MW are available, due to technical problems. A second plant, Ruzizi II, was successively commissioned downstream of the first one, in 1989, with a capacity of 36MW. However, due to technical reasons its available power is lower than the rated capacity.

As already said, Ruzizi II HPP is owned and operated by SINELAC, a commercial company, under public law, purposed to operate Ruzizi II HPP and the regional substation of Mururu II, and equally sell the energy production to the three national utilities, namely REGIDESO in Burundi, SNEL in DRC and EWSA in Rwanda. In May 2011, the export of electricity by SINELAC to three national utilities represented respectively 18%, 54% and 51% of the domestic production of Rwanda, Burundi and of the interconnected grid of the East of DRC.

For exploiting the Ruzizi river hydro potential downstream of the existing HPPs, the three countries mandated EGL to study and prepare the development of Ruzizi III and Ruzizi IV HPPs, with a capacity of 147MW and 287MW respectively, in view of the priority contribution to the energy deficit. With reference to Ruzizi III HPP, the countries agreed that the power produced will be equally shared by national utilities of Burundi, Rwanda and DRC, similarly as it happens nowadays with Ruzizi II HPP. However, the previous experience coming from Ruzizi I HPP and Ruzizi II HPP provides suggestions about the implementation of the Ruzizi III HPP. In fact, donors and government wanted a fully commercial and independent structure, protected from the interference of any of the involved countries, assuring equity.

The project structure selected for Ruzizi III HPP foresees a public-private partnership (PPP), based on a build, own, operate and transfer (BOOT) concession. The project company will operate the plant as independent power producer.

The three government gave to EGL mandate to select the Investor/Developer from the private sector. After two years of negotiations, in September 2014 the member states of the CEPGL, the EGL, and the Sithe Global Power Ventures LCC (USA) / Industrial Promotion Services Ltd (Kenya) consortium, i.e. the Investor / Developer of the Ruzizi III HPP, came to an agreement about the major conditions and terms to develop the project. The preliminary agreement foresees that the Investor/Developer will be in charge of the financing, design, construction and 25-year operation of the project.

The overall capital investment is estimated at 650MUSD. About 60% of the investment cost shall be financed via concessionary financing given by the international financial institutions that are supporting the projects, such as European Union (EU), European Investment Bank (EIB), Kreditanstalt Für Wiederaufbau (KfW), African Development Bank (AfDB), French Development Agency (AFD) and World Bank.

4 – Need for Cascade Coordination

The Ruzizi River context is a many-sided question due to several actors and interests (countries, national utilities, private sector, climatic, ecological, social, etc...) involved and due to the its overall strategic feature in the near future.

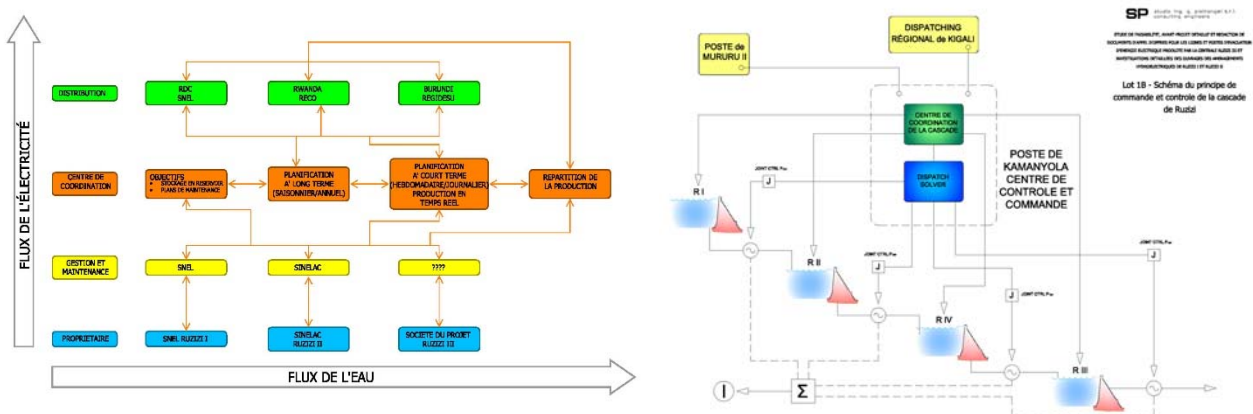


Fig. 2 – CCC structure and juridical positioning (left); conceptual diagram of the Ruzizi hydro cascade control through the dispatching solver and the coordination centre

One of the reason leading to the need for setting up a coordination platform, is the fact that the new planned hydropower plants, namely Ruzizi III and Ruzizi IV, will be placed downstream the exiting Ruzizi I and Ruzizi II. Hence, the operation

of Ruzizi I HPP will determine the energy production of the whole cascade, being the reservoir capacity of the downstream plants very small.

The selection of the actors from the private sector involved in financing, building, operating and maintaining these planned facilities is under the responsibility of EGL, an international organization formed and controlled by ECGLC. For this reason, EGL, among the others, proposed to set up a coordinated management system of the hydropower cascade on the Ruzizi river. The three countries members of ECGLC agreed that the function of “coordination” will be performed by the Cascade Coordination Centre (CCC) of Ruzizi.

The EGL considered as a priority the creation of a coordination center for coordinating and optimizing the entire hydro cascade energy production within an institutional framework, which also plays a key-role in mobilizing funding for the future Ruzizi III HPP that will be built, operated and managed under a public-private partnership.

The purpose of the present paper is to describe the benefits coming from the coordinated management of the cascade. The functions and the institutional framework of the CCC will be also discussed.

5 – Cascade Coordination objectives

The overall objective of the assignment was to demonstrate the possibility of energy production optimization and quantify it, through a wiser utilization of water, and to propose an operating organization based on a technical and commercial platform, aimed at:

- optimizing the cascade electrical energy production on a short and medium term basis;
- adapting energy production to the national electricity companies requests and the network load demand;
- enabling compliance with the concerns of investors and stakeholders by establishing a fair and transparent energy allocation mechanism;
- submitting a comprehensive organization by all, fair and equitable, positioning the Coordination Centre as Operator and unique agent for Ruzizi Cascade versus institutional actors in the region.

Studio Pietrangeli’s engineering services also focused on:

- institutional framework analysis, the development of the organizational structure to ensure proper staff allocation and facilitate its implementation
- roles, responsibilities and management functions definition
- hierarchy identification among the CCC, the national dispatching centres and Kamanyola’s DRC, being planned within the Eastern Africa Power Pool (EAPP).

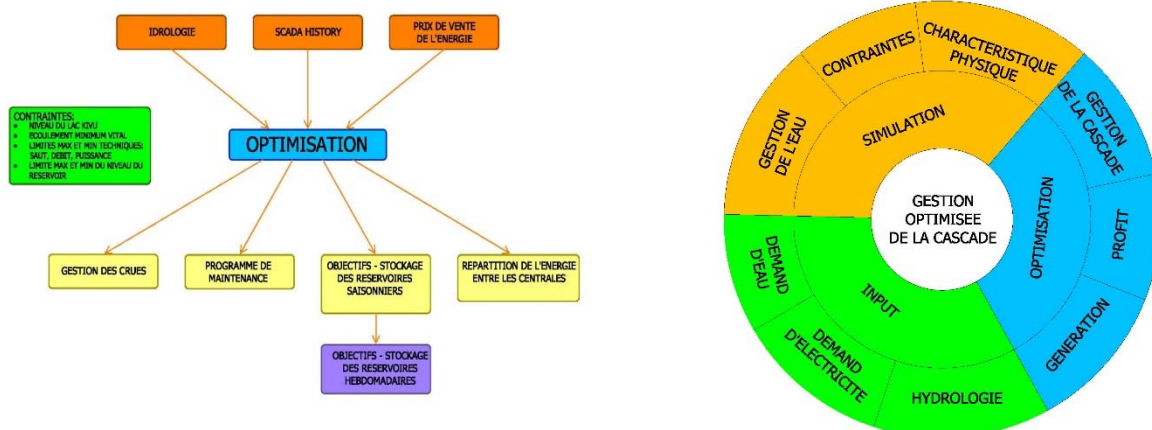


Fig. 3 – Hydropower cascade long-term planning (left); water resource integrated and optimized management chart (right)

6 – Ruzizi Cascade energy optimization methodology

SP has developed energy production simplified models allowing cost – benefits comparison for two base cases:

- hydropower cascade energy production not optimized (« Without CCC »)
- hydropower cascade energy production optimized (« With CCC »)

The model is based on the following assumptions:

- the main characteristics of the Ruzizi HPPs river in the target year 2020, including Ruzizi I (R1) and II (R2) rehabilitation works, as shown in the table; the hydropower cascade installed capacity is 211MW.

	RUZIZI I HPP		RUZIZI II HPP	RUZIZI III HPP
	Group A	Group B		
Year of commissioning	1959	1973	1989-2001	2020
Number of units [#]	2	2	3	3
Design flow [m ³ /s]	2 x 33	2 x 42.8	3 x 57.5	3 x 50.4
Rated Head [m]	24	24	28.5	107.5
Turbine capacity [MW]	2 x 6.95	2x 9.05	3 x 14.6	3 x 49
Power factor [cos Φ]	0.75	0.75	0.8	0.9
Generator capacity [MW]	2 x 6.3	2 x 8.6	3 x 12	3 x 48.3
Installed power [MW]	29,8		36	145

Table 1 - List of the characteristic parameters of the Ruzizi hydropower Cascade

- Units commitment was set up in the network study based on specific production cost [US\$/MWh] of existing and future power plants, agreed with EGL
- Daily power demand refers to the regional demand of Rwanda, Burundi and DRC in the target year 2020, as per updated demand forecast made by SP, resulting in 350MW of peak load in 2020; daily load demand is simulated in two humps, one in the morning (07:00 – 10:00) and the other in the evening (19:00 – 22:00), 0.6 load factor
- Only R1 has a relevant reservoir being directly connected to the Lake Kivu, while R2 and Ruzizi III (R3) HPPs have small reservoirs with a live volume of about 0.75Mm³ and 0.877Mm³ respectively, corresponding to 3 hours and 2 hours of full power operation. In the hydraulic model, water supply elevation is constant with time, say water discharged by R1 turbines at a certain hour X will reach R2 and R3 at hours X+3 and X+5 respectively.
- It is worthwhile recalling that the energy production of the cascade is determined by the operation of the upstream HPP, R1; R1 assumed plant factor (p.f.) is 54%, i.e.13 hours of full capacity operation per day, and due to constant reservoir elevation, the downstream HPPs p.f. will result lower or at least equal to R1 p.f..
- R1 operation will behave differently in case the production is optimized (with CCC) or not (without CCC).

In “non-coordinated” scenario (“Without CCC”), R1 production follows the load demand request of Sud Kivu only, thus peaking in 07 - 10 and 19 - 22 hrs, without taking into account operation of the downstream plants.

In the “coordinated” scenario (“With CCC”), R1 operation optimizes the energy production of the whole cascade, especially of R3, which has the highest installed power (147MW) and specific cost. Accordingly, R1 anticipates its operation about 5 hours in respect to the peak load hours, when all the cascade HPPs will deliver their full capacity.

7 – Energy optimization results

The analysis results in a coordinated scenario with about **+15% of increased production** versus the “non-coordinated”.

In the “non-coordinated” scenario, shown in the graph, the cascade runs at its maximum capacity only few hours per day, irrespective of load daily trend. At peak load (morning and evening hours), Ruzizi output is 75MW only, reaching about 175MW at flat hours in the afternoon, with a daily average production of 2.37GWh (47% of the regional demand). The contribution given by the largest installed power of R3 to the daily average production (2.37GWh) is reduced due to the high dependence on the upstream HPPs operation (R2 and R1). In fact, R1 (p.f. 54%) is tailored to RDC load demand without considering the downstream consequences.

R2 can still evacuate its power capacity into the network, with a p.f. of 54%, with peaking power about three hours later than Ruzizi I, as it is the concentration (water travelling) time from R1 to R2. Water becomes available to the reservoir of R3 when the grid load requirement is low, especially at night time, when the Ruzizi cascade available power overcomes the load demand and the power production has to be limited, affecting R3 operation, and decreasing its p.f. to 43.2%, far

away from its optimum value, about 54%. The major consequence is that the supply of regional power demand during the day is achieved by running more expensive power plants.

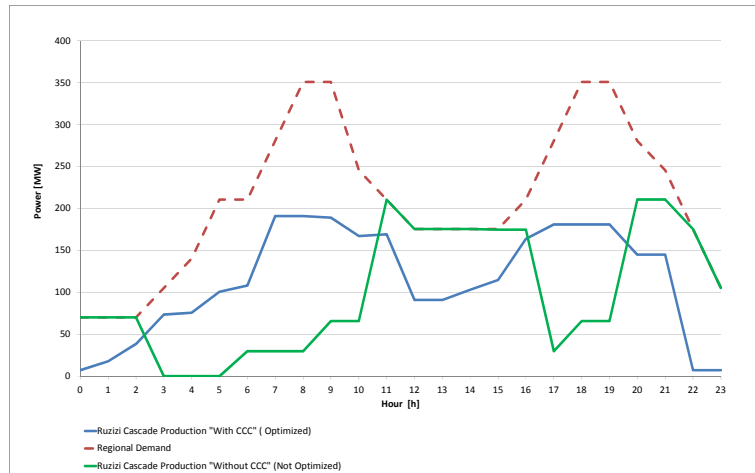


Fig.4 – Daily regional load demand and Ruzizi cascade power production (With and without Cascade Coordination Center)

The Ruzizi “coordinated” operation considers the water concentration time of the river and follows the two-humps load demand daily trend, the production decreases during the night time, and amount to an average daily production of 2.73GWh, about 54% of the regional demand.

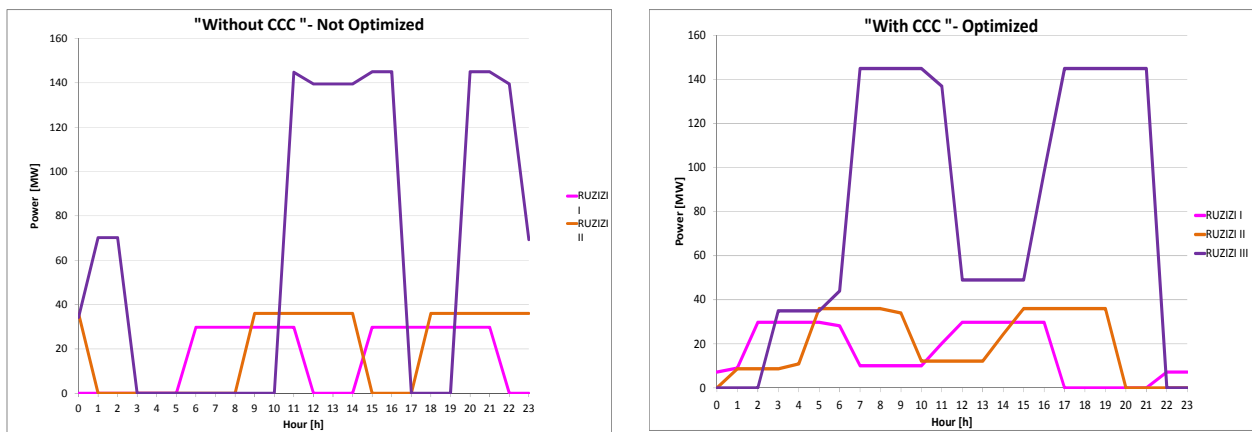


Fig.5 – Ruzizi power production without (left) and with (right) Cascade Coordination Center

It can be noted that the full capacity of the Ruzizi hydropower cascade (210.8MW) is comparable with regional average demand (about 200MW), therefore a non-optimized coordination could lead to generation limitation (and water waste/spillages) whenever the load request is low.

In this scenario, the plant factor of all the Ruzizi HPPs is about 54%. The increase of Ruzizi energy production has an economic benefit on the production cost, because it reduces the utilization of more expensive power plants.

8 – Economic benefits

Finally, the economic benefits due to the energy optimization of the Ruzizi cascade have been quantified.

	unit	Without CCC	With CCC
Load Demand - Regional	[GWh]	5.02	5.02
Total Production Cost - Regional	[kUSD]	487.7	424.3
Specific Production Cost, average	[cUSD/kWh]	9.7	8.4

Table 2 – Daily economic benefits of the coordinated operation of the Ruzizi cascade on regional production costs

It can be noted that the increased energy production by the coordinated operation of Ruzizi HPPs (cheaper than other power plants) allows a reduction in total production cost of about 63.4 kUSD per day, say 23.1MUSD per year, achieving

at the same time a wiser water resource exploitation, in a sustainable development framework, thus reducing use of more expensive power plants in covering the imbalance between load demand and the Ruzizi cascade output.

	unit	Without CCC	With CCC
Generation – Ruzizi Cascade	[GWh]	2.37	2.73
Total Production Cost - Ruzizi Cascade	[kUSD]	~150	~180
Unit Production Cost, average	[cUSD/kWh]	6.3	6.6

Table 3 – Daily effects of the coordinated operation of Ruzizi on the cascade production cost

As expected (table above), the coordinated operation of the cascade increases the energy production, by 0.36GWh per day, say 131.4GWh per year, affecting the daily (average) specific production cost, now increased by 4.7%. This expected result is mainly due to the increased energy production of Ruzizi III and the heavier weight of its specific cost.

9 – Interface with the Kamanyola Regional Dispatching Centre (RLDC)

Kamanyola premises, in addition to the CCC, will also host the Regional Load Dispatching Centre (RLDC).

The dispatching concept assumes that the energy quantity exchanges negotiation will gain ground in the three countries (an “energy market”) by the means of suitable physical or telematic platform, which will let the buy/sell transactions easy and transparent among the different utilities and operators.

In this regard, the RLDC will have a technical and institutional role, in assuring proper operation of the interconnected transmission network in the safest security conditions, to warrant continuity and quality of the service. Telemetry system will acquire in real time the status of the network at different levels (generation, transmission, distribution) and, in case of need, the RLDC will take relevant corrective action.

Dedicated software and managerial tools will allow the RLDC to perform his staged functions, such as:

- ❖ at planning stage, with the preparation of the generation programs on the basis of the energy and power demand forecast at national level and of the unit commitment and availability
- ❖ at real-time control stage, optimizing the transmission operation, acting on the network asset and configuration, offering service of urgent intervention to avoid major faults and black start coordination in case of major disturbance or black out
- ❖ at back-analysis stage, with operation data processing

These functions will be born jointly with the EAPP, Southern Africa Power Pool (SAPP) and Central Africa Power Pool (CAPP) within the coordination plans of each country. In view of the above, it is clear the need for a close collaboration between the RLDC and the Ruzizi CCC, placed in the same premises of the Kamanyola Substation in managing water and energy at the same time.

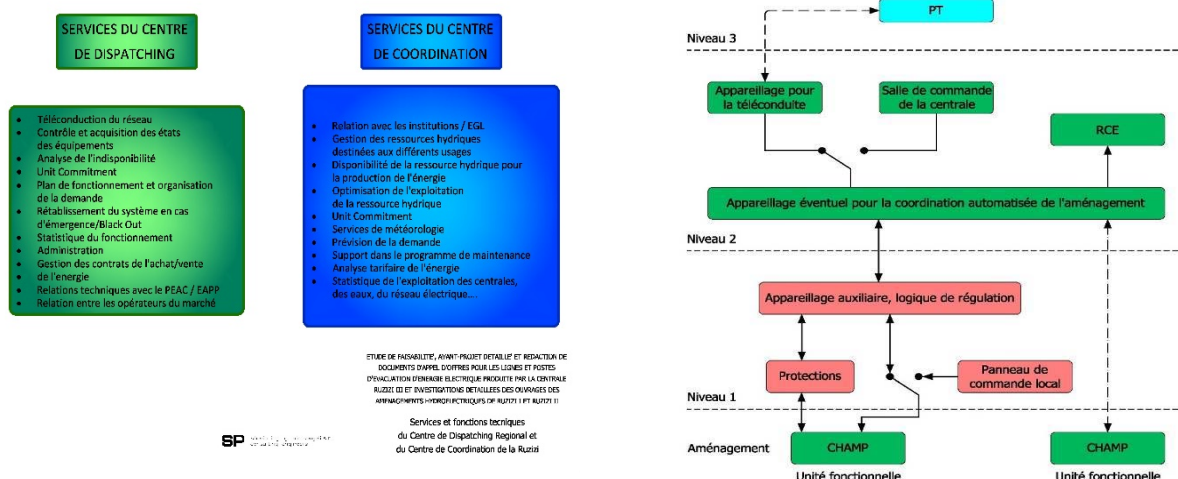


Figure 6 – Services of CCC and RLDC (left); configuration for the implementation of the control centres at the various levels (right)

The CCC’s role will consist in cascade energy production optimization and water uses with the aim at satisfying the national electric providers energy demands (SNEL, REGIDESO and REG, the Rwanda Energy Group) by taking into account the hydrology of the entire Lac Kivu hydrographic basin and the directives issued by the Lake Kivu and Ruzizi River Basin Authority (ABAKIR). The ABAKIR is the high-level authority responsible for the water release from the Lake Kivu, whose protocols must be considered by the Ruzizi CCC during the production planning.

Local and remote control of the hydro units will be implemented – as shown in the above figure – at the various levels: from the local field of one of the hydroelectric power plants of the Ruzizi Cascade (SCADA system, 1st and 2nd levels, green and pink blocks) up to the “poste de téléconduite” in Kamanyola (3rd level, remote console blue block).

The CCC, on the basis of the RLDC’s load demand forecast received from the national dispatching centres, computes the daily available energy capability of the different reservoirs and HPPs of the Ruzizi cascade (as subdivided in run-of-the-river, accumulation basins, etc.). Through a dedicated software, it elaborates water volumes and flows management in relation to their use.

10 – Implementation costs

The investment costs for procurement, supply, installation and commissioning of hydrological instrumentation, dedicated softwares (SCADA integrated) and relevant facilities of the CCC were estimated in about 765k€ (2012), including EGL’s staff capacity building and training. The CCC will employ 9-people staff, including a director, administrative personnel (legal advisors), technical expertise and data processing team.

The estimated annual budget for administrative, commercial and technical operation of the centre ranges in 500k€. A fee, added to the energy sale transactions, identified in about 60c€/MWh by a break-even analysis, will cover the CCC O&M costs.

11 – Institutional Framework and Financial Management Scheme

In the regional context, the Great Lakes countries are ready to create a platform of attractive private investments in the energy sector by implementing the most suitable institutional framework for management of the Ruzizi cascade and the future 220kV transmission network. This platform will help also in mitigating the hydrological risks, which could have an undesirable impact on sustainable operations of the existing and future plants of the Ruzizi cascade, and the mobilization of financing of hydropower development under Private Public Partnerships (PPP).

Studio Pietrangeli’ investigated viable institutional frameworks aimed at defining the most promising and convenient scheme to manage the new RLDC and CCC, in relation to the various stakeholders, such as the EGL itself, the national electric companies (REG, REGIDESO and SNEL) and the independent power producers.

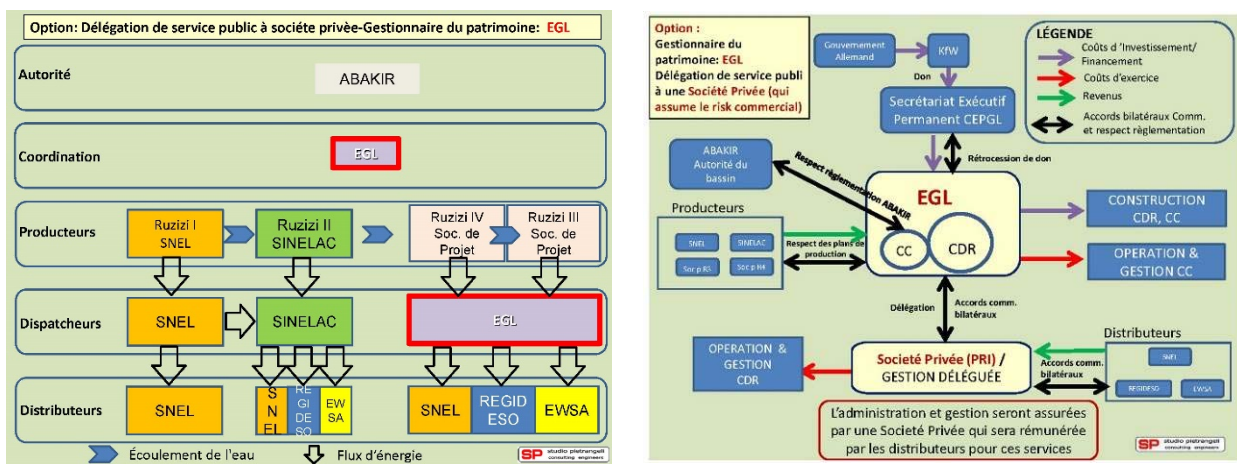


Fig. 7 - Selected option: hierarchical levels scheme (left side); costs/remuneration flows (right side)

Selection of the most appropriate management scheme took into consideration the need for equity, guaranteed remuneration for services rendered to support the infrastructures, independence and security for the Countries. After an in-depth analysis and fine-tuning of various options, a “Délégation de service public à une société privée” was identified as being the most viable. Consequently, the financial and technical management of the RLDC will be entrusted to a private or public (or mixed) company that will also bear the commercial risk of the business. In this way, the Countries retain ownership of the infrastructure.

Commercial agreements will be arranged and entered into among the power producers, the national companies and the RLDC agent company. In the proposed framework, the power producers of the Ruzizi Cascade plants together with the national electric utilities will bear the costs for the services rendered by the RLDC and the CCC.

12 – Conclusion

Further to the efforts made at technical and financial levels, ECGLC and EGL have finally set on the path towards the establishment of the most suitable institutional framework, aimed at the sustainable management of the Ruzizi water resource coordination and its energy production exploitation. In this scenario, the future 220kV Kamanyola Cascade Coordination Centre will play a key role.

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Key words: hydropower cascade, ECGLC, EGL, Ruzizi, Burundi, RDC, Rwanda, Hydropower Cascade Coordination, Load Dispatching Center, Institutional Framework

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Claude Kayitenkore is an Electromechanical Engineering, graduated at the University of Burundi in Applied Sciences Faculty in 1987. From 1987 to 1995, he worked in various fields of the transformation industries related to maintenance of equipment. From 1995 to 2002, he worked as Managing Director of Electricity Department of EWSA, electricity utility of Rwanda, where he concentrated on the rehabilitation and the development of the electrical infrastructures from generation, transmission and distribution network. From November 2002 to July 2007, he worked at SINELAC (Great Lakes International Electricity Company) as General Director Manager, where he mainly focused on the management of the great lakes electrical interconnected network, commercial, financial and institutional issues in the sg-regional context of the three countries: Burundi, DR Congo and Rwanda. Since August 2007, he is working as Energy Director Manager of the Great Lakes Energy (EGL), which is involved in the regional energy planning. Now, he is working on the development of Ruzizi III hydropower plant in public private partnership in collaboration with development partners, consultants and experts of the Great Lakes Countries.