The First Israeli Hydro-Electric Pumped Storage Power Plant
Gilboa PSPP

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Abstract. The Israeli Public Utilities Authority, PUA, decided to increase the instantaneous power available on the grid by adding Pumped Storage Power Plants, PSPP, to the existing generation capacity. PSP Investments Ltd. is a private investor that decided to develop the Gilboa PSPP. Its capacity is 300MWe. The project performance has to comply with PUA regulation for PSPP, and with all relevant Israeli laws and IECo standards. This paper itemizes an overview of the Gilboa PSPP through short summaries of units’ components from design step to manufacturing processes.

1. Introduction
The Gilboa PSPP is located at the Gilboa Mountain, on the North of Israel; close to the town of Beit She'an, about 120 Km from the North of Tel Aviv. The 300 MWe Gilboa PSPP, as shown in Figure 1 consists of:

• an upper reservoir of 2.4 Mm³ water;
• a High Pressure HP vertical shaft;
• an horizontal HP waterway tunnel and a steel lined bifurcation to feed the two penstocks;
• an Underground Power House composed of two caverns, see Figure 2:
  o one cavern housing the two Pump-Turbines and generator-motors, the Main Inlet Valves and associated equipment,
  o one cavern housing the two main power transformers and the common starting equipment (Static Frequency Converter and associated equipment);
• a low pressure LP waterway tunnel with a 70m height surge shaft;
• a lower reservoir of 2.4 Mm³ water;
• a 161 kV outdoor substation for connection to the Israel Electric Corporation (IEC) grid and operating buildings, one inside the premises for the substation, one at the entrance of the site to serve also as visitor center.
2. Electrical and Mechanical overview

2.1. Reduced scale model
The pump-turbines developed by GE past Alstom Hydro (France) for GILBOA PSPP were contractually tested on its hydraulic laboratory of model tests in Grenoble, from 20th to 31st October 2014, with a reduced scale factor of 1/5.5.

The hydraulic laboratory of General Electric in Grenoble is acquired with 6 test rigs. The dedicated test rig was designed to perform closed-loop tests on vertical shaft Francis turbines, or reversible pump-turbines, and to proceed with open-loop calibration of flow meters. The pumping unit supplying the tested models consisted in two centrifugal pumps driven by two variable speed D.C. motors controlled by a thyristor speed drive. The test rig was equipped with a direct current motor generator (360 kW at 1000 rpm, 2400 rpm max). In generating mode tests (turbine mode), the power is supplied by the network. The stator of the generator motor was supported by hydrostatic-oil film guide and thrust bearings for the purpose of torque measurement. In pumping mode tests, the energy produced
by the pump was dissipated by means of an adjustable energy breaker specially designed to operate without cavitation.

For Gilboa model tests with a low pressure side diameter of the model runner of 255.6 mm, the tests were operated for a net head of 45 mWC and a speed rotation of 1’200 rpm, see Figure 3.

2.1.1. Measurement
The measuring apparatus used were conducted according to the recommendations of IEC 60193:1999 standards. Furthermore, the total uncertainty agreed with the contractual expectations and according to standards, less than ±0.30%.

The measurements of the net head, of the discharge, of the torque and of the speed of rotation allowed calculating the mechanical and hydraulic power. The ratio of both of values determined the efficiency of the pump-turbine either in turbine mode or pumping mode.

Secondary set of measurements were performed, too, e.g.: absolute pressure to determine the setting level available during cavitation tests; pressure fluctuations at the inlet, between the guide vane and the runner, at the outlet on the draft tube; and hydraulic torque of guide vanes. And finally, geometrical checks were performed in the several locations of the model.

2.1.2. Results

2.1.2.1 Global performances
Both performances in turbine and pumping modes were explored by measuring the guide vane openings curves in the model scale and transposed to the prototype according IEC 60193:99 standards. All weight average efficiency points for both modes were measured and closed to the preliminary test results. Then, the expected weighted average efficiencies in turbine and pumping modes were coherent with the values obtained during the preliminary model tests.

2.1.2.2 Cavitation observations
Pump mode
Outlet cavitation observations were performed during NPSH break curves where the efficiency was derivative by decreasing NPSH, starting from a very high NPSH, where no cavitation phenomena appeared, to a value of NPSH where the efficiency decreased from 1% compared to its value at high NPSH. The Figure 4 showed 3 observations on pumping mode: on the right no cavitation bubbles at NPSHplant or site installation, on the middle apparition of some bubbles when decreasing the NPSH, and on the left cavitation vortices along trailing edge of each runner blade.
Outlet cavitation observations were performed during $\sigma$ break curves where the efficiency was derivate by decreasing $\sigma$, starting from a very high $\sigma$, where no cavitation phenomena appeared, to a value of $\sigma$ where the efficiency decreased from 1% compared to its value at high $\sigma$. The Figure 5 showed 3 observations on turbine mode: on the right only a vortex rope at $\sigma$ plant or site installation with no impact on the turbine efficiency, as well as on the middle at lower $\sigma$ but nevertheless with additional cavitation bubbles along lower labyrinths and on the right a fully cavitation rope and bubbles.

**Figure 5:** Efficiency versus cavitation number ($\sigma$) in turbine mode, $N_s = 119$,

\[n_{n_{\text{BEP}}} = 40.50 \text{ [rpm]}, \quad Q_{n_{\text{BEP}}} = 0.53 \text{ [m}^3\text{s}^{-1}]\].

2.2. Mechanical design

2.2.1. Distributor

The distributor mechanism, which adjusts the inlet discharge, consists of 20 independent servomotors instead of an operating ring. They offer large flexibility on mechanism operating and in order to fulfill with mode change time request and eventual desynchronization necessity to stabilize the unit during no speed load operation.

2.2.2. Runner

The runner is welded into two parts: crown/blades and band/blades by the middle height of the blades. It is very difficult to weld the blades to the crown and to the band inside the hydraulic profile due to the smallness of height for this pump-turbine.
2.2.3. Thrust bearing pad
Thrust bearing pads are coating with a specific thermoplastic layer: PolypadTM instead of standard tin babbitt. They are very low friction at start-up and a double load capacity compared to common white metal pads.

2.3. Generator Design
Gilboa PSPP includes two generator-motors. Each of them is directly coupled to one hydraulic Francis pump-turbine through the shaft with a rotational speed of 750 rpm. The principle of reversible units is to allow two rotational directions. In one direction, the hydraulic machine operates as a turbine supplied by the upper reservoir and drives the electrical machine as a synchronous generator to generate electric power and feed the network. In the opposite direction, the electrical machine energy is supplied by the network and operates as a synchronous motor and drives the hydraulic machine in pump to fill up the upper reservoir. The reservoirs are the means to store electricity and have it available when the network needs it in a very short period of time.

The output terminals of each generator-motor are connected through air-insulated bus bars, a coupling circuit breaker and disconnectors to:
- A step-up and step-down transformer for connection to the 161kV IEC network;
- The common starting system to start in pumping mode thanks to a static frequency converter, SFC. During starting sequence, the runner of the pump-turbine of the reversible unit is beforehand dewatered to reduce the friction torque and thus SFC size.

In generating mode, the instantaneous output apparent power will be function of the mechanical power transmitted by the pump-turbine (active power) and by the field current supplied by the excitation system (reactive power). In pumping mode, the instantaneous input apparent power will be function of the mechanical power required by the pump-turbine (active power) and by the field current supplied by the excitation system (reactive power). The generator-motor is able to operate in both rotational directions as a synchronous condenser in order to supply or absorb reactive power according to the need of the IEC network provided that the pump-turbine is dewatered.

The generator-motor safely withstands operation under all conditions as defined below when connected to the grid and its characteristics remain within the specified boundaries. It is designed for both local and remote operation. The units can be operated in any one of the following operating modes:
- Synchronous generator,
- Synchronous condenser in generator rotational direction,
- Synchronous motor,
- Synchronous condenser in motor rotational direction.

Each of the 2 generator-motors starts to the generating mode by the pump-turbine running as turbine. Each of the 2 generator-motors starts to the pumping mode by a static frequency converter.

![Figure 6: Generator conception.](image)
2.4. **SCADA system and protections**

The Gilboa PSPP Supervisory Control And Data Acquisition System, SCADA System, accomplishes supervision and control of all equipment in the entire scheme, with the co-operation of other control equipment. It accepts dispatching management of the Powerhouse from the IEC Load Dispatch Center. It meets all the requirements included in the IEC grid code. It ensures:

- Full Automatic start/stop sequences of the pump/turbine units and also changeovers between the different modes (start or change to following modes: turbine, pump, condenser in turbine direction, condenser in pump direction).
- Control and supervision of the units from the control rooms and from the local control boards.
- Individual control of the units from the control rooms or from the IEC Load Dispatch Center.
- Control and supervision of both reservoir water levels and water intake gates from the control rooms and from the local control boards.
- Safety and protection of the equipment.

The Gilboa PSPP SCADA System is an open system, using components of the latest, advanced technology, with high levels of reliability and availability, easy in repair and maintenance, convenient in future development. In all cases processing is designed to ensure safe operation so that power plant output is reliable and smooth. The system also includes tools for the maintenance, modification and creation of software, data bases, and views. It includes full-graphics user interfaces compatible with industry standards. Since only the powerhouse control room is intended to be manned on a continuous basis, the Graphical User Interface provides an effective and efficient interface for the powerhouse operators to remotely monitor and, where required, control the plant, equipment, systems and facilities of the facility. The user interface includes advanced alarm management features to clearly present the most critical alarms to the operators.

2.5. **Low Voltage AC supply system**

The Low Voltage AC supply system is defined by following requests:

- A very high availability of LV supply sources for all essential loads.
- Capability for “blackstart” for one unit.
- High flexibility for the operator to select any preferred electrical normal sources, depending on economic criteria, on operational situation and on maintenance needs.
- Hydroelectric units are considered as fully independent functional entities. In particular:
  - Common equipments are reduced to the minimum (e.g. HP compressors, SFC);
  - Unit 1 and unit 2 auxiliary equipment components are physically separate;
  - Locking of any hydroelectric unit can be achieved easily (this includes AC-DC power cuts), without any impact on the other unit.

The design of energy sources follows those criteria:

- The 161 kV network is a reliable source, and can be available in the UPH through the units’ main transformers and Medium Voltage bus bars.
- The local IEC 22 kV network is a reliable source and is available outside the cavern from IEC 22 kV network near the Operating Building and at the Upper Reservoir through underground cables.
- An additional and independent emergency source is installed, as:
  - it is assumed that in exceptional conditions, the sources mentioned above (i.e. 22 kV and tapped from 161 kV) can both be unavailable;
  - blackstart capability is required.

The AC supply system provides LV supply for all auxiliary systems which are located at the various sites of the Gilboa PSPP facilities. Equipment at Low Reservoir, Operating Building and substation (building and outdoor switchyard) are supplied from the same LV source, as they are in the same areas.
Equipment in access tunnel and various galleries are supplied either from the Underground Power House or from Substation Building. All information about AC supply systems are exchanged with the control system, through serial links and/or hardwired links. In particular, the following information is transmitted:

- Signaling about status of main switchgear and other equipment: open/close, trip fault, and if any: ready-to-close, local/remote, connected/disconnected/test positions, lack of control voltage, under-voltage, transformer overheating.
- Measurements: active and reactive power, voltage, current, frequency, energy consumption, transformer winding temperature.
- Remote control commands.

3. Manufacturing Inspection and Site installation

3.1. Manufacturing inspection
The main Electro-Mechanical contractor, GE, is manufacturing all components of Gilboa units all over the world: main inlet valves, spiral cases and stay rings, wicket gates, runners, draft tubes, cones of draft tubes, stator frames, rotors, stop logs and panels of the Low Pressure gate, LP gates casings and round/square transitions, see Figure 7.

Some components are casting abroad and welding in French GE workshop in Grenoble. During the manufacturing process, welding inspections are performed through Non-Destructive Tests (Dye Penetrant Test, Ultrasonic Test, and Magnetic Test).

3.2. Site installation
Civil Works (CW) has started since 2012 in different locations: Upper Reservoir (UR), Tunnels, Underground Power House (UPH) and Lower Reservoir (LR), see Figure 8.

Since end of 2015, Electro Mechanical (EM) works have started and increased it workload week after week, mainly in the UPH and in UR. CW and EM progressed in parallel, see Figure 9.
| Image | Description                |
|-------|---------------------------|
| ![Image](image1.jpg) | Half of the runner.       |
| ![Image](image2.jpg) | Draft tubes.              |
| ![Image](image3.jpg) | Draft tube cone.          |
| ![Image](image4.jpg) | Stator bars.              |
| ![Image](image5.jpg) | Insulated Pressorized Bars. |
| ![Image](image6.jpg) | Stator frame.             |
| ![Image](image7.jpg) | Turbine shaft.            |
| ![Image](image8.jpg) | Generator shaft.          |
Upper part of pit liner.  
Lower part of pit liner.  
Cooling pumps.  
Excitation cubicles.  

**Figure 7:** Manufacturing of Gilboa components.

**Figure 8:** Civil Work areas.

Upper Reservoir.
4. Conclusion

The private 300MWe Gilboa PSPP is the first Israeli Hydro-Electric Pumped Storage Power Plant in Israel. The Commissioning of the 2 Francis pump-turbines is scheduled in 2018. The first pump-turbine components as draft tubes arrived on site end of 2015 and installed beginning 2016.

This is an innovative project due to the fact that in Israel there is no any previous installed and generating hydraulic power plant. This paper briefly presented the project from the white page to the installation progress on site.

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