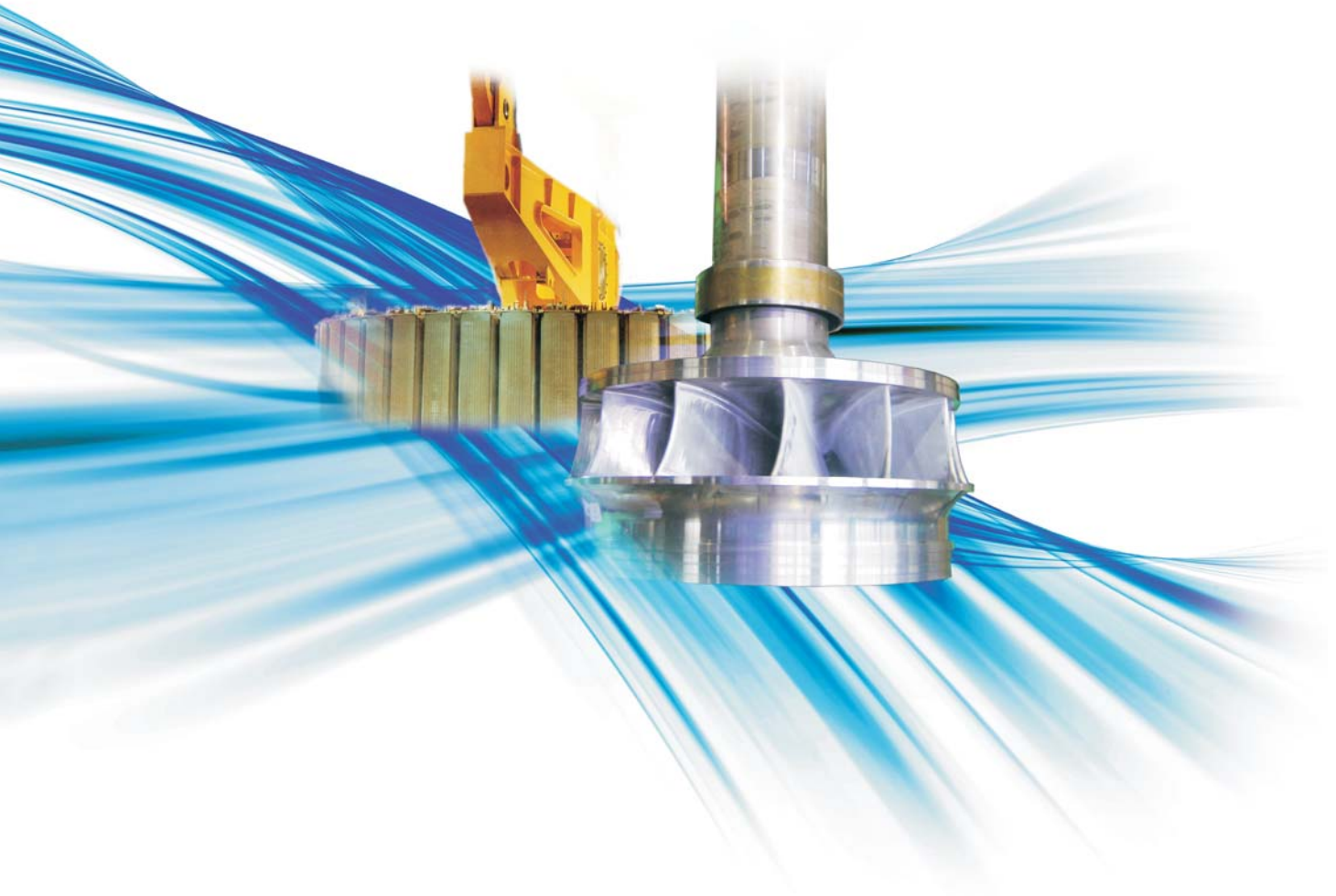


Hydropower Project
BAKUN
Malaysia

The most efficient power station in the world



We believe in the Power of Nature

Project description

Name	Bakun
Country	Malaysia
Customer	Sarawak Hidro Sdn Bhd
Scope of Supply	Turnkey equipment
Installed capacity	2,800 MW
Mean annual energy	18,900 GWh
Equivalent energy	83,000 BOED

The Bakun Hydropower Project is located in Sarawak, Malaysia, 60 km west of the city of Belaga on the Balui River, a tributary of the Rajang. It follows the guidelines of the Sarawak Corridor of Renewable Energy (SCORE) program, aiming to diversify Malaysia's energy matrix by increasing the use of clean energy. This project represents a first step towards harnessing the 20,000 MW potential of the Rajang Basin.

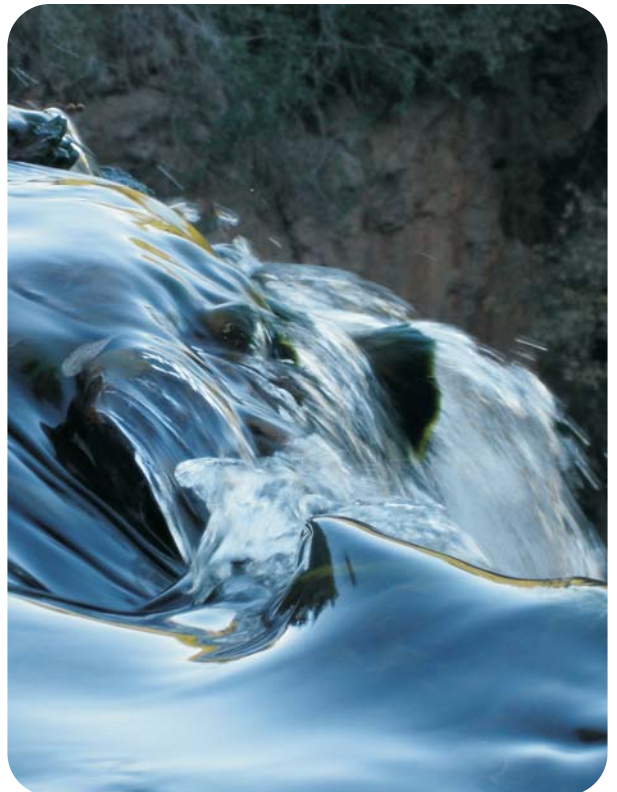
The project has been designed to supply electricity to the provinces of Sarawak and Sabah as well as to Peninsular Malaysia by means of a 650 km underground cable laid across the bottom of the South China Sea. There is also the possibility of supplying energy to the state of Brunei and Kalimantan, Province of Indonesia, both on the Island of Borneo.

Bakun comprises a 205 m high and 750 m long concrete-faced rockfill dam (CFRD), the highest of this type in the world, intake structure, a gated spillway, 8 pressure tunnels with their respective penstocks, and the powerhouse.

IMPESA's scope of supply includes electromechanical equipment for the power plant under a turnkey contract. It encompasses four of the eight 350 MW Francis generating units with their respective governor and excitation system, control and protection system, main power transformers, and the balance of plant.

IMPESA was contracted for this project after an international bidding process in which its turbines proved to be the most efficient. For Sarawak Hidro, this represents not only increased power generation but also higher incomes. The plant's overall efficiency is 94%, making it the most efficient power station in the world. Generation from other sources currently yield no more than 60% (combined cycle). Another relevant fact is the project's exceptional plant factor.

Bakun saves 30 million barrels of oil equivalent per year, eliminating the corresponding greenhouse gas emissions, thus aiding in the prevention of global warming and environmental pollution. In this way, resources are also strategically saved for export.



This project also triggered the decision to expand and modernize IMPESA's plant in Lumut, on the west coast of Malaysia, with state-of-the-art machine tools so that high value-added turbine and generator components can be manufactured locally. To this end, some 500 local workers from different disciplines were hired. This led to the transfer of technology to Malaysian professionals and technicians. This was achieved by means of a considerable personnel exchange program between Argentina and Malaysia.

Technical characteristics

Turbines

Type	Francis
Quantity x Capacity	4 x 350 MW
Rated head	172.4 m
Speed	1 66.7 rpm
Runaway speed	290 rpm

Governors

Type	Electro-hydraulic with PID control
------	------------------------------------

Generators

Quantity x Capacity	4 x 396 MVA
Generating voltage	18 kV
Frequency	50 Hz

Excitation system

Type	Static with electric brake
------	----------------------------

Power transformers

Type	Three-phase
Quantity x Capacity	4 x 396 MVA
Medium voltage side	18 kV
High voltage side	290 kV
Type of cooling	ODWF
Tap changer type	On load

Electrical systems

Main generator circuit breakers for 13,000 A - 18 kV
Auxiliary service transformers
Generator's isolated phase busducts for 13,000 A - 18kV
High and low voltage equipment
DC AC supply system
Full wiring
Grounding system

Ancillary systems

Water cooling system
Full compressed air systems at high and low pressure
Unit drainage system
Oil transfer and treatment system
Fire protection system for generators and transformers
Hoisting for the ancillary system

Control and protection system

The control system is made up of 5 main sections:	
Turbine	Alarm
Generator	Automation
Auxiliary services	

Other equipment and services

Spare parts for all equipment
Turbine model testing at IMPSA's laboratories in Argentina
Customer personnel training
Camp and infrastructure for assembly / erection and on-site testing
Assembly / erection, on-site testing and start-up

Turbines



Hydraulic design

Tests of the Bakun turbine's reduced model were performed at the Hydraulic Laboratory of IMPSA's Technology Research Center and witnessed by SARAWAK HIDRO's representatives and international experts. The development process comprised: hydraulic design, mechanical design of the model, internal tests to meet project requirements; and tests witnessed by customer's representatives. The tests made it possible to verify compliance with all project's guarantees.

All turbine components were initially analyzed and optimized with flow simulation programs (CFD). Results obtained were consistent with other measurements performed during model testing. The turbines, designed for a head range of more than 40 m, made it possible to achieve high efficiencies throughout the unit's operational range.

Mechanical design

A computerized 3D model was used for the mechanical design. It verified component stresses and also computed the deflections and natural frequencies using the finite element method (FEM).

The spiral case was made of welded steel plates designed for maximum operation pressure. The stay ring has two parallel plates welded onto 19 stay vanes. This component was pressurized on site at 150% of the design pressure.

The distributor has 20 wicket gates driven by two servomotors through an operating ring. The wicket gates, cast in 13.4 stainless steel, are equipped with self-lubricating bushings.

The runner was made of components cast in 13.4 stainless steel.

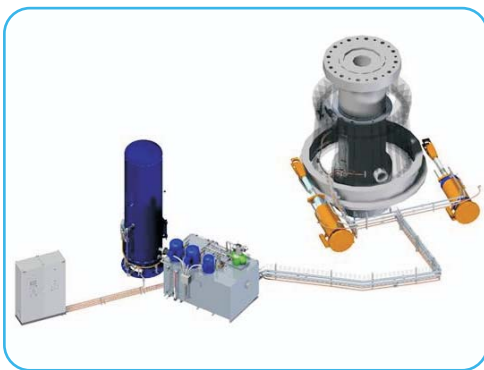
The shaft utilizes a thin-wall welded design. Because of its inertia, this increases the safety margin between runaway and critical speeds. In addition, it gives greater vibration stability and reduces manufacturing cost.

Since the unit operates as a synchronous condenser, special provisions were made for air injection and water drainage in the upper cover and bottom ring.

Once hydraulic energy has been converted into mechanical energy, the turbine restores the water through a draft tube made of welded steel plates.



Governor



IMPSA's governor is of the digital electro-hydraulic type with PID control. The control electronics, composed of standard high-quality PLCs, is highly reliable and facilitates maintenance. The control architecture consists of a main controller and a manual back-up one. This ensures high fault tolerance in the case of a main controller failure, preventing the generating unit from shutting down, otherwise, the load would be rejected and the power system would be adversely affected.

The software includes all speed power and position control functions required for these types of units.

The oil pressure system (air/oil) has a pumping unit with three screw-type pumps to pressurize the system and an air/oil tank with an accumulated volume of about 8,000 liters. The pumping unit was fully designed in 3D.

Automation

The project's control system comprises the supervision, control and protection of the four generating units that are part of IMPSA's scope of supply. Each generating unit has three main controllers.

Each unit's automated control coordinates the safe and synchronized operation of both the generator and turbine systems, such as: speed governor, voltage regulator, switchgear, etc.

Each controller is linked to the overall control system through its S8000 network, providing all the information required for the generating unit. The network makes possible to remotely control and integrate all units with the control modules in the power plant. These controllers have event sequencing (SOE) capacity with 1ms resolution and overall synchronization with GPS.

Generators

This machine converts the turbine's mechanical energy into electricity for transmission to consumption centers.

Hydro generators are three-phase, vertical shaft, salient-pole synchronous machines, each with a capacity of 396 MVA.

At 10 MVA per pole, it shows the high level of complexity of the design.

Integral dimensioning of the generator was performed with IMPSA's own ARGENT expert system, which analyzes the equipment's behavior, both in steady and transient states as well as under normal and fault conditions. This software simulates all the issues required to produce this type of machine: components' dimensioning, electromagnetism, electrical and magnetic circuits, fluid mechanics and heat transmission, strength and fatigue of materials, tribology, shaft-line stability, vibrations and oscillatory behavior.

3D Computer Aided Design (CAD) was used throughout the whole design process. Verification studies were carried out not only with tools developed by IMPSA and integrated into the PROGEN expert system, but also with applications that use FEM.

The stator's magnetic core was made from 0.5 mm oriented magnetic steel segments, which were die-cut, varnished and stacked. The stator winding, in which a three-phase alternating current is induced, is mounted on the slots. The set is supported by the stator frame, a welded structure which directs the air from the core to the heat exchange units of the cooling system.

The rotor consists of a steel-welded spider, a rotor rim made of die-cut stacked segments (for radial ventilation), and the poles that generate the rotating magnetic field in the machine's air gaps.

The arrangement of the line of shafts includes a guide bearing on the generator's rotor, a combined bearing below the generator's rotor, and a guide bearing in the turbine. This arrangement is very convenient for the rotor's dynamic stability.

Design characteristics include a membrane-type lower bracket which transmits radial stress to the foundation, minimizing the machine's length. This solution means a significant saving in the project's civil structure.

The ventilation system is of the asymmetric radial type, which uses the rotor to generate pressure for machine cooling.

Excitation system

The system includes:

Automatic Voltage Regulator (AVR): It consists of an automated system with a processing unit in redundant configuration (hot-stand by), and field current controllers for each SCR (thyristor) rectifying bridge. In the event of internal failure, this configuration performs either processing unit or power stage commutations.

Power stage: It is made up of two bridge rectifiers, one of them in cold standby to ensure double power redundancy without jeopardizing the other SCRs in the event of a power failure near the bridge rectifiers. Each bridge rectifier has its own air/air heat exchange unit and protection system.

Field discharge: In the event of a normal shutdown, the field breaker trips and the system performs a fast deexcitation by opening the field breaker. The energy stored in the rotor is discharged into a resistor.

Excitation transformer: Dry-type cast resin transformer. The epoxy-encapsulated winding is protected with its corresponding cell, which is connected to the segregated phase bus duct. Overcurrent protection is connected to the primary circuit by means of current transformers.

This project is yet another example of IMPSA's commitment to providing integrated solutions for renewable power generation.

IMPSA

www.impsa.com

IMPSA LATIN-AMERICA
Camil Rodríguez Peña 2451
M5503AHY, San Francisco del Monte
Godoy Cruz, Mendoza
Argentina
Ph (+54 261) 413 1300
Fax (+54 261) 413 1416

IMPSA MALAYSIA SDN BHD
T2-8, 8th Floor, Jaya 33, N° 3 (Lot 33)
Jalan Semangat, Section 13
46100 Petaling Jaya, Selangor Darul Ehsan
Kuala Lumpur
Malaysia
Ph (+60 3) 7954 1168
Fax (+60 3) 7954 1169

IMPSA RECIFE
Estrada TDR Norte, 1724 Km 3,3
Distrito Industrial de Suape
Cabo de Santo Agostinho, PE, Brazil
CEP: 5490-000
Ph (+55 81) 3087 9300
Fax (+55 81) 3087 9372