

Pumped Storage Hydro Plant model for educational purposes

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Abstract – The energy crisis requires more generation capability, and that is why the importance of the storage technologies increases. Up to this time only the Pumped Storage System (PSS) is used in the power system level with great storing capacity. In Budapest Tech a model has been built in the renewable energy park where the idea, the operation and some optimization can be taught.

Keywords – pumped storage, Pelton turbine, hydropower application, education

I. OBJECTIVES

Nowadays the energy supply has a lot of challenges. The renewable sources and the energy storage are important points of the education of the future power engineers.

The pumped storage plant is the only way of the large-scale energy storage. In the campus of the Budapest Tech a model has been built for demonstration purposes. It fits to the wind turbine, solar cells, solar collector, fuel cell, heat pump and microgrid model structure. Through this model can be taught not only the operation of the storage question but also the operation of the power system. Some scheduling optimization methods can be developed too.

II. THE OPERATION OF THE PSS.

In case of the surplus generation capacities, the relatively cheap energy is stored to the upper reservoir of the PPS, otherwise, in case of peak demand or in emergency situation the energy is recuperated with 65-75% total efficiency (see fig.1.).

The construction of the PSS is similar to the other hydro plant that is a Pelton turbine is used for high niveau difference (great heading) and Kaplan turbine is used (reversible) for low headings. The typical storage load is 100-1000 MW and the recuperation is used to run up-to 3000 MW. The cascade river system used to be controlled according to the demand, but the water is not pumped back. The PSS do not affects the natural load curve but it's double face characteristics (load or generator) helps to avoid the unnecessary peak plant construction and also the better utilisation of the existing base power plants.

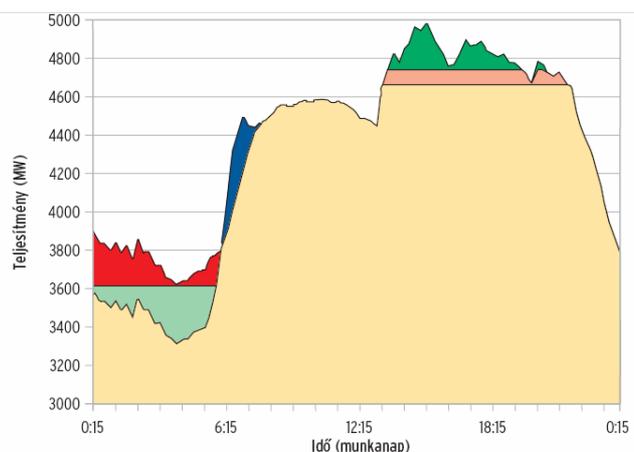


Fig. 1. Daily operation of the PSS [4]

The balance effect of the PSS (see fig.1.):

- Yellow – base load curve
- Cyan – buy (store) of base energy
- Red – buy for overstore
- Blue – help for steep system upload
- Green – sell of the normally stored energy
- Pink – sell of emergency reserve



Fig. 2. The Cierny Váh PSS in Slovakia (Source: GoogleEarth)

III. THE PSS MODEL

In the Budapest Tech on the building of the Power System department a PSS model has been built.

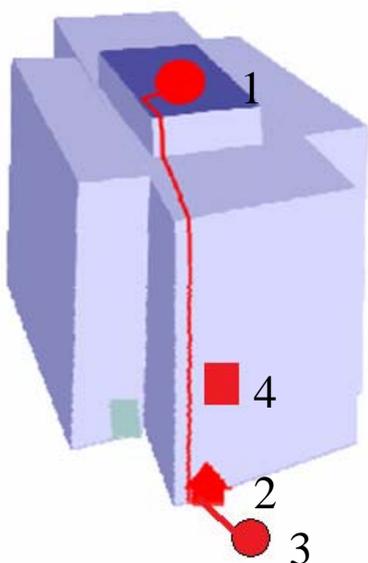


Figure 3.: The development of the pumped storage model

The main elements of the system are

1. Upper reservoir (6th floor)
2. Turbine –generator (1st floor)
3. Lower reservoir (1st floor)
4. Remote control panel (2nd floor)

The LPH0052 type 30 cm diameter Pelton turbine works with 15 m headings, 1000 liters of water, 5 l/s flow, 300 W generator power. The energy storage capacity is 0.045 kWh. The uploading work (230V AC pump) is measured on the panel, and the discharge power (12 V DC) is measured remotely too. This is necessary for the efficiency calculation. The generated energy is fed into the existing Microgrid model. The water level of the reservoirs is measured and signaled on the laboratory panel. The operation can be start/stop by a magnetic valve.

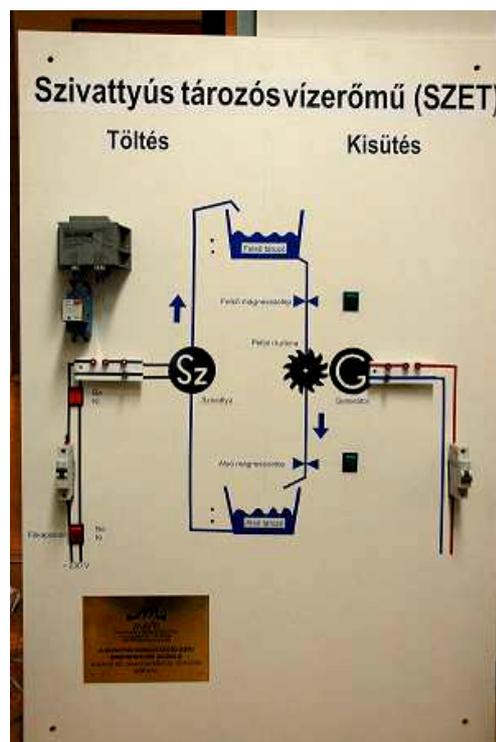


Fig. 4. Laboratory remote control panel



Fig. 5. The Pelton turbine



Figure 6.: The turbine house



Figure 7.: The upper reservoir

The students can investigate the structure and construction of the different elements of the system, as the

- Water level sensors
- Valves
- Pelton turbine
- Pipes
- Storage containers
- Pump
- Stored energy
- Efficiency
- Remote control
- Quick start

IV. THE STORAGE BUSINESS

In our energy park laboratory we are plan to play and test different operation scheduling methods. Let we have as

assumption that the power market is big, our operation has no effects on the market situation.

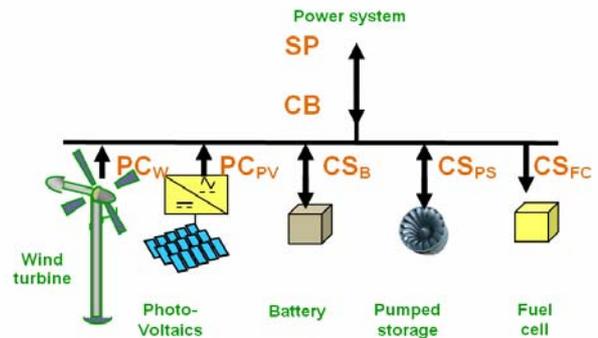


Fig.8. The energy generating/storing facilities in the energy park

The physical tools (see fig. 8.):

- Generation facility 1.: Wind turbine
- Generation facility 2.: PV panel
- Storage facility 1.: Battery
- Storage facility 2.: Pumped storage unit
- Storage facility 3.: Hydrogen generator/fuel cell

The game:

- We generate renewable energy
- We buy cheap energy for storing
- We sell it in peak time

Where the orange marked letters in fig. 8.:

- SP – Selling Price – function of the market
- CB – Cost of Buy – function of the market
- PC_W – Prod. Cost of Wind gen.– function of the actual efficiency
- PC_{PV} – Prod. Cost of PV gen. – funct. of act. eff.
- CS_B – Cost of Battery operation– function of eff.
- CS_{PS} – Cost of Pumped Storage – funct. of act. eff.
- CS_{FC} – Cost of Hydrogen Storage – funct. of act. eff.

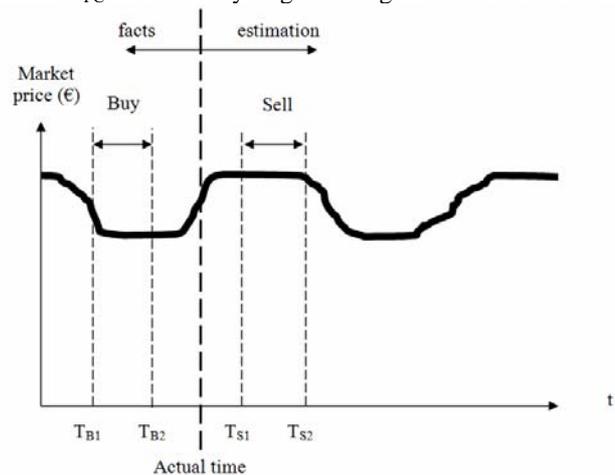


Fig.7. The market price of the energy in time

In the market environment the cost of the energy production and the price of the sold energy are independent. We realize profit if our cost are lower than our incomes. If we can buy cheap energy and we sell it for higher price, the difference must cover our costs and profit. The profit depends only on the difference, but it is not clear what does it mean cheap or expensive. It can be stated only in the future about the past values. If all the prices were fixed, we could make a year-long plan and we could calculate our profit. In the market (or Power Exchange – PX) we can only estimate the future prices. Meanwhile we can have some own generation as wind power or Photo Voltaic generation. This weather dependent generation form can be forecasted for the future.

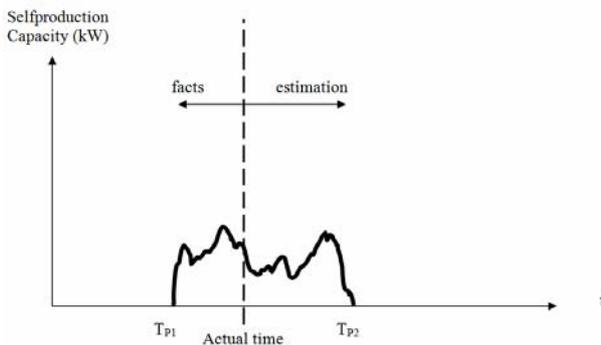


Fig.8.: The renewable production in time

Our objective is to optimize our profit with the following constraints:

- Prices and amount are known only from the past
- Future prices and amounts are estimated

Questions to make decision:

- When to start the buy?
- What is the appropriate amount for buy?
- When to sell?
- What is the appropriate amount to sell?

It is hard to hit a moving target, hard to make an optimization task in a continuously changing environment. The Goal Programming method is closely related to weighted aggregation optimization technique. This method seeks to minimize the deviations among the desired goals and the actual results according to the priorities assigned. [1] The objective function of a goal programming model is expressed in terms of the deviations from the target goals. The common formalization is

$$\text{Minimize } Z = \sum_{j=1}^N w_j |f_j(\vec{x}_j) - T_j|$$

Where T is the target or goal we set for Decision Criteria

In a good turn we realize high profit. In a bad turn (when the night prices stays high and day prices do not go up) our costs are higher than our income.

We set the expected profit minimum to our goal. If we think that we can reach it in the round (buy + generate + sell) then we shall act.

Maximize Profit = Income – Production cost – Storage cost – Purchase cost

$$\text{Maximize } P = \int_{T_{S1}}^{T_{S2}} SP(t) - \int_{T_{FW1}}^{T_{FW2}} PC_W(t) - \int_{T_{FV1}}^{T_{FV2}} PC_{FV}(t) - \int_{T_{BS1}}^{T_{BS2}} CS - \int_{T_{B1}}^{T_{B2}} CB(t)$$

For the simplicity we can calculate with a daily period all the integration can be calculated from 00:00 AM to 12:00 PM.

The main questions:

- When to start a unit?
- When to stop a unit?
- The power level of a running unit
- To store or sell the self generated energy

There is no closed formula to solve the problem but it can be decomposed:

$$P_{\text{MAX}} = \text{Income}_{\text{MAX}} - \text{Production cost}_{\text{MIN}} - \text{Storage cost}_{\text{MIN}} - \text{Purchase cost}_{\text{MIN}}$$

For we have no exact data series about the forthcoming time period, we can set up only a rule base with the following constraints:

- We can sell OR buy
- The charging capacity has min/max limits
- We can charge OR discharge
- The sell/buy has min/max capacity too
- Efficiency of the storage 60-75%

Finally we can recommend some rough and robust rules of thumb for the operation:

Generate AND sell IF

- There is renewable potential AND the PC < SP (we spare the storage cost moreover not only during peak time).

Generate AND store IF

- There is renewable potential AND there is storage capacity AND PC + CS is remarkable lower than SP_{average}

Buy AND store IF

- There is storage capacity AND $CB + CS$ is remarkable lower than $SP_{average}$

Sell IF

- The storage is full AND the SP is remarkable higher than PC
- There is stored energy AND SP is remarkable higher than $CB + CS$

- Remote control
- Generator/pump protection, etc.

The optimization of the schedule is a non definite task so some robust thumb rules can be used.

The energy park of Budapest Tech makes possible to test some operational schedules of the power system operation. In the future we make possible the physical modeling of such schedules. This practical application in the middle of a city makes more colorful and interesting the learning.

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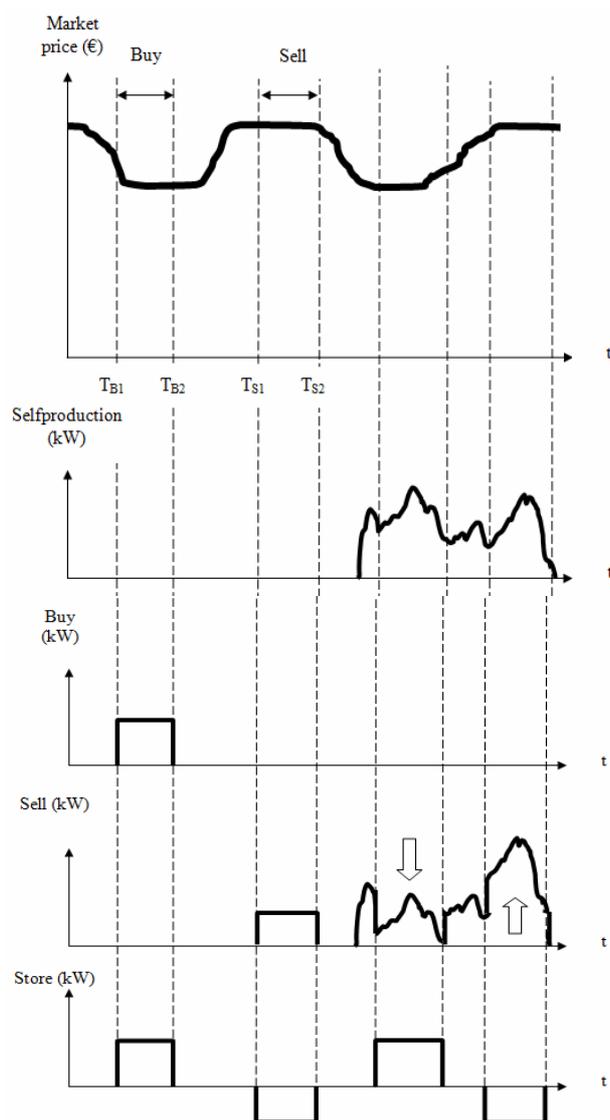


Fig.9.: A possible dynamic operation schedule

V. CONCLUSION

The pumped storage plant model helps the education for teaching the

- Hydro turbine applications
- Energy storage systems

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