Joint development of hydropower and navigation on a major river: example of the Mekong River

Jean-Louis MATHURIN[1], Sébastien ROUX[2] and Benjamin GRAFF[3]

ABSTRACT

The study of the potential of the Mekong River for run-of-river hydroelectric development began almost 25 years ago, taking into account the joint development of navigation and other water usages, following the model of the multipurpose Rhône run of river cascade in France. Guidelines for locks design and operation were established by the Mekong River Commission (MRC) in 2009.

Today, a first hydropower project is under construction in Xayaburi (Laos), including a lock allowing crossing a lift of 39 m. Project reviews of high lift locks are still on course for several other developments under study in Laos.

CNR has contributed and is currently contributing to all these stages of joint development of hydroelectricity and navigation on the Mekong River, first on behalf of the MRC and nowadays on behalf of the Government of Laos.

The purpose of the paper is to highlight, along with the example of the Mekong at its various stages, the right principles and points of attention, to allow the harmonious development of navigation and hydroelectricity, on large rivers where modern navigation is emerging and where no major navigation structures exist.

Whatever the river considered, emphasizing the importance of global conception of the cascade, on contrast with a succession of disconnected development schemes, the paper deals notably with the search of a good compromise between the performance and safety for navigation, on the one hand, and the acceptable financial effort for the hydropower developer on the other hand, both at the guidelines adjustment phase and at the phase of guidelines enforcement for a new project review.

1 INTRODUCTION

Compagnie Nationale du Rhône (CNR), as concession holder for the Rhône River, is responsible for the production of hydroelectricity, navigation and agriculture since 1934 on a 550 km long river line, extending from the Alps (Swiss border) to the Mediterranean Sea in the south of France.

CNR Engineering, the integrated consulting office of CNR, brings to its external customers 85 years of experience and expertise in design, construction and operation of multipurpose run-of-river Hydroelectric Power Projects (HPP) along the Rhône River.

[1] CNR, Compagnie Nationale du Rhône
[2] CNR
[3] CNR

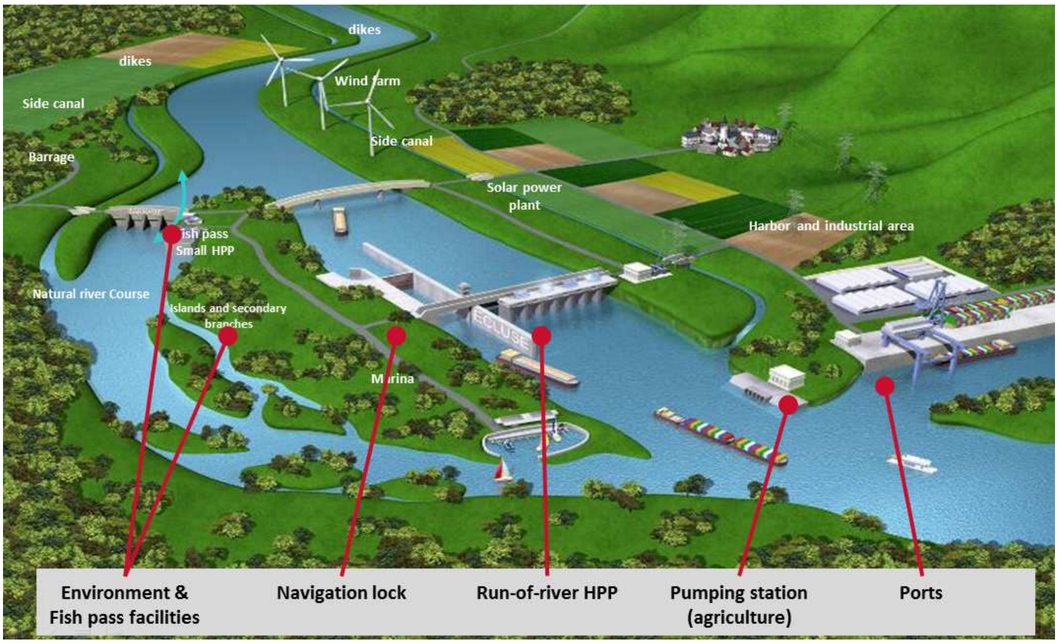

Fig. 1. CNR typical run-of-river multipurpose HPP

For nearly 25 years, CNR Engineering has been supporting the sustainable development of the Mekong River in close relationship with the Mekong River Commission (MRC) and its Member States (Laos, Thailand Cambodia and Viet Nam), particularly in the field of hydropower and navigation on the Mekong mainstream.

This paper aims at presenting this experience of joint development of hydropower and navigation on a major river. Thanks to its sound experience of integrated river development in both France and abroad, CNR is in a position to share its expertise regarding balance and efficient development of multipurpose HPPs along the same river including run-of-river hydropower generation and non-power interest such as inland navigation.

This paper engages CNR only and not its counterparts along the Mekong River.

2 CHRONOLOGY

CNR Engineering brings since nearly 25 years in Laos its know-how in terms of design and operation of hydroelectric run-of-river development.

In 1994, CNR Engineering did the master plan of the Mekong River for MRC. This Master Plan is still the reference study regarding Mekong River development.

Then in 2009, CNR Engineering carried out on behalf of the Government of Laos (GoL) the optimization study of the hydraulic and hydropower generation of five facilities planned on the Mekong mainstream upstream Vientiane in Laos. This study aimed at optimizing the cascade of 5 HPPs as a whole in the interest of GoL instead of an optimization project by project. This is still the reference study regarding the final design of the 5 corresponding projects.

Then, following a request of the Ministry of Energy and Mines (MEM) of the GoL, CNR Engineering assisted the developer of the Xayaburi project regarding hydrometeorology monitoring and forecasting, navigation and sediment management in order to optimize the design and to prepare operation phase. Xayaburi project consists of a power station totaling to an installed capacity of 1,285 MW and expected yearly energy production of more than 7,000 GWh. Furthermore, the project features a two-stage navigation lock, a spillway with 7 surface gates and 4 low level outlet gates, which have been designed specifically for the purpose of releasing sediments, and an intermediate block. Extensive provisions for both upstream and downstream fish migration have been included (figure 2).

Fig. 2. General overview of progress of work as of January 2018 (photo: Marie Keller) From left to right: lock, spillway, low level outlet, intermediate block, power house and fish facilities

Xayaburi HPP is the first of the five HPP under development on the Mekong River upstream Vientiane. End of 2017, its construction was nearly 90% completed. The project and its final design are considered as a benchmark by the GoL and provide the minimum requirements every other mainstream project should feature. In particular, Xayaburi navigation lock has been the first lock to start operation on the Mekong River downstream China mid of 2015.

From 2015 onwards, CNR Engineering has also been entrusted by the MEM in several other missions:

- projects feasibility study (FS) reviews for 4 HPPs (Pak Beng, Pak Lay, Sanakham and Phou Ngoy) ensuring the consistency of the cascades design along the Mekong River and checking the quality of the design regarding hydrology, dam safety, sediment management and of course navigation;
- construction monitoring for Don Sahong HPP in the south of Laos as GoL Contract Engineer;
- FS of a Coordination and Monitoring Center dedicated to the coordination of operation and maintenance of all the multipurpose HPPs in Laos.

3 THE CASE OF MEKONG RIVER DEVELOPMENT

3.1 General outline of the cascade

The Lower Mekong River is a large potential source of energy. But, as in all lower courses of large rivers, development must respect other non-power water interests, notably navigation, and avoid, as much as possible, population resettlement.

Development of major rivers by realization of run-of-river cascades demonstrated its capacity to optimize services while limiting environmental and social impacts.

It is in this spirit and based on the model which has been proven on the Rhone River in France, that CNR conceived the overall hydropower development of the Lower Mekong, in 1994, on behalf of MRC.

The overall project concerned a 2300 km river course, from Chiang Khong (North of Thailand) to Phnom Penh (capital of Cambodia in the South), including the notable singularity of the Khone Phapheng waterfalls, 400 km north of Phnom Penh.

From Chiang Khong to Khone Phapheng waterfalls, corresponding to a river length of around 1600km, the total elevation gap is around 280 m. This gap has been split into 10 major steps.

The design of the Mekong cascades and of each site was done in order to:

- Minimize projects impacts on both downstream and upstream communities;
- Minimize the physical changes of the natural river regime;
- Comply with up to date standards of safety;
- Provide facilities which can be operated economically and safely, in harmony with other activities along the river;
- Provide lock facilities for passage of river boats and barges, taking into account future improvement and development of inland navigation;
- Provide appropriate facilities to support fish passage;
- Provide facilities for sediment routing, so that the natural sediment regime of the river can be maintained after projects commissioning;
- Provide practical and efficient facilities for electricity generation.

In this scheme, each step offered the opportunity of wide gauge navigation development on a great length of river (160 km on average), provided that a lock be built at each dam site, with an average drop of an acceptable order of magnitude (28 m).

In 2009, the Optimization Study of Mekong mainstream run-of-river hydropower, performed by CNR on behalf of the Lao Ministry of Energy and Mines, was dedicated to the formulation of an optimized scheme, from a hydraulic and power generation point of view, for the part of the cascade (5 sites) located in Lao PDR, upstream Vientiane. This study confirmed the spatial arrangement of the cascade, with some refinements regarding operating water levels to limit impacts on the riparian territories.

At present, on the course of the Mekong River in Laos, the construction of Xayaburi hydropower development is nearly 90% completed; Don Sahong HPP is under construction and shows progress of around 40%.

3.2 Design of the navigation guidelines for the MRC

In 2008, CNR Engineering was entrusted by MRC with a study dedicated to propose guidelines for planning, design, construction, and operation of navigation locks in relation with development of hydropower projects on the Lower Mekong Mainstream.

MRC wished to define good practices for the planning and design of the navigation locks within the Lower Mekong Basin context with the aim that, as far as possible, the development of hydropower projects on the Lower Mekong Mainstream would have a positive impact on the improvement of the navigation conditions.

The main challenge was how to set the size of the locks without traffic forecast, while preserving the potential development of navigation on the long run and not overburdening private hydropower developers. Indeed, hydropower development is an opportunity to develop navigation. Without hydropower development, there is no option for navigation improvement. But private developers have to bear all the costs related to navigation.

The first step of the study was devoted to benchmarking, especially with large rivers in Europe, which led to some key lessons:

- Hydropower developments on large rivers could finance wide gauge locks, sometimes with the support of public funding;
- Close coordination in the design, construction, maintenance and operation of locks and channels associated with “run-of-river” hydropower developments is essential;
- Hydropower developments provide an impetus for the construction of navigation facilities, but the increase in waterborne traffic may be gradual (20 to 30 year horizon);
- Impounded stretches and “natural” free-flowing channels may coexist along a river for a long period of time.

The second step consisted in taking into account navigation conditions, existing waterways or ongoing projects, upstream and downstream.

Upstream, consistency with the planned improvement of the Lancang / Upper Mekong in China was mandatory, with long term planned capacity of 4 x 500 DWT convoys.

Downstream, an important network of wide gauge waterways is operated in the delta of the Mekong River but the Khone Phapheng waterfalls at the border between Lao PDR and Cambodia currently present a physical obstacle to navigation. This is the reason why Don Sahong HPP located close to Khone Phapheng waterfalls in Sipandone does not feature any navigation lock.

Tentative proposals for lock dimensions and performance were made, taking into account long term vision (especially in this region of strong economic growth), sustainability, high reliability and consistency of projects along the Mekong Mainstream.

Considering waterway traffic capacity, and without any available global transport study, it was recommended that the envisaged hydropower developments include, at first stage, ship locks accommodating medium term traffic (i.e. 5 million tons per year as an order of magnitude) and allowing for future lock system expansion.

The design vessels envisaged was based on Chinese standards class IV (2 x 500 DWT) vessels, with a single line of barges (109 m x 10.8 m x 1.6 m). It was proposed to raise the draft up to 2.5 m, in the perspective of comprehensive development of the river with dams and complete impounding of the river.

Given current lock technology and taking into account reliability and life cycle costs (investment costs and maintenance costs), it was strongly recommended to limit the maximum hydraulic head of a single chamber to 30m, while the option of tandem locks (two-step locks) was considered to be a better alternative than ship lifts for crossing height differences greater than 30 m.

Emphasis was given to the coherence at river scale of transit time of each lock system, either with single chamber locks or two-step locks, leading to specifications for total lockage time (30 mn for a single chamber lock and 50 mn for a two-step lock) and for safe and smooth emptying/filling operations.

MRC issued the navigation part of its “Preliminary Design Guidance for proposed Mainstream dams in the Lower Mekong” in 2009 on these bases.

39 m high lock of Xayaburi hydropower project has been commissioned mid of 2015 according to these guidelines.

MRC guidelines are currently being revised but at the time this paper is written, the final version is not available.

3.3 Xayaburi hydropower project

In order to allow the vessel transiting the Xayaburi HPP, a two steps lock complex has been designed with a maximum head of 39.0 m for lF/E operations between the 2 lock chambers and 19.5 m for F/E operations between a lock chamber and upstream/downstream pond. Each lock chamber size is 120 m long by 12 m wide and has a minimum draft of 4 m.

CNR carried out an independent review of the lock design and released a set of recommendations in order to help the design to comply with MRC guidelines and to improve the navigation issues.

The main recommendations were dealing with the following items:

- Review of the number and dimensions of the filling & emptying system (F/E) components (culverts and ports) in order to improve the flow distribution,
- Review of the valves size and assessment of cavitation occurrence,
- Review of the water intake and outlets geometry in order to improve the flow distribution and reduce head losses,
- Assess the maintenance easiness of the filling & emptying system and bring modification in order to improve the limitation of the lane outage.

The review was performed on the basis of the MRC guidelines and was supported by implementing a 3D numerical model.

3.4 The other hydropower projects

Among the projects identified in the Mekong Master Plan in 1993-1994 and on behalf of GoL, CNR has been involved in the review of the following HPPs:

- Pak Beng HPP: this project is the northern most of the Low Mekong Basin dams. The project features a dam of 64 m height enabling a normal water level at 340 m asl, a 32.0 m navigation lock with a single lock chamber, spillway, fish passage and the powerhouse. The installed capacity is 912 MW.
- Pak Lay HPP: this project is located around 240 km upstream Vientiane. It is located downstream the Xayaburi HPP and upstream the planned Sanakham HPP. The project features a dam of 52 m height enabling a normal water level at 240 m asl, a 21.0 m navigation lock, spillway, fish passage and the powerhouse. The installed capacity is 770 MW;
- Sanakham HPP: this project is located on the mainstream of the Mekong River, 155 km upstream Vientiane. The project features a dam of 56 m height enabling a normal water level at 220 m asl, a 20.6 m navigation lock, spillway, fish passage and the powerhouse. The installed capacity is 660 MW;
- Phou Ngoy HPP: this project is located in the south of Lao PRD, 15 km downstream of Pakse city. It is the last project located upstream Khone Phapheng waterfalls. The project features a dam of 44 m height enabling a normal water level at 98 m asl, a 11.3 m navigation lock, spillway, fish passage and the powerhouse. The installed capacity is 728 MW.

For these 4 projects, CNR has been charged by GoL to review the FS regarding:

- Hydrology,
- Dam Safety,
- Sediment Transportation,
- Navigation.

CNR review takes place at the Lao level before submission of the project to MRC. The purpose of this internal review is to control the compliancy level of each project on the 4 above-mentioned topics in comparison with international standards, including but not limited to MRC guidelines. For the first three topics, international standards are based on ICOLD bulletins about safety of dams, World Bank operational policy on safety of dams, and international best practices regarding monitoring and modelling. For navigation, in addition to the MRC guidelines, CNR uses the European standards as well as the PIANC recommendations stemming from the available reports.

The main issues controlled and addressed by CNR regarding navigation during the reviews at Lao level are as follows:

- Lock design:
  - General design such as head, length, width that must fulfil specific requirements for navigation on the Mekong mainstream,
  - Design of the filling and emptying system,
  - Control of its hydraulic performances (lockage time, flow velocity in the culvert…),
  - Analysis of forces exerted on the vessel,
  - Risk of overfilling or over emptying of the lock if any;
- Lock approach and alignment:
  - Flow conditions both upstream and downstream for the range of discharge values corresponding to the operation of the lock,
  - Safety of access both upstream and downstream,
  - Length of guiding walls both upstream and downstream,
  - Sediment deposition in upstream and downstream approach channels and corresponding mitigation measures;
- Comparison between calculation on hydraulic modelling and measurements made on 2 physical models (scale 1/20 for the F/E system and scale 1/100 for the approach conditions);
- Maintenance, safety and operating policies taking into account both the coordination in the design and future operation

Usually, Developers are quite familiar with design and construction stages but the standards are not always fully appropriate or compliant with MRC guidelines for navigation.

Regarding operation of the project and, more precisely, operation of a navigation lock located in a cascade of dams, there is most of the time a lack of capacity and experience on the Developers side whereas it is important to keep in mind at design stage the future operation of each HPP, including their respective navigation locks.

By operation, we mean the follow-up of run-of-river concept, the definition of an appropriate operation pattern for the project and the management of the transparency of the project regarding flow, sediment and boats (considering only the 4 topics addressed by CNR) in order to ensure the safety of people, boats and dams whatever the inflow is.

The fact that the above mentioned HPPs are being developed by Independent Power Producers (IPP), has made the GoL aware of the need to set up a state agency dedicated to the coordination and the management of all the multipurpose hydropower plants implemented in Lao PDR. Regarding navigation in particular, the purpose is to make sure that navigation lock maintenance is coordinated at the level of the whole Mekong River in Lao PDR in order to limit the duration of navigation closure. CNR is currently working on a feasibility study for the implementation of Coordination and Monitoring Center (CMC), supported by its sound experience on the Rhone.

4 WHAT LESSONS FOR THE JOINT DEVELOPMENT OF HYDROPOWER AND NAVIGATION ?

4.1 Hydropower as an opportunity to develop navigation

The development of the waterway in shallow river courses can firstly be ensured by free flowing river training. This type of development, which aims at improving the conditions of navigation in low water by concentrating the flow of the river in a single channel, reaches quickly its limits (draft of the order of 1.5 m / 2m during low flow periods) that are incompatible with the transit of wide gauge boats, only able to compete economically with road and rail.

Finally, in shallow rivers courses, only water level control in low flow periods can ensure opportunities of year-round wide gauge navigation. From this point of view, the realization of run-of-river projects, by creating reservoirs -the lateral extension of which may be limited by dikes- allows the development of such navigation on long lengths of rivers with large draughts.

In lower courses of rivers, to take into account the full potential offered by the development of a river, there is no interest to implement high head dams. On the contrary, a cascade of run-of-river projects is particularly convenient. Navigation crossing is facilitated by acceptable lifts; transit of sediment can be permitted by suitable flushing device (implementation of Low Level Outlets) and good operation coordination.

By creating dams controlling water levels and financing all or part of lock structures, hydropower developments are major opportunities to improve navigation conditions on a river.

But, regarding power generation optimization, as well as impact minimization, operation coordination or navigation conditions coherence, the best method is to globally design the cascade of schemes at the river scale. That is all the more true with a different developer on each site. In that case, it is very suitable to implement a coordination and control body, as it is envisaged on the Mekong River, in Laos.

A second step of optimization has to be done at the scale of each individual site of dam and lock.

4.2 Choice of the lock dimensions

Lock dimensions must be based on a long term vision: length, width and depth can hardly be modified once they have been built and they have most of the time a very long service life (generally about 100 years). Lock chamber dimensions fix the design vessel for the connected waterways.

Another important point is the coherence at the regional level: existence of regional standards, or design with a view on further standards.

Technical- economical aspect should also be born in mind: total lock cost has to be compared with future transit projections to evaluate the general interest of the investment. Usually, considering only navigation transit issue is not enough profitable. Total additional cost of navigation works should be acceptable for the hydropower plant developer owner.

So, it is understandable that lock dimensions associated to hydropower is the result of a compromise between the performance and safety for navigation on one hand, and the acceptable financial effort for the hydropower developer on the other hand, especially on a river where industrial navigation is emerging.

4.3 Recommended design dispositions and guidelines

According to our experience, the guidelines with respect to navigation issue should be organized according to 9 major items detailed hereafter:

- General requirement

Give to the developer the definition of the different operating level and discharge that are required in upstream and downstream pond (as Lowest Navigable Level (LNL), Mean High Navigable Level (MNL), and Highest Navigable Level (HNL) in order to standardize these data for every project.

- Dimension and design vessel

Fix the lock dimension and layout and specify the design vessel for which the lock structure has to be studied and built.

- Lockage time and availability

Give the target filling and emptying time, specify the lock minimum availability and the maximum lock outage to be allowed. Give also the maximum allowable water slope and thus the acceptable level of forces exerted on the design vessel during a lockage. This second issue being in total opposition to the first one, indeed the faster the lock is filled/emptied, the greater will be the turbulence in the lock chamber and consequently the forces applied on the vessel.

These guidelines are very important since they permit determining the daily throughput and thus the transit capacity of the lock system. The main difficulty is obviously to set targets suitable to the navigation context, either for F/E time or for the water slope threshold value. Indeed too stringent requirement would lead to over design the lock F/E system and would severely increase the construction and operating costs.

- Location and alignment

Fix the required layout (such as the features of the guiding wall for instance) of upstream and downstream channels in order to ensure a safe approach from both sides for the design vessel. The designer has to study and take into account the natural flow fields and the man-made currents stemming from the HPP and/or the spillway operations. He has to check that the longitudinal currents, and cross-current do not exceed respectively 0.5 m/s and 0.3 m/s in lock approach channel (according to European standards). The sediments issues, especially the risk of major deposit in the lock approach channel and their management, are also addressed.

- Construction

Ask the designer to assess the navigation condition during the construction period (increase of the flow velocity due to the construction cofferdam for instance), to propose mitigation or alternative to keep the navigation and the goods transit going on during this period.

- Service life

Specify the functional life time of lock structure and lock equipment.

- Expansion

Specify the layout requirement for implementing a second lane of lock if needed in the future.

- Chamber equipment

Detail the minimum equipment to be implemented in the lock chamber such as bollards, ladders and gate protection device.

- Design, operation, safety and maintenance

Specify the requirement for issues such as lock access, control and command system, emergency accesses, redundancy in lock components, environmental impact. These items are generally not very well addressed by the developer in the design phase since they deal with issues that appear to be far away from the concern related to the design of the structure. They need anyway to be looked at with attention since they may lead to major modification of the design in its late stage.

Each lock being designed by a different developer, the introduction of such guidelines is of utmost importance in order to standardize the quality of every scheme. It also allows to check every design at the same level and to make consistent the lock structures along the full cascade on the river.

5 CONCLUSION

CNR has contributed and is currently still contributing to all these stages of joint development of hydroelectricity and navigation on the Mekong River, first on behalf of the MRC and nowadays on behalf of the Government of Laos.

This experience shows that run-of-river hydropower developments provide an impetus for the construction of navigation facilities over a great length of a major river, provided that the cascade of schemes is globally designed at the river scale, keeping in mind the coherence of operation conditions all along the future waterway.

In this aim, the implementation of common guidelines for navigation facilities are of utmost importance, especially for the design of locks which are major and costly structures which can hardly be modified once they have been built and, then, condition the maximum dimensions of the vessels. These guidelines allow standardizing the quality and performance of each lock system. This is all the more true when every scheme is designed by a different developer, which is the most frequent scenario.

When a new development is launched, in the framework of the overall cascade scheme, a second step of optimization has to be done at the detailed design level, taking into account the performance and safety for navigation, on the one hand, and the total cost of the project on the other hand.