IWPP PROJECTS: A CHALLENGE FOR THE OPTIMIZATION OF COMBINED POWER / WATER PLANTS

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Abstract

Looking back just to few years ago, we can see how many aspects in the desalination market have been rapidly changing. Among them, one of the most representative for the market trend is the more and more growing interest by the clients for IWPP projects rather than for conventional bids. In an IWPP project the most competitive bidder is the one who can guarantee the lowest selling price for the water and the power throughout the whole plant life, and not the designer of the most economical desalination / power plant only. This leads desalination and power contractors to coordinate their joint efforts looking very carefully to each other needs and constraints.

The paper presents an analysis of the subsequent levels of optimization necessary to achieve the minimum water and power price, moving from conceptual choices (overall plant configuration, selection of technologies, etc.) to the optimization of the single equipment, always focusing on the final common target. Some practical examples inspired by real cases are presented for a better comprehension of the “integration” concept taken as an attitude, an issue which is going to become more and more a key winning factor for the future bids in the market.
I. INTRODUCTION

Like in many other world markets, also in the desalination / power plants business Requests For Proposal (RFP) are issued by Clients to allow Companies to participate to Tenders and submit their technical and economical proposal according to the Clients requirements. However, in the field of our interest, a new type of Bid is presently coming along with the Conventional ones: the so-called IWPP. Since these kind of projects, whose details will be better explained in the following, are taking more and more space in the desalination / power plants market, new strategies have to be set forth by the Bidders to assess their competitiveness. This goal can be reached by a careful analysis and optimization of the plants considered as a unique system, and not anymore as two separate and somewhat independent single plants.

II. CONVENTIONAL VS. IWPP

2.1 Some Basic Concepts

By all means, RFPs are issued by Clients towards Bidders in order to build a new plant (or an extension of an existing one) to produce potable water and/or power. In most cases, of course, power and water plants are combined together, since water can be produced by the water plant using energy (thermal and/or electrical) available by the power plant.

In a Conventional project, Bidders for power plants and water plants are requested to submit their technical and economical proposal for evaluation separately. The coordination between the power bidder and the water bidder is in charge to the Client, and there is a direct connection between the Bidders and the Client itself.

In an IWPP (Independent Water and Power Project), the Client is not going anymore to directly purchase two (power + water) plants from a Bidder selected among the participants, but it’s rather interested to buy the water and power produced by the new plant, and to distribute it on the grid. In this case, an intermediate actor, called Developer or Sponsor, plays a fundamental role in the game; in a few words, the Developer purchases the plant from the Bidders and sells the water and power to the Client.

![Diagram](image-url)
2.2 Some Basic Differences

One of the main differences encountered is in the Tender requirements.
In a Conventional project, since the Client is purchasing the plants, the tender documents show a high level of detail on each single plant-related issue (materials, operating conditions, constraints, etc.), both for power and for water. Moreover, being the water / power coordination a Client’s task, interfaces between the two plants have to be very precisely defined in all respects. These factors lead eventually to poor flexibility and scarce chance for optimization by the Bidders.

In an IWPP, as explained above, the Client is purchasing directly water and power from the Developer; as a consequence, the tender documents issued by the Client are focused mainly on the quantity and quality of water and power, and more freedom is left on how they are achieved. Basically, only reference design conditions (RSC) and environmental constraints are fixed by the Client. These factors lead eventually to higher flexibility and good chance for optimization by the Bidders. The details of plants design and operating conditions choice can be mutually agreed between the Developer and its Bidders trying to reach the best compromise between compliance with Client requirements and Bid competitiveness.

2.3 Some Basic Strategies

Who is the winner in a power / water plant tender? The answer to the question is ambiguous, depending on the type of tender. The evaluation parameters are in fact different if we are dealing with a Conventional project or with an IWPP.

In a Conventional project, since the plant is what is purchased, the first ranked bidder is the one with the lower price for the offered plant, providing it’s fulfilling the tender requirements.

In an IWPP, since water and power are eventually purchased, the first ranked bidder (still providing the fulfillment of tender requirements) is the one with the lower tariff for these two items, which not necessarily corresponds to the cheapest plant.

Using more precise terms, we can say that in a Conventional project only the CAPEX (Investment cost) counts for evaluation, while in an IWPP a combination of CAPEX (Investment cost) and OPEX (Operational cost) is considered.

As a consequence, if in a Conventional project the winning strategy is settled by lowering the CAPEX as much as possible, in an IWPP the winning strategy must take into account several factors, and particularly the CAPEX, the OPEX, the years of plant life and the share between power output/cost and water output/cost.

III. POWER / DESALINATION PLANT CONFIGURATION

3.1 The Possible Choices

There are several possibilities to choose from when the plant configuration has to be selected. From the power plant point of view, the possible alternatives range from the GTs in pure open cycle, to the Boilers + BPST, while for the water plant different thermal technologies (MSF, MED, TVC) can be selected together with a range of possible Performance Ratios, plus the possibility of partial / full water production by RO.

The main parameters to guide the bidder in a first selection of the overall configuration is a key factor in the IWPP projects: the Power/Water ratio.
3.2 The Power / Water Ratio

The Power/Water ratio characterizes how much water can be produced by the seawater desalination and power plant in relationship to the electricity it generates, and depends on the performance ratio of the thermal desalination process that is coupled to the power plant (Fig. 2). Today’s multi-stage flash (MSF) evaporators are designed commonly with performance ratios of 8 to 9. Also usually lying within the same bandwidth are multiple effect distillation (MED) processes, although these in the form of MED-TVC (thermal vapor compression) could certainly be dimensioned for higher performance ratios of up to 12 or higher.

Power/Water ratios of from 17 to 23 are attained within this performance ratio range with today’s combined cycle systems. The lowest Power/Water ratio of between 2 and 4 is exhibited by the BPST configuration. Lying between these extremes are the usual power plant configurations.

But the full bandwidth potential as above is not fully available for a specific desalination and power plant configuration, as it is only designed for a narrow range of performance ratio for the thermal process and for a defined power plant configuration, although operation with or without supplementary firing would add a certain flexibility.

For the inverse of this ratio, the water/power ratios for BPST and HRSG configurations (Fig. 3) exhibit a marked rise of water production with increasing performance ratio. If therefore the emphasis of a projected dual-purpose desalination and power plant is on electricity supply, then a combined cycle configuration should be preferred, but if water is the supply priority, consideration should be given to a boiler/backpressure steam turbine or HRSG variant. This picture changes if alongside thermal processes reverse osmosis is to be applied, as this uses energy for water desalination only in the form of electricity.

IV. TOTAL HEAT CONSUMPTION (THC) AND HEAT RATE (HR)

4.1 The THC

This parameter is specific for the Water Plant, and represents the amount of thermal energy (in kJ/s) necessary to produce one kilogram of distillate water. Hence, despite its name (total), it constitutes an indication of specific consumption. Due to this, the THC is strictly connected to a very well known basic parameter of a desalination plant: the Performance Ratio (PR).
In fact, being $THC = \frac{Q}{D} \left[ \frac{kJ}{s/\text{kg}_D} \right]$ and $PR = \frac{D \cdot 2326}{Q} \left[ \frac{kg_D}{kJ/s/\text{kg}_V} \right]$, we have:

$$THC = \frac{2326}{PR} \left[ \frac{kJ/s}{\text{kg}_D} \right]$$

### 4.2 The HR

This parameter is specific for the Power Plant, and represents the amount of energy from fuel (in kJ/s) necessary to produce one kiloWatt of electric power. As per the THC, also the HR constitutes an indication of specific consumption, relevant to fuel, and can be easily calculated as follows:

$$HR \left[ \frac{kJ}{kWh} \right] = \frac{F \cdot LHV \cdot 3600}{P} \left[ \frac{kg_f/s}{kJ/s/\text{kg}_f} \right]$$

where:
- $F$ = fuel consumption
- $LHV$ = fuel low heating value
- $P$ = electric power

### V. CAPEX, OPEX AND OTHER PARAMETERS

Either we deal about power, water or a combination of the two, we always have to take into account that two different values are going to affect the real plant cost: the investment cost (CAPEX), constituting the capital expenditure necessary to design, build and assemble the plant with all of its parts before it starts to produce water and/or power, and the operational cost (OPEX), representing the sum of the costs necessary to operate the plant for many years after it has started to produce water and/or power. Both these costs are strongly influenced by the above described parameters.

#### 5.1 The CAPEX

- Water plant

When we design a new water plant constituted by several desalination units, we know that the investment cost of each unit will be higher or lower if we choose units with low THC (high PR) or high THC (low PR). A first level of optimization starts then when we think to the CAPEX of the whole water plant and not to the single units only: in fact, despite the higher cost of high PR units, we may realize that in some cases they might allow savings in other parts of the plant. For example, given the environmental constraint of a maximum sw temperature rise, the higher the units PR, the lower the sw amount needed, with corresponding savings in everything which pertains to the sw intake and discharge system (civil works, pumps, piping, valves, etc.) (Fig. 4a).
Dealing with power, after the type of plant configuration has been selected, we have to think about the type of machines to be installed. A basic difference between water plant and power plant comes from the fact that the size of some power plants components available on the market are fixed, while desalination units can be customized for each and every need. The choice of a more expensive configuration and/or cost impacting high efficiency machines and equipment leading to low HR values increases by all means the power plant CAPEX (Fig. 4b).

5.2 The OPEX

- Water plant

As far as the operational costs are concerned, higher PR units can assure a lower operational cost of the plant due to the lower energy consumption throughout the lifetime of the plant (Fig. 5a).

- Power plant

Here is where the role of HR comes out. For a power plant, the choice of a configuration and/or high efficiency machines and equipment leading to low HR values can give a lower operational cost of the plant due to the lower fuel consumption throughout the lifetime of the plant (Fig. 5b).
5.3 The NPV

In order to account for the fact that the CAPEX is a one-shot investment at the beginning of the project, while the OPEX is a continuous expenditure distributed over the whole lifetime of the plant, we need a parameter to assess the real overall cost that’s not simply the sum of CAPEX + OPEX. This parameter is represented by the plant Net Present Value (NPV).

The NPV is the right figure to be considered when we want to compare the cost effectiveness of two or more possible solutions for a plant. In fact the NPV, given a lifetime period and an interest rate, represents the money that we have to invest now to cover the all the costs of the plant until the end of its life. The definition of NPV is:

\[
NPV = CAPEX + OPEX \cdot \frac{(1+i)^y - 1}{(1+i)^y \cdot i}
\]

where:
- \(NPV\) = Net Present Value [\$]
- \(CAPEX\) = Investment cost [\$]
- \(OPEX\) = Operational cost [\$/year]
- \(i\) = Interest rate [%]
- \(y\) = Life period [years]

VI. HOW TO MINIMIZE THE COSTS

The analysis of the effects of THC and HR on water cost and power cost respectively, and consequently on the overall Power + Water cost, represents an interesting exercise which allows to better understand the concept of joint optimization in IWPP tenders.

6.1 Effects of THC and HR on the Overall Costs of Power and Water

- Water plant

On top of all, the choice of the desalination technology to be used plays a fundamental role in optimizing the water costs depending on the quantity and quality of energy available.

A second level of optimization starts when we think not only to the plant investment cost (CAPEX) but rather to the overall cost (CAPEX + OPEX) of the water plant throughout its life. In this case, a higher value of the investment cost due to higher PR units can be compensated by a lower operational cost of the plant due to the lower energy consumption throughout the lifetime of the plant (Fig. 6a).

Figure 6a: Water costs vs. PR

Figure 6b: Power costs vs. HR
- Power plant

As for the water plant, also the power plant is constituted by several power units, and again we know that the investment cost for a given net power output can significantly change according to several factors.

Again, the choice of the plant configuration to be used plays a fundamental role in optimizing the power costs, but in this case it has to be defined focusing also on the water plant requirements, as we’ll see later.

The second level of optimization starts again when we try to minimize also for the power the overall cost (CAPEX + OPEX) of the plant throughout its life. In this case, the choice of a more expensive configuration and/or cost impacting high efficiency machines and equipment leading to low HR values can be compensated by a lower operational cost of the plant due to the lower fuel consumption throughout the lifetime of the plant (Fig. 6b).

6.2 The Overall Optimization

It’s now time to stop considering the two plants (power and water) as separate entities, and to start thinking about how to minimize the overall cost of the overall plant (power + water). This is what we can call the third level of optimization.

The two plants are not acting independently, but everything that affects the cost of one of them usually also affects the other one, mostly in opposite directions. To make a practical example, if we increase the Water CAPEX choosing high PR desal units, on the other hand we have a lower Water OPEX, but also a reduction in the CAPEX and OPEX of the Power, since the lower steam demand from the desal units is reflected in more power produced.

The target is to find out what are the parameters of the best power + water configuration in order to reach the minimum cost (investment + operational) for the joint production of the requested net amount of MWs and MIGDs.

As a matter of fact, we can easily see this is not an easy task, considering how many levels of subsequent optimization are needed and how many parameters are involved. To better explain the concepts which the overall optimization should be based on, a simplified but well explaining case study is necessary.

6.3 A Case Study

Almost any possible configuration of a Water / Power plant can be built as a combination of one or more of the following basic systems, according to what is the Power/Water ratio required for the plant (Fig. 7):

![Diagram of plant configurations]

Figure 7: The elements for a possible plant configuration
In most of the cases, for Power / Water ratios in the normal range (10 to 20), the combined cycle configuration is the one which offers the best overall efficiency. So we will base our simplified case study on a system of this kind. The main parameters are shown in Figure 8.

![Figure 8: Calculation basic parameters for a Combined Cycle](image)

The example is based on an hypothetic plant capable to produce 100 MIGD net of potable water together with 1,500 MW net of electrical power (Power/Water ratio = 15). Calculations have to be carried out at different values of PR in order to minimize the NPV of the overall plant.

In Figure 9 the results for low PR (7) and high PR (10) are reported. It should be noted that auxiliaries consumptions of power by the water plant and of water by the power plant have to be considered. Overall CAPEX and OPEX are calculated for the different cases, and finally the plant NPV is evaluated.

![Figure 9: Two sets of results at different PR](image)
To reach our target, it's necessary to find out the behavior of NPV vs. PR. By several runs we can create the following table (Table 1) and diagram (Fig. 10), where it appears how a desal units PR of about 9.0 kg/2326kJ gives the minimum NPV for the overall plant, with a saving of severall MUS$.

<table>
<thead>
<tr>
<th>PR (kg/2326kJ)</th>
<th>CAPEX (MUS$)</th>
<th>OPEX (MUS$/y)</th>
<th>NPV (MUS$)</th>
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<td>12</td>
<td>1628</td>
<td>47.7</td>
<td>2035</td>
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Table 1

VII. POSSIBLE IMPROVEMENTS

The IWPP projects constitute the best chance to study and apply new ideas and solutions to desalination plants aimed to reach the optimum performances evaluated like in the example above with remarkable cost reductions. In fact, the freedom given by a situation where the Client is mainly interested in buying water and power allows bidders to propose to the developers new technical solutions to be sometimes applied for the first time.

7.1 Mechanical Improvements

Some important cost items in a plant can be reduced on the basis of long term experience of the bidders about material behavior through many years of plant operation. As far as the evaporator body is concerned, for example, a tailored selection of materials for the different sections of a distiller, ranging from duplex stainless steel to integral or cladded steel, can significantly reduce the cost of the structure, while assuring the presence of the right material for each service. As far as the tube bundles are concerned, a slight reduction of tubes thickness can be envisaged, positively influencing the costs without affecting the reliability and lifetime duration of the plant. Other plant sections can be reconsidered from the materials point of view, as for example piping and valves, where the application of proper materials, sizes and thicknesses together with the avoidance of useless redundancies can lead to considerable cost reductions.

7.2 Operational Improvements

While the mechanical improvements described above have an impact on the plant investment cost, also several new solutions relevant to operating conditions are possible to achieve a reduction in the plant operational cost as well. One of these possible improvements is constituted by the plant operation at TBT higher than the normally adopted ones. In this way, for a given distillate production and performance ratio, the plant designed for high TBT operation results more economical in many aspects (heat exchange surface,
piping, pumps, etc.), while the present status of the technology about chemical additives and OLTC systems allows a totally safe and reliable operation at increased thermal levels. Other possibilities are in the application of particular pre-treatments to the seawater fed to distillers, like NF, capable to selectively reduce the salt content so enhancing the evaporators overall performances, or even design modifications of some parts of the distillers according to the new frontier of the so called Advanced Technologies.

VIII. CONCLUSIONS

From what presented in the paper, it is clear that IWPP projects, when compared to conventional ones, represent both a hard challenge and a promising opportunity. The challenge lies in the fact that the water + power tariff economical optimization, necessary to win the bid, is extremely difficult and requires the joint and well coordinated efforts of power and water specialists. Despite the simplicity of the case study presented in the paper, we do hope to have given an idea of the high complication of this task and of the huge amount of variables involved.

The opportunity is represented by the higher number of technical degrees of freedom available to the designers, who only must basically fulfill the requirements of plant outputs while matching few environmental constraints. In such a scenario, it is possible to think, develop and apply new ideas which, if proven effective by the experience, can become the future standards in power and water production business.

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IWPP Projects: A Challenge For The Optimization Of Combined Power / Water Plants

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DESALINATION MARKET TREND

Growing interest of the clients for I.W.P.P. rather than for the conventional projects.

I. Independent
W. Water and
P. Power
P. Project
PROJECTS

Conventional

- Power Bidder
- Water Bidder

Power plant

- Client

Water plant

I. W. P. P.

- Power Bidder
- Water Bidder

Water / Power plant

Water + Power

Developer

Client
### DIFFERENCES

<table>
<thead>
<tr>
<th>Tender Requirements</th>
<th>Conventional</th>
<th>I.W.P.P.</th>
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<tr>
<td><strong>Purchase</strong></td>
<td>Plant</td>
<td>Power / Water</td>
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<tr>
<td><strong>Tender Requirements</strong></td>
<td>Very precisely defined</td>
<td>Focused mainly on quantity &amp; quality of power and water</td>
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<td></td>
<td>Poor flexibility</td>
<td>Best compromise between requirements and competitiveness</td>
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<td></td>
<td>+</td>
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<td></td>
<td>Scarce chance for optimization</td>
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STRATEGIES

- Conventional
  - Lower price for the offered plant
  - Only CAPEX counts for evaluation

- I.W.P.P.
  - Lower tariff for power and water
  - A combination of CAPEX and OPEX is considered
DEFINITIONS

- **CAPEX** = CAPital EXpenditure ➔ one shot investment

  Investment cost, constituted by the necessary expenditures to design, built and assemble the plant with all its parts.

- **OPEX** = OPerational EXpenditure ➔ continuous cost, whole lifetime of the plant

  Operational cost, representing the sum of the costs necessary to operate the plant for many years after it has started the production.
CAPEX: One shot investment.

OPEX: Continuous expenditure distributed over the whole lifetime of the plant.

The parameter representing the Real Overall Cost is not $\text{CAPEX} + \text{OPEX} \cdot \text{years}$, but NPV.
NET PRESENT VALUE

- **NPV** = it’s the right figure to be considered for comparing the cost effectiveness of two or more possible solutions of plant.

It represents the money that we have to invest now to cover the all the costs of the plant until the end of its life.

\[
NPV = CAPEX + OPEX \cdot \frac{(1+i)^y - 1}{(1+i)^y \cdot i}
\]

\[
i = \text{Interest rate [\%]} \quad \quad y = \text{Life period [years]}
\]
PLANT CONFIGURATIONS

Power plant

- GTs in open cycle
- GTs + HRSG in simple cycle
- GTs + HRSG + ST in combined cycle
- Aux. Boilers + ST
PLANT CONFIGURATIONS

Water plant

- MSF
- MED
- RO
- TVC
HEAT RATE (HR)

It’s the amount of thermal energy [kJ/s] necessary to produce one kW of electric power on the Power Plant.
HEAT RATE (HR)

\[
HR \left[ \frac{kJ}{kWh} \right] = \frac{F \cdot LHV \cdot 3600}{P} \left[ \frac{kg_F}{s} \cdot \frac{kJ}{kg_F \cdot s} \cdot \frac{s}{h} \right] \frac{kW}{kJ} \cdot \frac{kJ}{kW} \cdot \frac{kg_F}{s}
\]

- F = fuel consumption
- LHV = fuel low heating value
- P = electric power
TOTAL HEAT CONSUMPTION (THC)

It’s the amount of thermal energy [kJ/s] necessary to produce one kg of distillate on the water plant.
TOTAL HEAT CONSUMPTION (THC)

It’s connected to the PR.

\[
THC = \frac{Q}{D} \left[ \frac{kJ}{s} \right] \left[ \frac{kkg_D}{s} \right]
\]

\[
PR = \frac{D \cdot 2326}{Q} \left[ \frac{kkg_D}{s} \right] \left[ \frac{kJ}{kg_v} \right] \left[ \frac{kJ}{s} \right]
\]
POWERS / WATER RATIO

Quantity of electricity generated by power plant vs. the quantity of water produced by seawater desalination plant.

It depends on the performance ratio (PR) of the desalination plant.
POWER / WATER RATIO

The Power/Water Ratio

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WATER / POWER RATIO

Quantity of water produced by seawater desalination plant vs. the electricity generated by power plant.

It depends on the performance ratio (PR) of the desalination plant.
WATER / POWER RATIO

The Water/Power Ratio

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RELATIONSHIP BETWEEN CAPEX, OPEX AND OTHER PARAMETERS

- Power plant
RELATIONSHIP BETWEEN CAPEX, OPEX AND OTHER PARAMETERS

- Water plant
OPTIMIZATION
- First level -

- Choice of the best configuration for the power plant
- Choice of the best desalination technology for the water plant
OPTIMIZATION
- Second level: Power Plant -

Analysis of the overall cost of the power plant throughout its life

Power costs vs. HR
OPTIMIZATION
- Second level: Water Plant -

Analysis of the overall cost of the water plant throughout its life

Water costs vs. PR
OPTIMIZATION
- Third level (overall) -

- Water and power plants are considered as a unique unit.

- The two plants are not acting independently, but everything that affects the cost of one of them usually also affects the other one, mostly in opposite directions.

E.g. If we choose high PR value ➔ Water CAPEX increases but Water OPEX decreases and Power CAPEX and OPEX decrease
CASE STUDY

Combined Cycle configuration is, in most of the cases, the one offering the best overall efficiency.
CASE STUDY

Calculations have to be carried out with different values of PR in order to minimize the NPV of the overall plant.
CASE STUDY

First case: calculation for low PR value
CASE STUDY

Second case: calculation for high PR value
OPTIMIZATION OF PLANT NPV

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OPPORTUNITIES

- I.W.P.P. constitute the best chance to develop and apply new ideas and solutions to desalination plants.

- Aim is to achieve the best performances thanks to the higher number of technical degrees of freedom available to the designers.
POSSIBLE IMPROVEMENTS

- Mechanical improvements
  Knowledge of the material behavior through many years plant operation

- Operational improvements
  New solutions relevant to operating conditions, e.g. TBT

- Configurational improvements
  New solutions relevant to the adoption of hybrid plants
CONCLUSIONS

I.W.P.P.

= hard challenge + promising opportunity

- Hard challenge: the aim is water + power tariff economical optimization, necessary to win the bid = well coordinated joint efforts by power and water specialists

- Promising opportunity: higher number of technical degrees of freedom = possibility to develop and apply new ideas
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Thanks for your attention!!!

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THANKS FOR YOUR ATTENTION

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