PUMPED WATER ENERGY STORAGE

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Summary

This chapter is concerned with pumped water storage plants. These units are mainly to peak-shave daily (diurnal) variations in electrical energy demand. They are useful in storing energy produced as hydraulic potential energy during low demand periods, to be used at peak demand periods, converted back to electrical energy. The excess power at low demand periods is used to pump water from a lower reservoir to a higher reservoir. Later, when needed, the potential energy stored in the upper reservoir is recovered as electrical energy; leading the water back to the lower reservoir, expanding through a turbine. Frequently a single reversible pump-turbine unit acts as a motor-pump unit elevating the water and acts as a turbine-generator unit recovering electric energy back from down flowing water.

There is obviously a loss involved through this conversion process. This loss is mainly composed of line losses, pump and turbine losses, and motor generator losses. The total overall efficiency of the pumped water storage system is the ratio of the energy generated per day to the daily required pumping energy. When suitable water reservoirs exist or can be created, this method of electric energy storage as hydraulic potential energy is highly economical and used throughout the world.

1. Introduction

Although thermal energy can be stored in matter at much larger amounts than mechanical energy, thermal energy can not be converted to work completely according to the second law of thermodynamics. Hence the mechanical energy, especially potential energy, is a convenient way of storing energy in matter, when this energy will be used as work, e.g. electrical energy, subsequently.

Electrical energy utilization is one of the main criteria of social development. However the consumption or demand for electricity changes during a daytime, also along a year. When the demand is low it is called trough; when it is highest, the peak. It is not economic to build new thermal power plants to satisfy the peak demand, because the expensive investment cost will be charged to a short period of peak operation over a year. The easier way is to increase peak hydropower production by pumping up the already flown water back to the high reservoir using cheap electricity of trough periods. Fig. 1 shows the pumped storage and peak hydropower operations. By development of electrical generators which can work as motor and turbines which can work as pump when rotation direction is reversed, investment cost of pumped storage hydropower decreased to half and it became economically more attractive. The net effect is to store the electricity produced during the low demand period, to be used during peak demand.
Pumped water storage is at present the most widely used method of peak satisfaction of electrical power systems.

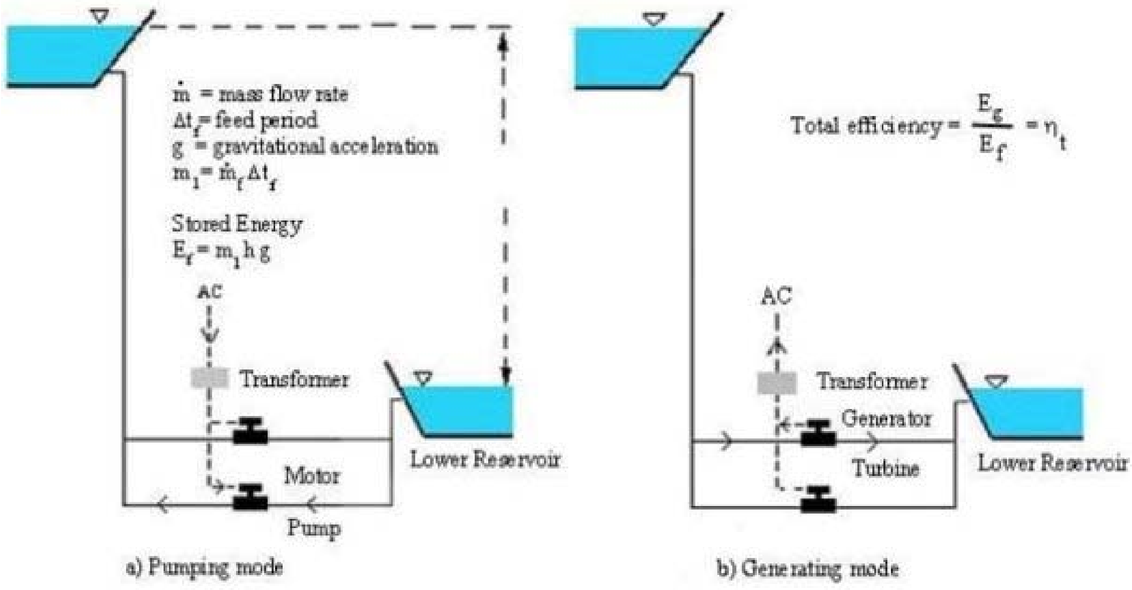

Figure 1: Pumped water storage plant in pumping and in generating modes

2. Matching Demand and Supply in Electrical Power Systems

2.1 Demand Variation

Demand for electrical power is lowest during the night and highest during the morning and especially evening time. In winter, because of increase in lighting, up to 50% greater consumption is usual. However the extent of fluctuations depends very much on geographical position and industrialization. In warm climates air conditioning load increases summer consumption close to winter consumption, but day/night consumption ratio increases. One shift factory work during the day, especially manufacturing consumption and electrical transportation are other causes of increased fluctuation of demand curve. In comparison to developing countries, in countries with higher living standards, the commercial and domestic consumption causes morning and evening peaks. Fig.2 shows an average daily demand profile called diurnal demand variation profile and the role of pumped water energy storage in satisfying peak demands called "peak shaving".

2.2 Supply

The demand curve is 1. Its satisfaction by various means is explained as follows: 2. Wind, river, nuclear, hydraulic and large coal sets 3. Smaller coal sets, solar power 4. Gas turbine sets, oil fired sets, imported power and, peak plants. Curve 5 shows total production of power plants. Area indicates the energy storage operation. The surplus energy stored (6) is discharged at peak periods (7).

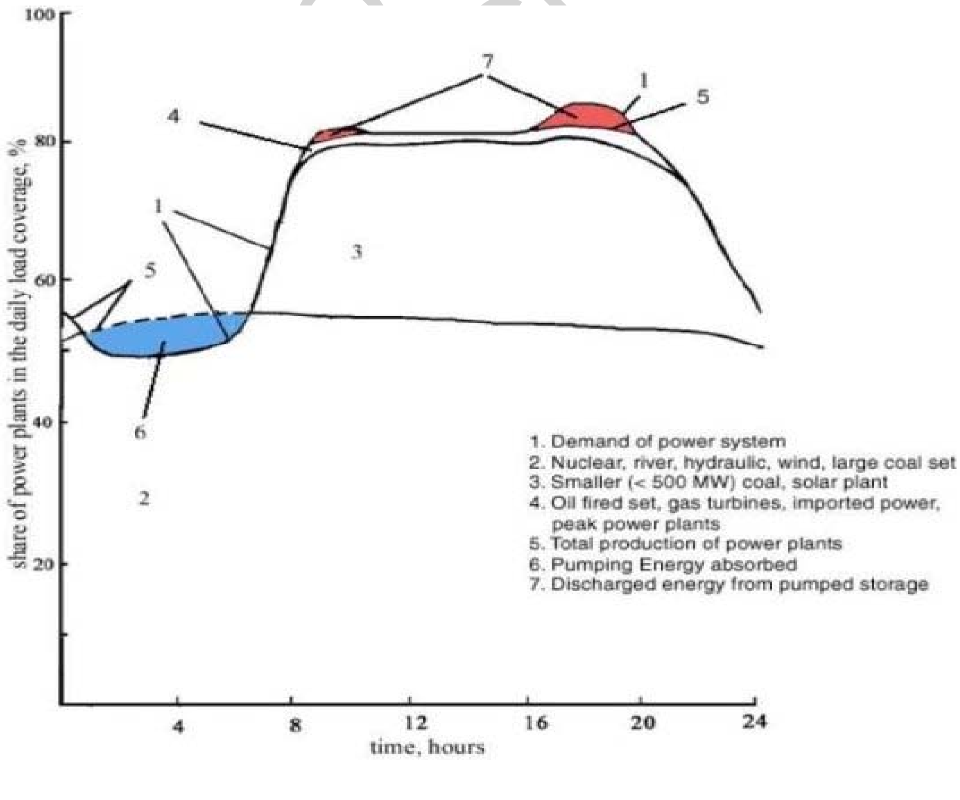

Figure 2: Variation of power system demand in one day period and its coverage by various types of power production and pumped water stored energy.

An electrical power plant operates most efficiently at its rated power. For nuclear and large coal power plants, the start up and shutdown require many hours, therefore uniform operation is a necessity for these plants. Also water and wind power plants are run as far as possible uniformly at their rated power for base load because their running cost is negligible. For coverage of very short peaks spinning reserve is used; it is explained in *Spinning Reserves*. Solar electricity coincides with high demand, therefore it can be considered as intermediary load plant. Rest of the intermediary load during the daytime is covered by smaller coal fired sets. For larger peaks gas turbine plants are run which can start up within 5 to 10 minutes.

As explained in the following section the pumped water storage reaches its full power in one to five minutes. Furthermore its running cost is negligible, considered that for pumping the hydro energy will be used. Hence for the highest peak, discharging pumped water storage energy is always preferred.

3. Types, Economic Considerations and Historical Perspective

3.1 Types

Pumped water storage plant consists of upper and lower water reservoirs, pump-turbine unit, motor-generator unit with its transformer and control equipment. According to the water reservoirs following types are possible applications:

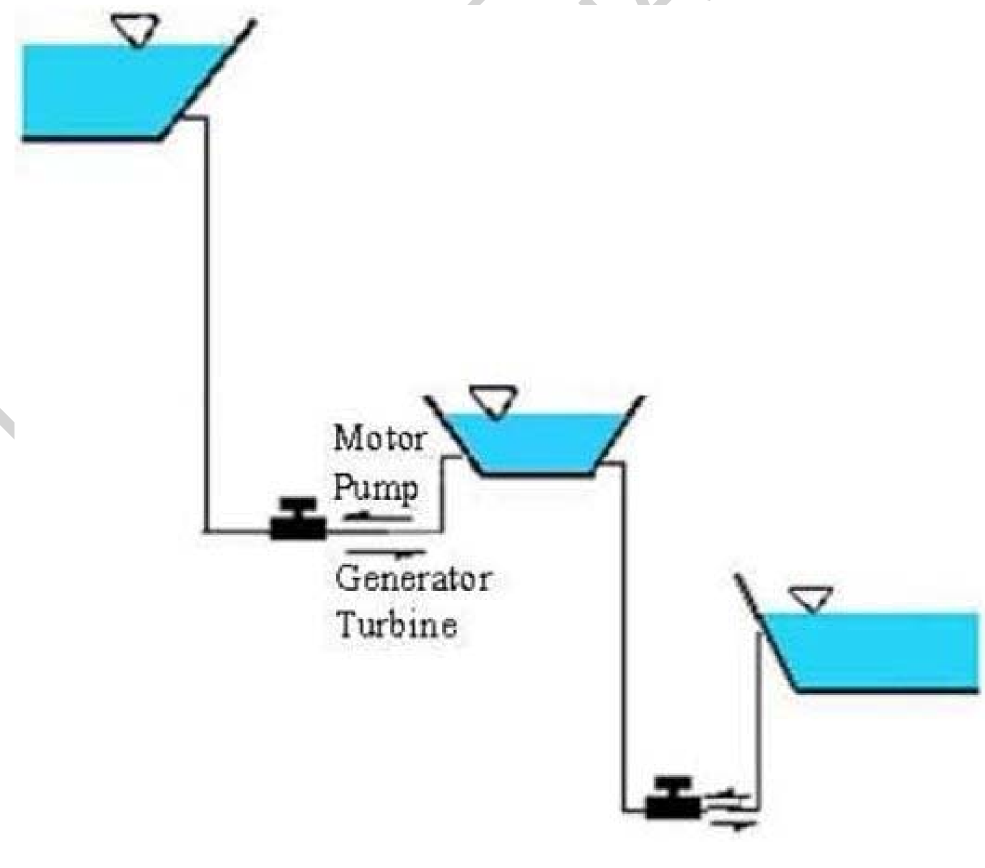

Figure 3: Two level pumped water storage plant

- Both reservoirs may be natural water bodies, which is rare.
- One of them is an existing hydro power reservoir, the other one is a constructed surface reservoir. This may be a mountain reservoir.
- Both reservoirs may be constructed surface reservoirs, which is also rare because of its high investment cost.

Along the historical development, the following types can be distinguished according to the power equipment.

- Separate pump with its motor and turbine with its generator. It has four units.
- Separate pump and turbine, but the generator and motor is a single unit. The plant has three units. The motor-generator unit is generally between the pump and turbine.
- Pump / turbine is a single and same unit. Depending on the direction of rotation and the direction of energy flow, it works for pumping or for power production. The plant has only two units: pump-turbine and motor-generator.

By development of reversible two unit plants the investment cost for equipment is reduced to almost half. To store more energy by pumping a given amount of water, the head should be increased as far as possible. Because of the pressure caused by increased head, beyond 1000 m multilevel pumping is preferable. Fig.3 shows a multilevel pumped water storage plant. The intermediary water storage does not need to be large.

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Biographical Sketches

Yalçın Göğüş received his high school training in Ankara, his B.S. degree in 1958 and his PhD degree in 1964 at the Faculty of Mechanical Engineering of Technical University of Munich. He was Alexander von Humboldt Fellow in the years 1959 to 1961. He joined METU (the Middle East Technical University, Ankara) in 1961 and was Professor of Mechanical Engineering in the years 1976 to 1982. After working for UNESCO as a specialist and Project Director at Makarere University, Uganda 1980 to 1986 he returned to the Department of Aerospace Engineering of METU. He was as NATO-Fellow at Brown University (1970) and as Visiting Professor at University of Gaziantep (1975), Technical University Munich (1979) and Technical University Istanbul (1999). He has written, translated or edited ten books and more than one hundred journal or conference papers and research reports. He was founding Chairman of Turkish Society for Thermal Sciences and Engineering and Editor-in-Chief of its scientific journal Isı (1976), Founding Vice-Chairman of International Centre for Applied Thermodynamics (1997) and Associate Editor-in-Chief of its *Int. J. of Thermodynamics* (1998-2004) He received academic awards. Since 2001 he is working as Emeritus Professor at METU in the fields applied thermodynamics and propulsion engineering. He contributed to EOLSS as Honorary Theme Editor on Energy Storage.

O. Cahit Eralp received his BSc. in 1971, and MSc. in 1974 in Mechanical Engineering, at the Middle East Technical University (METU), Ankara, Turkey. He got his Ph.D from the Cranfield Institute of Technology, UK, in 1980 and he started his academic career as an Assistant Professor in the Mechanical Engineering Department of METU. He got Associate Professorship in 1984 and Professorship in 1990, in the same department. Dr. Eralp's fields of interest include Fluid Mechanics, Gas Dynamics, Gas Turbines, Turbomachinery, Natural Gas Engineering, Pipeline Engineering, Industrial Ventilation and Experimental Techniques. He is the director of Fluid Mechanics and Turbomachinery Laboratory of Mechanical Engineering Department since 1980. He is the co-author of a book on Gas Dynamics. He is involved in a large number of research and industrial projects and holds a couple of patents. He works as a consultant to industry in applied fluid mechanics. He served as a panel member, panel coordinator, worked in various committees and working groups of NATO-Agard Propulsion Energetics Panel during 1996-1998, then served in the working groups of the succeeding organization RTO-Applied Vehicle Technologies until 2001. His current interest is in the emergency and comfort ventilation of underground transportation systems and passenger safety issues in case of train fires in tunnels and underground stations.