VARIABLE SPEED PUMP-TURBINES TECHNOLOGY

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The energy market development and the implementation of alternative energies have an important impact on the hydro development. New developments are planned such as green energy sources (such as wind, solar, waves, tidal stream,…) or nuclear energy. In this network, an important issue is the stability of the grid and the availability of peak energy. Thus the development of the new hydraulic power plant based on variable speed pump turbines is the new orientation for the hydro-electrical market. This improves the global effectiveness of the grid and among these technologies the variable speed technology is quite interesting.

Keywords: pump-turbines, variable speed, energy market, green energy

1. Introduction

The most widely form of renewable energy is the hydropower, which produces electrical power using the gravitational force of falling or flowing water. Hydropower is essential to operate the others sources of renewable energy that are intermittent generation. If the appropriate conditions for implementation of the hydroelectric power plants are considered, it's ecological impact is very limited - see Bucur et al.,[1].

Today, the renewable energy represent 18.7% of the world electricity production (as a comparison, nuclear energy represents 13,5%) – see [2]. The hydraulic energy is the most important resource of renewable energies, being 86.3% of the total production (5.7% wind energy, 1.7% geothermal energy and 0.3% solar energy). The hydraulic energy is used as a complementary resource for the rest of the renewable energies, being the only clean energy that can insure the mass storage of energy (pump-turbine operation regime). Also, it offers, the capacity to regulate the electric network in order to allow integrating resources that rely on different factors that cannot be controlled (solar, wind, etc.).

This paper point out the advantages of the implementation of variable speed pump-turbines and describes the variable speed technology. Two examples of variable speed power plants in realisation are presented.

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2. Interest of Variable Speed Pump-Turbine

The energy market development and the green energy have an important impact on the hydro development. For European countries the objective for 2020 is to reduce the amount of Carbon emissions by 20% and integrate at minimum 20% of renewable power production. New network developments are planned combining nuclear energy with green energy sources (like wind, solar, tidal stream, waves, etc.). In this network, an important issue is the stability of the grid and the generation of peak energy.

As example in the Danemark power network the evolution of wind energy is presented in Fig. 1. Not only the power average is about 30% of the installed power, but the intermittency of the provided power request balancing from other type of energy production that needs high flexibility: to compensate the sudden stop of production in peak regime and to valorise the production in the not charged periods. The same for the stabilisation of the grid frequency.

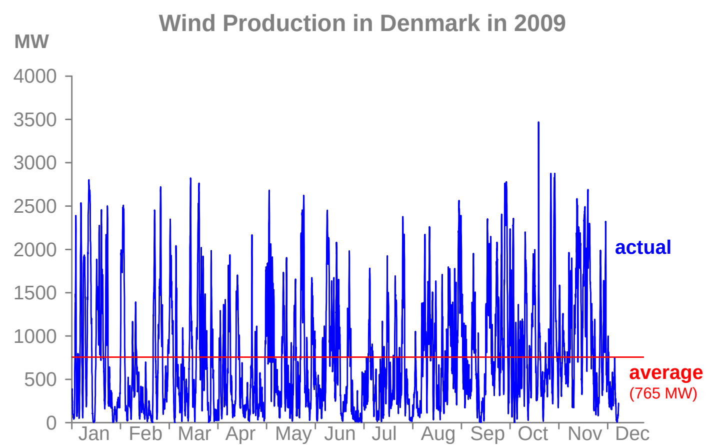

Fig. 1 Wind Power generation in Denmark 2009

Clearly thus the development of new hydraulic power plants based on pump-turbines are new trends for the hydro-electrical market. This will improve the global effectiveness of the network and variable speed technology is thus quite interesting.

When power demand is at its peak, water is released through the turbines to generate electric power. As the demand decreases, a large amount of electric power is available on the grid. With its ability to pump back water from the lower into the higher reservoir the plant acts like a giant rechargeable battery, using readily available power to provide reliable and flexible power to cover peak demand. The same power lines, connected to the power transmission grid, will provide the electric power required to pump back water, and transport the power generated by the plant when it is operating in turbine mode. The environmental impact of this operation mode is neutral for a “green energy” production point of view.

Thus the pump turbines are an important lever for the grid regulation. The liberalisation of the electricity market in Europe requires the separation of the production and distribution of energy. The control of the active and reactive power in order to keep the frequency constant of the grid is regulated on the market. The energy price on the market has higher fluctuations – see Fig. 2, Caro et al. [3] - and request fast reactivity of the production/consumption. The availability and the reactivity of the power injection is an important factor of profitability for the electrical power plants. The start of the machine and/or the change of regime are performed in few minutes.

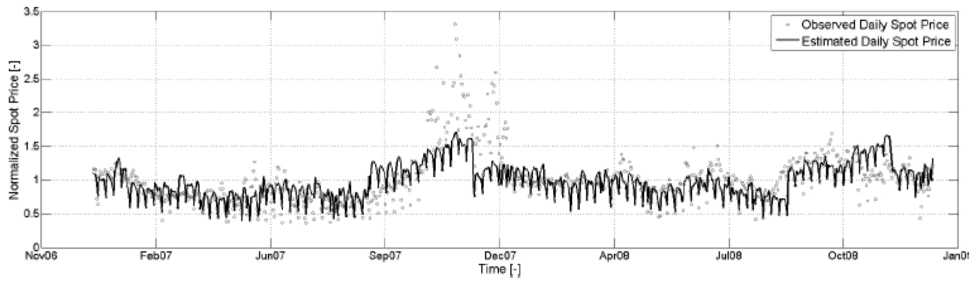

Fig. 2 Evolution of the Swiss electricity price

3. Variable Speed Pump-Turbine Operation

The variable speed is a new technology applied for pumped-storage power plants. In variable speed technology static frequency convertors are used to vary the speed of the electrical machine. For small machines – less that 50 MW – a synchronous generator is linked to the grid by a static frequency convertor. For larger units, this solution is not justified economically. For units larger than 50 MW double fed induction machines with a static frequency converter feeding the rotor is the preferred solution. The double fed induction technology consists in creating of a rotating field on the rotor allowing the machine to be operated with a certain speed range around the synchronous speed while attached to a fixed frequency network– see Schwery et Kunz [4]. The relative difference in speed is called the slip (usual range less that +/- 10%).

The use of variable speed technology has some major advantages among which:

- In pumping mode, the power absorbed can be varied subsequently at fixed head, permitting a grid frequency regulation, even in pump mode. This variation can be up to ~30% of the absorbed power. The operating mode is extended related to the normal operation – see Fig. 3. This is a key advantage with respect to fixed speed units that can only regulate their power in generation mode and operate at fixed power in pumping mode.

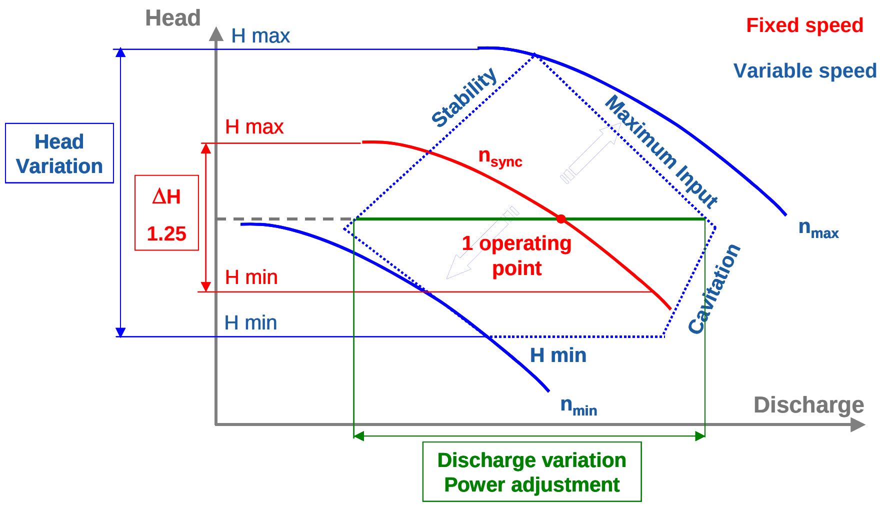

Fig. 3 Operating domain for fix speed – red and variable speed – blue: grid frequency regulation

- For fixed operational speed, the top of the efficiency hill charts in turbines is generally not within the operating range. The variable speed permit to have the optimal efficiency level at operating points in both turbine and pump modes – see Fig. 4. Moreover higher individual efficiency are achieved compared with the fixed speed, in particular at partial loads;

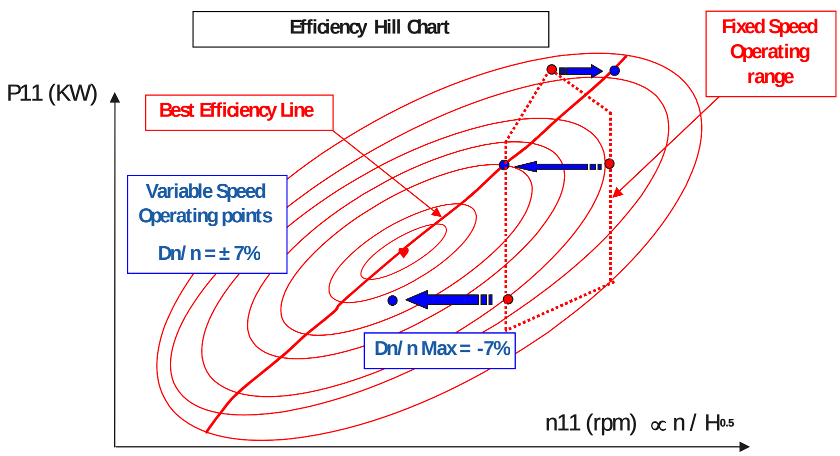

Fig. 4 Operating points in turbine regime for fix speed – red and variable speed – blue: efficiency optimization

• The variable speed permits a more dynamically setting of the power thanks to the flywheel effect. Indeed, for fixed rotational speed, the power is changed only by adjusting the discharge (changing of the guide vanes opening) while for the variable speed, the electrical machine can be adapted faster on the new power requirements and compensate the inertia of hydraulic system. An optimization of the hydraulic and electric parameters is realized for the variation of the operating point.

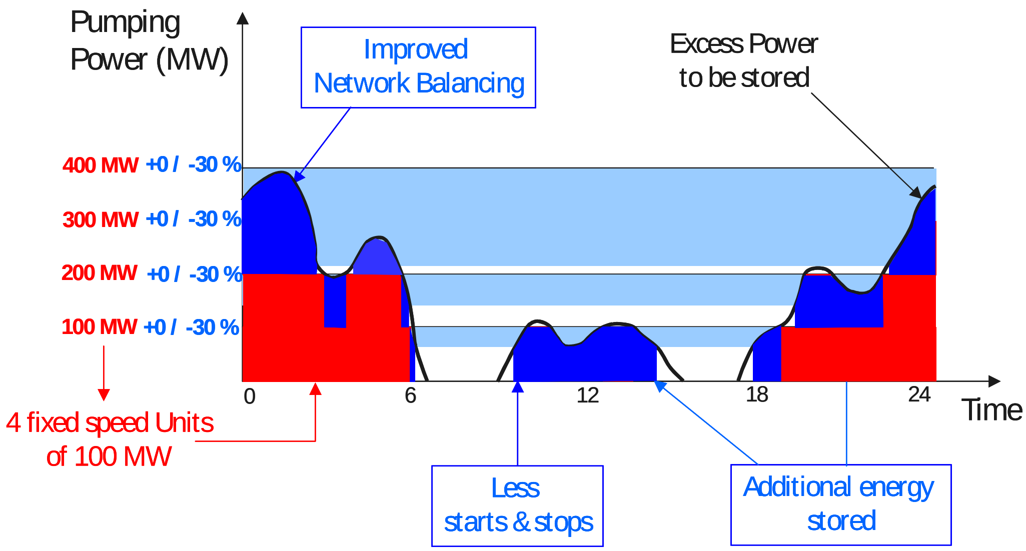

Fig. 5 Operation of fix speed – red and variable speed – blue power plant

- The variable speed permit a fine tune of the operating regime to the power adjustment with the grid request. In this way the energetic balance of the power plant is improved – by improving the network balancing and the storage of power excess in hydraulic energy, the number of machines start and stop is reduced – see Fig. 5.

Besides, variable speed technology offer technical and economic advantages like extension of the operating range increased cycling efficiencies and therefore higher operation flexibility towards the grid - see Teller et al. [5].

4. Variable speed pump turbine technology

The implantation of pump-turbines, single and multi-stages with classical products for the pumped storage plants (PSP) – see Fig. 6, are in progress worldwide – see Henry et al. [5] and Houdeline et al. [7].

The variable speed technology in pump-turbines is a breakthrough technology that starts to be implemented, due to the new energy market configuration.

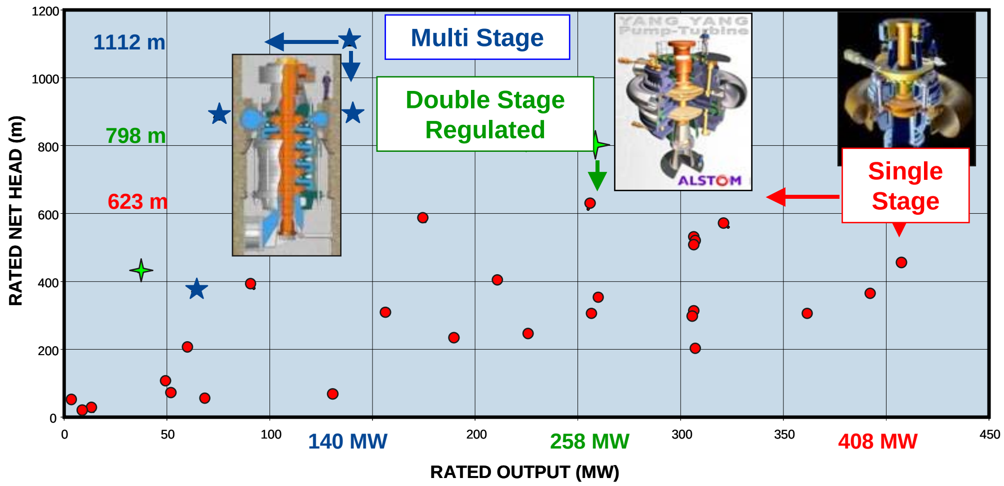

Fig. 6 Alstom pump turbines for more than 21 MW – 125 references (20% of the world PSP)

The generator – rotor – design is the most impacted by this new technology. Tree main parts are completely different compared with classical machines: slip rings, winding overhang retaining system and rotor rim - see Schwery et Kuntz [4].

Slip ring: to feed the rotor with the three phase current system, at least one slip ring per phase and usually one slip ring for the star point are needed. In normal operation, the frequency of the currents is low. At synchronous speed, the currents become constant. During start up, the frequency increases gradually and is equal to the grid frequency at the end of the startup process. The brush system and the slip rings need to be designed for these requirements. For a regular consumption of the carbon brushes air temperature and humidity need to be controlled. Special attention has to be paid to an even distribution of the currents on the different carbon brushes.

Winding overhang retaining system: The rotor winding overhang has to be supported to avoid deformation and damage if the machine speed comes close to runaway speed during load rejection. Three basic concepts can be used:

- The first concept uses a steel retaining cap similar to the design used in Turbo generators (cylindrical rotor generators). The caps can be shrunken and are dismountable. The steel cap needs to withstand high mechanical forces and is made of forged nonmagnetic steel.
- For the second concept, the whole overhang is bandaged either by a steel or synthetic wire or a synthetic foil. The application of the wire or the foil needs special tools. Dismantling of the system without destruction of the bandage is generally not possible. Special attention needs to be paid to the cooling of the

winding overhang for the first two solutions, because the cooling airflow cannot pass through the winding overhang in radial direction.

- The third concept consists in a set of retaining bolts that fix the winding overhang to an auxiliary rim mounted on the rotor rim. Cooling air can directly pass through the winding overhang in radial direction. Furthermore it is possible to dismantle individual bars if required. A strict quality process defining individual checking of each bolt is required due to the huge mechanical solicitation of these bolts.

Rotor rim: similar to the winding overhang retaining system, the rotor rim is also exposed to mechanical cycling. Since the rotor rim consists of a highly inhomogeneous stack of varnished steel laminations, it is advisable to cross check the calculation by practical tests. In contrast to the rotor rim of a salient pole machine, the rim of an induction machine is carrying an alternating magnetic field. To reduce the iron losses created by eddy currents and hysteresis effect materials with low loss coefficients can be used. Generally materials with high yield strengths have relatively high magnetic loss coefficients. The right compromise is to be found between the mechanical and magnetic proprieties of the material.

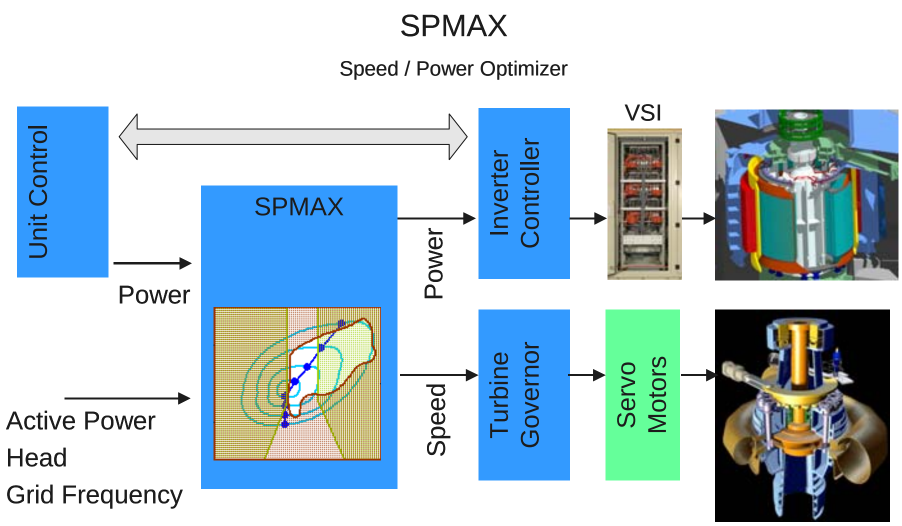

Fig. 7 Command architecture for variable speed pump-turbines

For the governing system a particular stage – SPMAX – are added to optimize the operation of the machine and to implement the best fit of the pump-turbine operation related to the grid request. This Speed/Power optimizer manage simultaneous the governor and the inverter controller – adjust the rotational speed of the generator – see Fig. 7**.**

For the turbine side, no major changes are needed. The configuration with independent servomotors (one for each wicket gate) is often preferred. However attentions are to be pay of the mechanical calculation because the variable speed or the runner generates more exciting frequencies for the mechanical structure. Another aspect is related to the operating regimes. The normal request was limited to 2-4 start/stops by day. For the new machines the exigencies becomes 10-12 start/stops by day and the fatigue calculation can be dimensioning.

5. Linthal-Limmern power plant

The power stations belonging to Linthal-Limmern AG in mid Switzerland were built between 1957 and 1968. They use the water inflow from a catchments of about 140 km² in the headwaters of river Linth. The ongoing project will increase the plant capacity by 1000MW by developing the existing power plant,. 4 new pump-turbines operating with variable speed will be installed – see [8]. In this way KLL will increase considerably the capacity to produce value peak energy when the demand is particularly great, to participate on the grid stabilization in both operating mode pump and turbine and to increase the production of green energy by pump storage. This project will represent 1,5 billions € and the power plant will be operating in 2015-2016.

This new underground pumped storage facility will be used to pump the water from Lake Limmern (elevation: 1’857 m; capacity: 92 million m^3 water) back up to Lake Mutt which is 630 m higher – see Fig. 8. The Mutt Lake elevation 2’500 m has a reservoir of 9 Million m3. Its capacity will be increased at 25 Million m^3 by the erection of a concrete dam along the south side of the Mutt Lake.

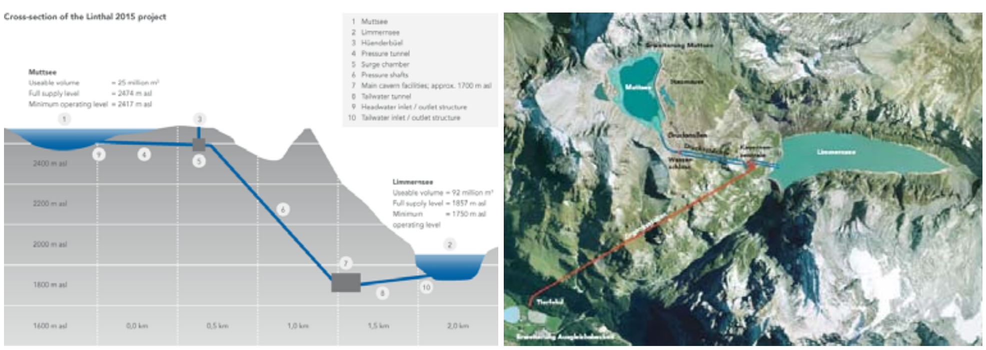

Fig. 8 Linthal-Limmern power plant implantation

600 meters deep in the mountain-inside will grow up a big size Power Cavern: the new machines will be in a room with a wide of 30 Meter, 50 Meter high and 120 Meter long. 2 in parallel led penstocks connect the Mut Lake with the Power Plant and 2 about 500 meter long tailraces the Power plant with the Limmern lake. The direct access to the Power Plant is guaranteed from the valley

in Tierfehd with a more than approximately 4 kilometers long Tailrace which is equipped with a funicular railway.

Besides high levels of efficiency in a wide range of operation required in both Pump and Turbine modes, variable speed technology provide to Linthal-Limmern project several benefits such as the use of a wide head variation (maximum head / minimum head is about 1.27), increases the partial load operation range to 30% of rated output in turbine mode and thus increases the generation flexibility.

The 4 new reversible pump turbines units will insure a rated output of 255 MW each with a variable speed motor-generator, rated at 500 rpm with a slip range of $^{+}/_{-}$ 6%. All the 4 machines will be manufactured and installed by ALSTOM.

6. Nant de Drance power plant

The new underground power station will be built between two existing lakes Emosson and Vieux-Emosson – 11,4 Mio. m^3 for a head of 250-390 m, see Fig. 9.

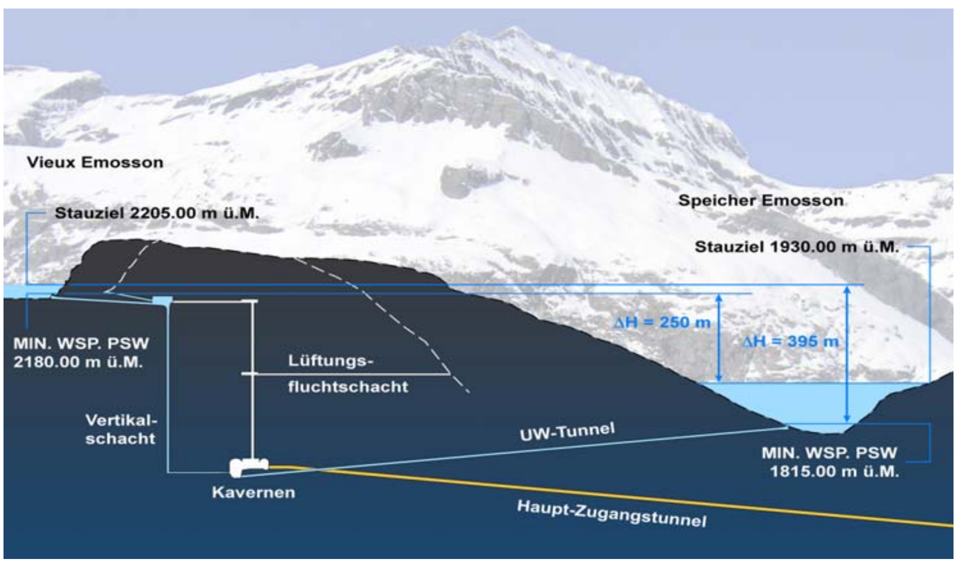

Fig. 9 Nant de Drance power plant

By the developing the existing power plant, the Output will be 900 megawatts. 6 new pump-turbines operating with variable speed will be installed. This project is a partnership between Alpiq, CFF and Forces Motrices Valaisannes – see [9]. The project represent less than 1 billion € and will be operating in 2015-2017.

The 6 new reversible pump turbines units will insure a rated output of 157 MW each with a variable speed motor-generator, rated at 428,6 rpm with a slip range of $^{+}/_{-}$ 7%. All the 6 machines will be manufactured and installed by ALSTOM.

7. Conclusions

The new configuration of the electrical market impose more capacity for grid regulation, more flexibility in power availability on network and high volatility for the prices in peak period. The ecological raisons - CO_2 emission reduction - impose the development of green energy sources for production and storage.

The variable speed technology in pump-turbines is a breakthrough technology that responds to this need. In fact this technology permits the energy storage and production with a fast reactivity (seconds), the grid frequency regulation (in both regimes pump and turbine) and the optimization of the efficiency of the hydraulic power plants.

ALSTOM is developing the variable speed pump turbines technology and is leader in pump-storage power plants on the hydro-electrical market.

R E F E R E N C E S

[1]. *D.M. Bucur, F. Bunea, G.D. Ciocan, G. Băran, E.C.Isbăşoiu* "Water parameters evolution in a hydroelectric site", Environmental Engineering and Management Journal, Vol.9, No. 11, 469 – 472, 2010

[2]. ****, 11e Inventaire Observ'ER – edition 2009

[3]. *G. Caro, C. Jeroen, M. Hildmann, D. Dannacha, F. Herzog,* "A quantitative analysis of the electricity market in Switzeland", 2008

[4]. *A. Schwery, T. Kunz*, "Variable Speed, Technology and Current Projects in Europe", Waterpower XVI Conference, Spokane, July 27-30, 2009

[5]. *O. Teller, T. Kuntz, E. Goutard, L. Schmitt,* "Renewable integration boost thanks to pumped hydro storages upgrade into variable speed coupled with energy and market management solutions", Renewable Energy World Europe in Milano, Italy June 7-9, 2011

[6]. *J.M. Henry, H. Marin, L. Melet,* "Pumped Storage Technology For High Duty Water Pumps: The 90 MW Beni Haroun Water Pumps", AIRH Lyon 2009

[7]. *J.B. Houdeline, D. Roulet, T. Kuntz, J. Liu,* "Regulated and reversible pump turbine design: the recent PSP achievement experience", Hydropower Technology & Equipment, Beijing, 20-22 April 2009

[8]. ****, "Refurbishment of the Linthal-Limmern Power Station", http://www.axpo.ch/axpo/en/hydroenergie/wissen/kraftwerksprojekte/ausbauprojekte_linth-limmern.html

[9]. ****, "Station de pompage turbinage Nant de Drance", http://www.nant-de-drance.ch/home.htm