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# THE ENERGY ISLAND – AN INVERSE PUMP ACCUMULATION STATION

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## *Summary*

In this paper we describe an innovative concept for an energy storage system consisting of an inverse offshore pump accumulation station (IOPAC). To store energy, water is pumped out from a reservoir, and to deliver energy, water is flowing into the reservoir passing through water turbines. The IOPAC will be stationed on an artificial island at sea, called Energy Island, consisting of a ring of dikes enclosing a 50 meters deep dredged reservoir. The proposed energy storage system will have a maximum generation capacity between 2.000 and 2.500 MW dependent on the water level. The store capacity will be 30 GWh. These design criteria does originate from the capability of the system to handle (most of) the imbalance due to wind energy forecast errors as well as to download wind energy at night.

## *Introduction*

Energy storage can offer several attractive features for electricity production, especially in combination with wind energy. It can compensate unexpected wind power variations and/or store energy during high wind periods at night in order to prevent wasting wind power or conventional units being shut down. Also it can be applied for download “conventional” power during low energy prices and extract power during peak hour prices.
The storage system of interest in this paper is an inverse offshore pump accumulation station (IOPAC) that seems to be capable for these hard tasks. This paper will describe the technical concept first. Thereafter background will be given for the chosen preliminary design specifications of the storage system followed by the conclusions.

## *Technical concept*

The IOPAC will be stationed on an artificial island at sea, called Energy Island, consisting of a ring of dikes enclosing a 50 meters deep dredged reservoir. In figure below an artist impression of the concept is given.

**Figure 1 Artists impression of the inverse off shore pump accumulation station**

The size of the internal reservoir will be 10 x 6 km holding a capacity of 30 GWh. The island can be build from the sand, which will be obtained from deepening the reservoir. In Figure 2 a cross section of the concept is given.

**Figure 2 Cross section of the concept through the turbine**

The intended depth of the reservoir will be –50 m below sea level. The water level of the reservoir will vary between –30 and –40 m. The pump and turbine capability are combined in one pump/turbine system for which a Francis type seems to be most suited. The preliminary design, which will be motivated in next section, does have a maximum pump/turbine power rate of 2.500 MW, existing of 16 modules with a maximum of ~ 160 MW. The efficiency of the pumps and turbines near maximum load is around 90%, resulting in a total efficiency of 81%.

One great uncertainty in the concept, is seawater leakage into the reservoir. For the coast of the Netherlands, thick layers of clay were found, on a right depth (50 m below sea level) and with a good thickness (40 m). This clay layer should be able to resist the ground water pressure at -90 m below sea level. From aside bentonite walls should prevent seawater leakage. Current practice shows bentonite walls till a depth of 60 m.

On the island additional power systems can be build such as wind turbines and safety critical installations (eg LNG). The reservoir on the right of figure 1 is a tidal central, but is only attractive when the difference between high and low tide is strong. Last but not least, it can offer coast protection, a barrier against increasing water level due to climate change.

In this paper we will further be focused on the size of the storage system.

*Optimal size storage system*
The following applications for storage systems are attractive:

1. Regulating power for Program Responsible parties and/or TSO to compensate wind power forecast errors
2. Download capability during high wind periods at night
3. Download capacity during off peak for conventional power plants combined with additional generating capacity during peak load
4. Additional generating capacity during cooling water limitations
5. Primary control.

In this paper we will show our approach for deriving an optimal sized storage system for the first 2 (most important) applications.

Required storage size for wind power forecast errors
We have analyzed the required storage size for wind power forecast errors for 2 scenarios of nominal installed wind power in the Netherlands:
2015: 4.600 MW: 2.200 MW off shore + 2.400 MW on shore

2020: 9.000 MW: 6.000 MW off shore + 3.000 MW on shore

The last scenario is a goal for the Dutch government to have installed in 2020 or at least in 2030.

We have analyzed the size of the forecast faults based on 24 hours ahead and 6 hours ahead forecast. For the imbalance due to the 24 hours ahead forecast we applied real wind speed measurements and forecast made with a Hirlam method. It is the same data set as applied in [1] and [2].

For dimensioning the storage system the following specifications are required for maximum:

- Amount of power consuming / delivering [MW]
- Rate of change capability [MW/min]
- Energy capturing capability [GWh].

Based on the analyses of the yearly data for wind power realization / forecast, we have found the following values. We have showed them as a function of MW, GWh, MW/min. The values are depicted with their confidence intervals of 90% and 98%.

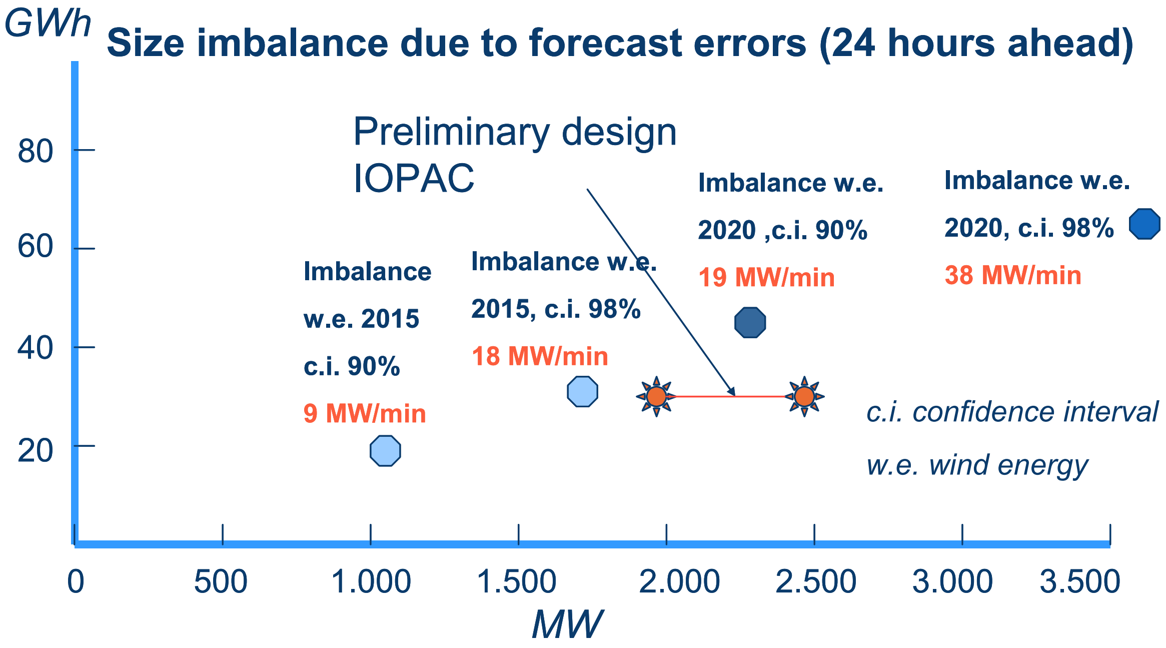

**Figure 3 Summary required size of storage system as a function of the 90% en 98% confidence interval based on forecast errors (forecast 24 hours ahead)**

The MW values are easy to derive; just observing the tailor ends of the cumulative distribution of the yearly imbalance data. Similar the rate of change values. The GWh data gives us information of the persistency of the imbalance, but are more difficult to derive. It was shown that the integrated value of the imbalance is not symmetric, meaning that there is more shortage then surplus. Therefore the system can be saturated soon, which disables its functionality. Also if the integrated imbalance holds more then 8 hours, we can interfere. We did apply the following strategy. We fed the imbalance as input power for the storage system and did operate the system in such a way that it was kept in a capable state of action, meaning around half of its capacity by means of selling or buying power on intra day market. So we did combine the imbalance reduction with market selling/buying actions. At peak hours we did sell power if a surplus was noticed and we did buy power during off peak hours if a shortage was noticed. This seems to be feasible, because a surplus or shortage of energy available in the reservoir can be noticed in advance by simply monitoring the water level of the reservoir. Based this strategy we found GWh sizes as depicted in Figure 3.

The depicted MW- GWh hours are based on the imbalance due to 24 hours ahead forecast. An 24 hours ahead forecast can be used for nominating wind power in the E(nergy) Program. The E-program is made by a Program Responsible party to nominate its power to be supplied / consumed and is submitted to the TSO; time period 24 hrs ahead (more precise 12-36 hrs ahead). Coming closer to the moment now, the Program Responsible party will most probably refine its nomination by means of more accurate forecast and intra day trade actions. We have roughly assessed the impact of these kind of actions. This was done based on [3]: taken the difference in forecast accuracy between 24 hours ahead and 6 hours ahead. From figure 5 of [3], it can be derived that the forecast error (normalized RMSE) is reduced from 14% to 8%. As a rough assumption we did multiply our imbalance values with a factor 0,57 (8/14), given the results showed in figure 4. These values are within the domain of our preliminary design of the storage system.

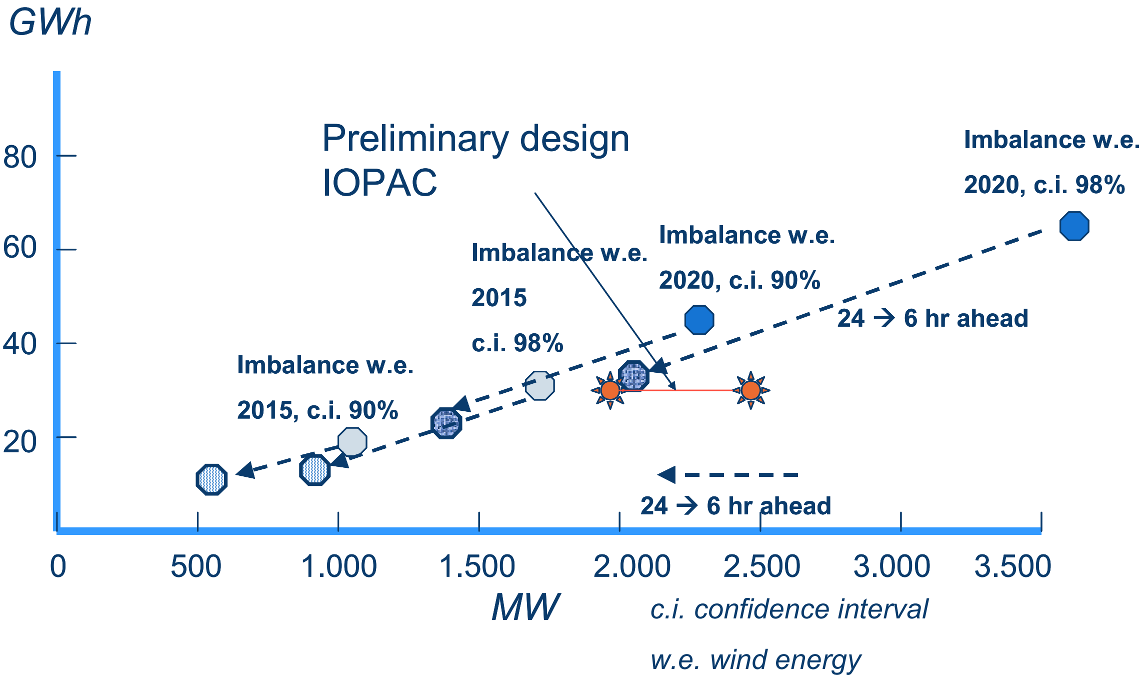

**Figure 4 Summary required size of storage system as a function of the 99,4% en 98% confidence interval based on forecast errors; forecast 6 hours ahead**

<u>Required size for download during high wind periods at night</u>
Another welcome energy storage feature is to download wind power during high wind periods at night. At night, at low load periods, the conventional power units are lowered. If the wind power generation at those periods is high, the conventional units have to be lowered more. This can be done till a certain amount before shutting down the units. Shutting down units (and afterward starting up again) is not economic and should be limited as far as possible. We have analyzed, that between 2.000 MW – 4.000 MW of wind power can be absorbed in the Dutch grid at off peak hours, without additional shutting down power plants. We will further apply an average value of 3.000 MW. Thus, if wind power exceeds 3.000 MW, wind power must be limited, or being absorbed in an energy storage system.

In figure below we do show the yearly wind power production for the 2020 scenario, based on our measurement data set. We have given the night-production above 3.000 MW marked with red and ∗.

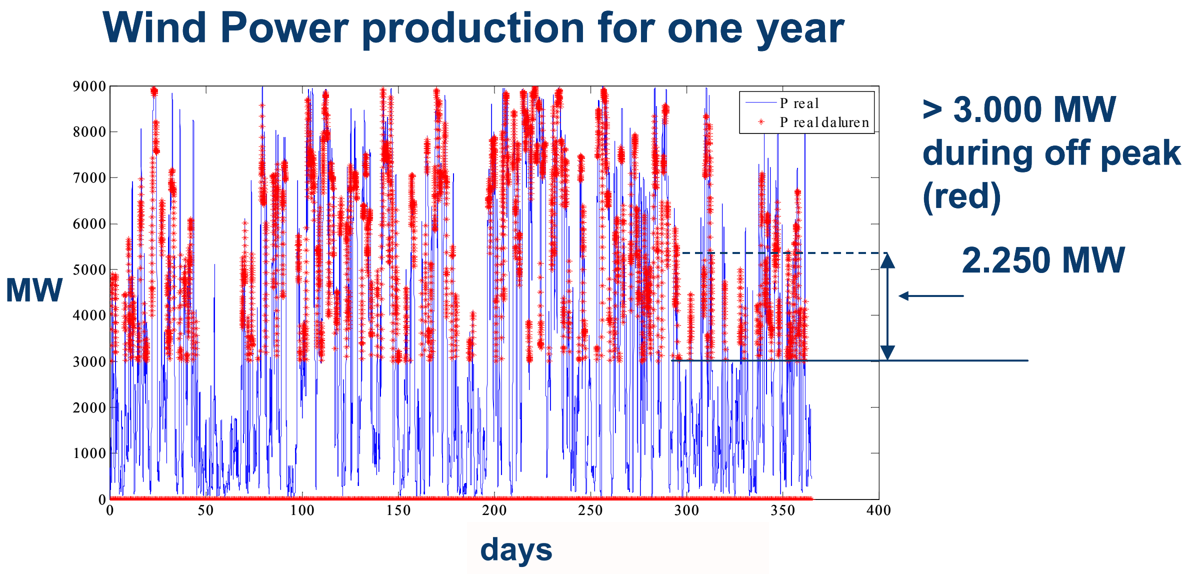

**Figure 5 Yearly power production of a 6.000 MW off shore and 3.000 MW on shore scenario for the Netherlands.**

To dimension the storage system, 6.000 MW could be a maximum value. The energy storage of the preliminary designed (2.000 MW and 2.500 MW) can absorb 2,37E6 MWh (integrations of power within 2.250 MW marge). This can be sold during peak hours, taking into account an efficiency of 81% remains 1,92E6 MWh. We assume that this can be sold for 50€/MWh giving a revenue of 95 M€. If we can absorb more the 2.250 MW, the revenues are higher but will not justify the additional E-connection costs. This trade off and other benefits analysis such as CO2 reduction are still part of a current study.

*Conclusions*

In this paper we introduced our Energy Island, an innovative plan for a large energy storage system. Still part of a current study, we are analyzing the benefits in respect to the costs of additional regulating reserve, download (wind) power, CO2 reduction and coast protection. The first results show that this concept is technical and economical feasible.

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