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OAK RIDGE NATIONAL LABORATORY

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Assessment and Evaluation of New Small Hydropower Technology to be Deployed to the United States 45-Mile Project: "The Turbinator®"

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UT-BATTELLE

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Assessment and Evaluation of New Small Hydropower Technology to be Deployed to the United States 45-Mile Project: "The Turbinator®"

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And
Kevin Stewart

Report

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Executive Summary

The U.S. water supply infrastructure has a hydropower generation potential of about 60,000 MW, which would nearly double the U.S. hydropower production and could create as many as 1.4 million jobs during the next two decades. The *Hydropower Improvement of 2011* and *Small-Scale Hydropower Enhancement Act of 2011* were introduced in 2011, setting a dynamic hydropower agenda with key highlights including grants, permits, and studies. In September 2011, the Oregon, U.S. based company, Earth By Design Inc. (EBD), was awarded a Department of Energy (DOE) grant to support a two-year project for installation and testing of a new small hydro innovative technology, the Turbinator.

The Turbinator, developed by CleanPower AS Company in Norway, is a compact and sealed machine with an axial flow turbine and a permanent magnetized synchronous generator, allowing for a simple but reliable installation while reducing the investment for installing small hydropower plants. Many irrigation canals and non-powered dams in the U.S. could be potential candidates for the Turbinator technology with a much lower cost than existing designs.

This project was part of a Funding Opportunity Announcement (FOA) awarded by DOE in 2011, to Earth By Design (EBD) where Oak Ridge National Laboratory (ORNL) was awarded funding to assess, evaluate and report to DOE the pre- and post-installation phases of the technology findings. The main purpose of the trip to CleanPower, located in Kristiansund, Norway, was to assess and evaluate the Turbinator technology that will be shipped, and installed for the first time, in the U.S. for the 45-Mile irrigation canal project in Oregon. The trip to Norway that was in the original work plan (awarded FOA) proved to be very beneficial for the project progress advancement.

The trip to Norway took place from November 19 to November 24, 2012, and several meetings and site visits were scheduled. The first two days were an assessment and review of the hydraulic, mechanical and electrical components of the conceptual designs that included explanations of critical dimensioning by CleanPower design engineers. The third day was spent understanding the team approach and processes that CleanPower and Oshaug Metall AS employ for bronze mold construction and post-mold milling of Turbinator components and visiting the molding company, Oshaug Metall AS, a specialized bronze molding company that fabricates the runner wheel of the Turbinator. The fourth day was spent visiting the second installation of a Turbinator, at Tjeldbergodden, where energy is recovered from a methanol plant cooling water pumps. Discussion about the project progression, ease of implementation, challenges, and installation were very promising. The installation procedures of the second Turbinator at Tjeldbergodden were very basic and simple. The fifth day was scheduled for a visit to the Hegset Dam site, where the first Turbinator was installed. Discussions of the functioning of the Turbinator unit and operational performance and maintenance requirements with facility staff at Hegset Dam were held to gather valuable information.

Based on the findings about the Turbinator's conceptual design and preliminary performance results from the pilot Turbinator installation at Hegset Dam, and the ease of manufacture and installation of the Turbinator at the Tjeldbergodden site; it was concluded that the technology is appropriate and ready for deployment at the EBD 45-Mile site in Oregon. Since the 2013 irrigation season starts April 15 and ends on October 15, and to meet the DOE FOA schedule and deliverables, it was important to have operational data in year 2013. Therefore, a communication was sent from ORNL to EBD on November 23, 2012, with the recommendation to release funds to CleanPower for the final design, manufacture, and deployment of the Turbinator to the U.S for the 45-Mile project in Oregon. As of January 21, 2013, no communication has transpired between EBD and CleanPower. DOE-HQ was notified regarding the status of the project.

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Assessment and Evaluation of New Small Hydropower Technology to be Deployed to the United States: "The Turbinator"

1 BACKGROUND

The overall objective of the advanced and innovative hydroelectric Turbinator technology is to promote cost-effective and sustainable small hydropower development. The proposed deployment and installation of this technology will provide quick and efficient methods for reducing the levelized cost of energy (LCOE) to less than $0.07 per kWh. Implementation and success of the proposed innovative technology at this site could enable numerous other plants to be developed at similar sites. The proposed advanced hydroelectric project in this location would provide a water-to-wire energy generation cost under the desired $0.07 per kWh, and develop competitive market data that DOE needs to advance its strategies for developing low-head hydropower technologies at reduced capital investments. Other developing U.S. electricity markets and LCOE plants could benefit from the lessons learned from this project since there are minimal infrastructure modifications needed to construct the facility at this site. This project will validate the sufficiency of the technology and methodologies being used to reduce capital costs and effectively generate income from low-head projects.

CleanPower's new technology, with its ease of implementation, low capital cost, and long-term, reliable energy production, will assist in securing power cost increases and keeping farmers profitable and willing to continue supplying food products at reasonable prices. CleanPower's technology performance, cost-effectiveness, sustainability, and overall benefit of increasing the value of renewable energy will be assessed after installation.

1.1 Research Integration

The goal of this grant was to support the development and deployment of innovative technologies that produce power more efficiently, significantly reducing costs and increasing development at low-head sites with variable flow ranges that have been previously considered unfeasible or marginally feasible. The United States Department of Energy (DOE) Wind and Water Power Program (WWPP) has a mission to research, test, evaluate and develop innovative technologies capable of generating renewable, environmentally responsible, and cost-effective electricity from water resources while increasing plant capacity, improving efficiency, flexibility and environmental performance of energy generation. The 45-Mile hydroelectric project will provide DOE with an opportunity to test the advanced technologies during manufacturing to create benchmark figures to use in cross-applications; gather data from real-world operations to effectively transfer the technical and economic results of this project to a variety of stakeholders to facilitate widespread adoption of the advanced technology; and provide published results on new technology that capitalizes on the undeveloped resource potential offered by sustainable and small hydropower.

This information will be useful to the conventional hydropower industry and regulators, and preliminary results will be distributed rapidly in the form of conference presentations, Oak Ridge National Laboratory (ORNL)/DOE technical reports (publically available online), and publications in the peer-reviewed scientific literature. These communications will emphasize the relevance of the activities carried out over the two-year study (i.e., performance, robustness, capabilities, and reliability of the advanced technology).

1.2 Technical Approach

CleanPower has developed and begun pilot implementation of a technologically advanced turbine, designed to address the issues in implementing cost-effective solutions in low-head sites. The validation and analysis of the actual data on the economic and technical performance of this project is vital to facilitating replication of this technology across the U.S. The turbine configuration is based on existing test data from empirical model testing performed on a similar type of runner wheel setup. The transformation from model test data to that of a prototype turbine is based on site head and flow data using traditional engineering design methods. ORNL reviewed information on the runner wheel geometries, gathered performance data from real-world operations that are based on model and prototype tests, and reviewed and commented on the computer tools developed by CleanPower that are based on the empirical data from the model tests.

During the manufacturing of the new technology, the necessary Factory Acceptance Tests (FAT) will be performed to verify the electrical performance for the generators. An electrical measurements test used to detect assembly errors will be performed on the assembled yoke temporarily situated in a rotating jig that is mounted on a test shaft fixture, relative to the assembled stator. In addition, insulation tests will be performed on the windings to assess the insulation between windings and the absence of any broken windings. Once commissioned, ORNL will obtain and assess the data related to electrical generation, project efficiency, and electrical transmission and operating costs for the plant. ORNL will then compile all of the project's technical and financial information and prepare a thorough report that will be submitted to a peer-reviewed publication conveying the experimental findings and the implications for future application and implementation.

1.3 Summary Information for the 45-Mile Project

- Full Project Title: 45-Mile Hydroelectric Power Project Demonstration of New Methodologies to Reduce the LCOE for Small Hydropower Development
- Organization or Affiliation: Earth By Design, Inc.
- Principal Investigator: J Gordon, Norm Bishop, and Boualem Hadjerioua
- Project Partners or Subcontractors: Knight Piésold, Oak Ridge National Laboratories, CleanPower
- Date of Project Initiation/Contracting: 10/1/2011
- Current Planned Date for Project Completion: 10/1/2014
- Total DOE FOA Award Amount: $1,500,000.00

1.4 Project Plan/Schedule (Original)

- Project Permitting and Licensing: FERC conduit exemption, water rights usage and construction permits, 6 months through April 2012
- Engineering Studies: Geotechnical surveys, planning and equipment, 9 months through July 2012
- Interconnection and Transmission Studies: All studies and Power Purchase Agreement (PPA) Process, 3 months for the interconnection process through January 2012, and 2 more months for the PPA through March 2012
- Project Financing: State and private loans and incentives; filing process for State loans and incentives, 5 months through March 2012, and private loans secured by January 2012
- Turbine equipment: Testing and manufacturing, 8 months through August 2012
- Hydropower plant construction: Final construction through January 2013, and commissioning and testing during April 2013 (during the irrigation season)
- Hydropower plant operations and testing: Through September 2014
- Reporting on successful completion/status of all phases of this project: Publications from ORNL published and submitted for peer review through October 2014

2 SUMMARY OF HYDROLOGICAL DATA AND DESIGN CRITERIA

Based on measured flow at the site, a flow duration curve (Figure 1) was developed to determine the design flow and size of the Turbinator.

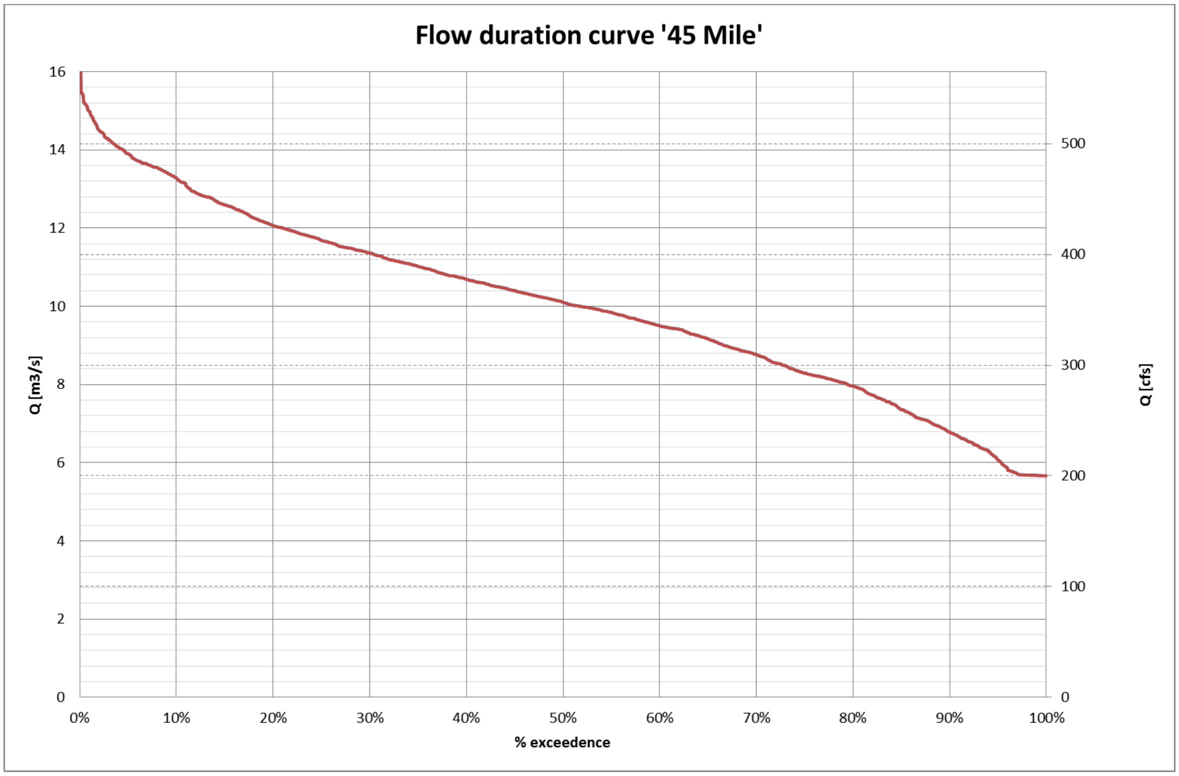


Figure 1. Flow Duration Curve

Season length (100% on the x-axis) is **188.7 days**.

Also received from EBD is the relationship between flow Q and net head H_n (Figure 2).

Q (CFS)	H (ft)	Q (m3/s)	H (m)
200	108,24	5,66	33,0
225	107,77	6,37	32,8
250	107,26	7,08	32,7
275	106,69	7,79	32,5
300	106,07	8,50	32,3
325	105,4	9,20	32,1
350	104,67	9,91	31,9
369	104,09	10,45	31,7

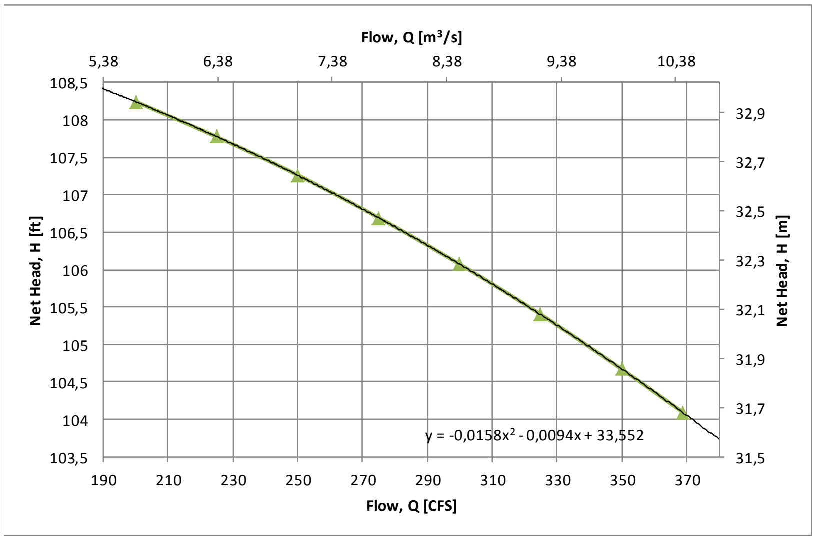


Figure 2. Flow vs. Net Head

The Excel trend line function is used to establish the following estimation:

$$H_n\,(Q) = -0{,}0158*Q^2 - 0{,}0094*Q + 33{,}552\ [m] \qquad (Q \text{ in } m^3/s)$$

The site engineering assumes a nominal flow of 369 cfs in total:

$$\mathbf{Q_{n\_tot} = 369\ cfs = 10.45\ m^3/s}$$

One of requirements for this project is that the plant shall not produce more than 3 MW. This corresponds to a flow of around 14 m^3/s located at the upper interval of the flow/efficiency curve (Figure 3) of the Turbinator. Another requirement suggests having a nameplate-rated power as high as possible, but below 3MW in total.

3 Design Parameters and Energy Estimate for 45-Mile Project

For the purpose of this document, it is assumed that the site will not require active regulation of voltage and reactive power, which would imply installing an inverter system. Flow regulation will be accomplished using the wicket gate system in the Turbinator, which is estimated to regulate the flow within the following limits:

$$Q_{min} = 85\% * Q_{nom}$$

$$Q_{max}\,[1] = 110\% * Q_{nom}$$

Within this interval, the expected efficiency loss compared to the design point is:

15% at Q_{min}

10% at Q_{max}

Based on the flow duration data, an optimum number of three machines is being considered, such that two machines are always in operation, and the third can be used subject to water availability. An advantage to using the Turbinator at 45-Mile is that the site conditions lend itself well to the existing design, such that identical machines can be used without additional redesign and/or major adjustments.

Using the aforementioned data and constraints, the optimum design point is found to be:

Nominal flow:	$Qn = 3.7\ m^3/s$	(130,7 cfs)
Net head at nominal flow:	$Hn = 31.5\ m$	(103.3 ft)

In this configuration:

- One Turbinator will run alone: 6% of the irrigation season[2]
- Two Turbinators will run in parallel: 94% of the irrigation season
- Three Turbinators will run in parallel: 62% of the irrigation season

[1] Higher flow is possible but not very useful, as the power output would decrease due to the reduced efficiency.

[2] The irrigation season is from April 15 to October 15.

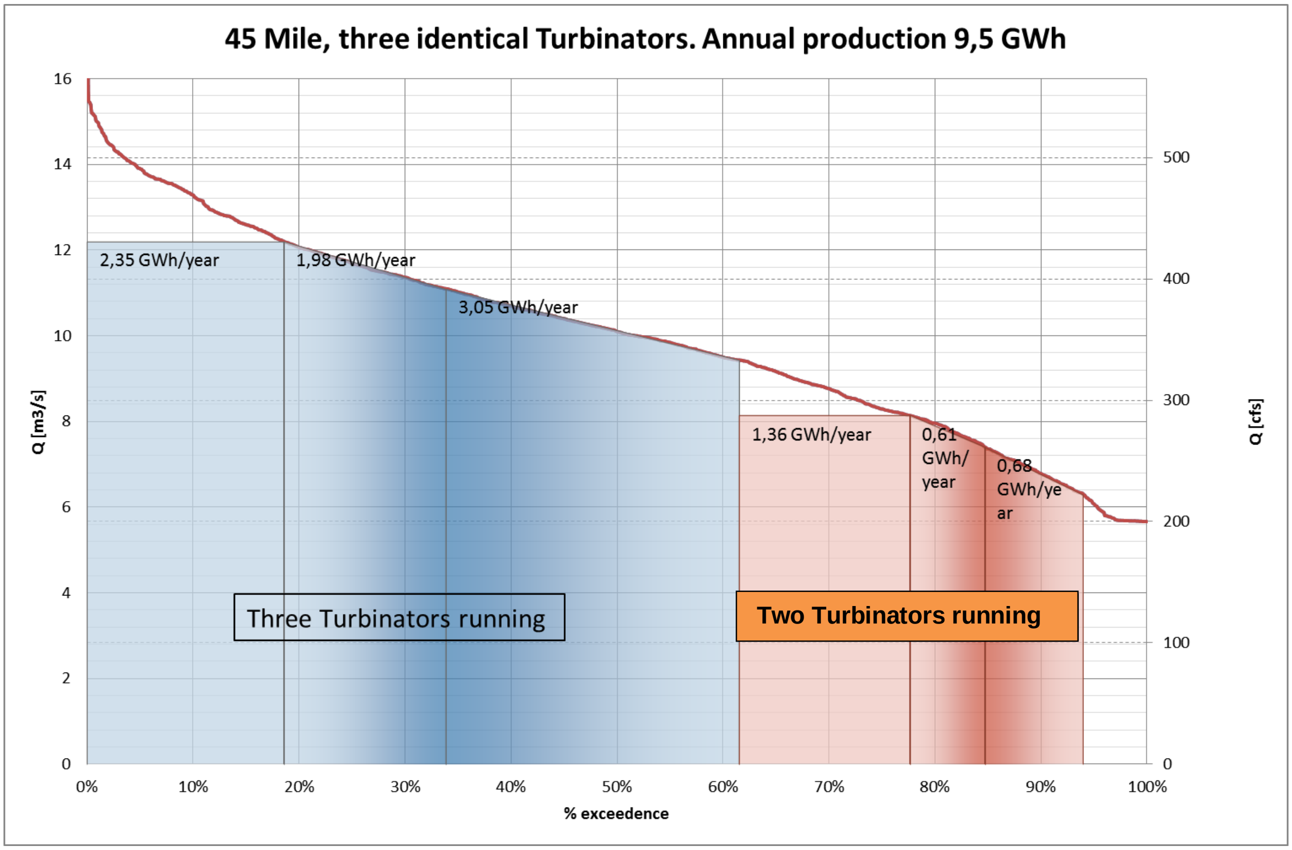


Figure 3. Flow Regulation and Power Generation

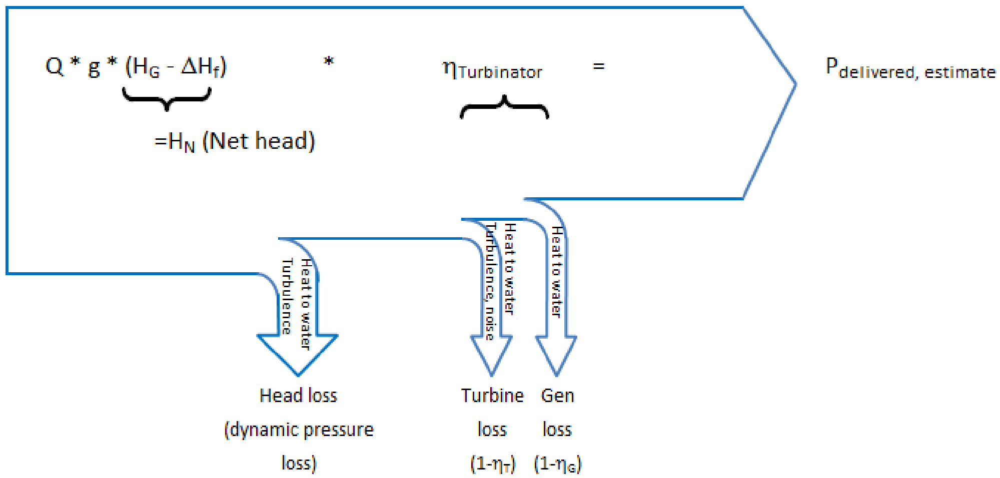
Note Number Convention: 9,5 should be read as 9.5

In addition to the software-calculation above, one Turbinator will be running alone in the 11 days per year (6% of the season) when there is not enough water to start the second Turbinator, giving an estimated additional yearly production of around 0.2 GWh out of a total estimate of 9.7 GWh/year.

A summary of design specifications is listed in Table 1.

3.1 Estimated Energy Production

Considering the estimated efficiency of the Turbinators, the proposed configuration is estimated to produce a total of 9.7 GWh/year. At the design point, each Turbinator will deliver an estimated power of 915 kW. The schematic in Figure 4 depicts breakdown of losses associated with the power estimate.



Water flow	Q	3,70	m^3/s	130,7 cfs
Standard gravity	g	9,81	m/s^2	32,20 ft/s^2
Net head	H_N	31,5	m	103,3 ft
$\eta_{Turbinator}$	≥	80 %		
$P_{delivered, estimate}$		**915**	**kW**	

Figure 4. 45-Mile Project Estimated Delivered Power

Table 1. Main parameters for the turbine and generator for the Turbinator for the 45-Mile project

TURBINE						
Nominal net head (dynamic water pressure at flow Q_N)	H_N	=	31,5	m	103.3	ft
Nominal water flow (at head H_N)	Q_N	=	3,70	m^3/s	130.7	cfs
Runner wheel diameter	D	=	1000	mm	39.4	in
Nominal rotational speed	n_N	=	514	rpm		
Estimated runaway speed	n_{RW}	=	1040	rpm		
Estimated water flow at runaway	Q_{RW}	=	5,55	m^3/s	196.0	cfs
Axial hydraulic load at full load	A_{hx_nom}	=	160	kN	35400	lbf
Axial hydraulic load at runaway speed	A_{hx_RW}	=	240	kN	54500	lbf
Maximum suction height	H_s	=	2,5	m	8.35	ft
Specific speed	n_s	=	220	rpm		
Number of runner wheel blades	N_{R_blades}	=	8			
Number of guide vane blades	N_{GF_blades}	=	18			
Bearings	Roller bearings					
PT-100 temperature sensors at bearings	1 per bearing (2 in total)					
Vibration sensors at shaft	x- and y-axis (2 in total)					
Runner wheel material	NiAl bronze: CuAl10Fe5Ni5					
GENERATOR						
Apparent power	S_n	=	1170	kVA		
Cos phi	$\cos\phi$	>	0,95			
Dimensioning power	P	=	1110	kW		
Voltage	U	=	400	V		
Nominal current	I_N	=	1690	A		
Number of poles	N_P	=	14			
Frequency	f	=	60	Hz		
Nominal rotational speed	n_N	=	514	rpm		
Runaway rotational speed	n_{RW}	=	1040	rpm		
Reactance (estimate)	x_{pu}	=	0,2	p.u.		
Maximum ambient temperature	T_{max}		40	°C	77	°F
Isolation class			F			
Protection level			IP 68			
Bearings	Common with turbine					
PT-100 temperature sensors in gen. windings	2 per phase (6 in total)					
Rotational direction	CCW					
MAIN MEASURES						
Turbinator total length	L_{Turb}	=	170	cm	71	in
Turbinator diameter	Dia_{Turb}	=	155	cm	61	in
Turbinator total height incl socket	H_{Turb}	=	170	cm	67	in
Bulb diameter	Dia_{Bulb}	=	63	cm	25	in
Total weight (±20% at this stage)	M	=	7500	kg	16500	lb

4 DRAFT TUBE DESIGN

The purpose of the draft tube is to release runner outlet flow to the downstream and recover as much as possible from the head difference between the outlet of the runner wheel and the tailrace water level. The draft tube dimensioning is a tradeoff between the recovered energy and the cost of the draft tube as a longer and larger draft tube could decrease the head loss in the system but would be more expensive.

The sketch below shows the proposed draft tube dimensions. The efficiency for this draft tube is estimated at 86.5%, which is close to what is considered optimum. An optimally designed draft tube would reduce the head loss by only 6 cm (less than 3 inches). A longer draft tube with larger end area could recover more energy, but the stated loss is considered acceptable.

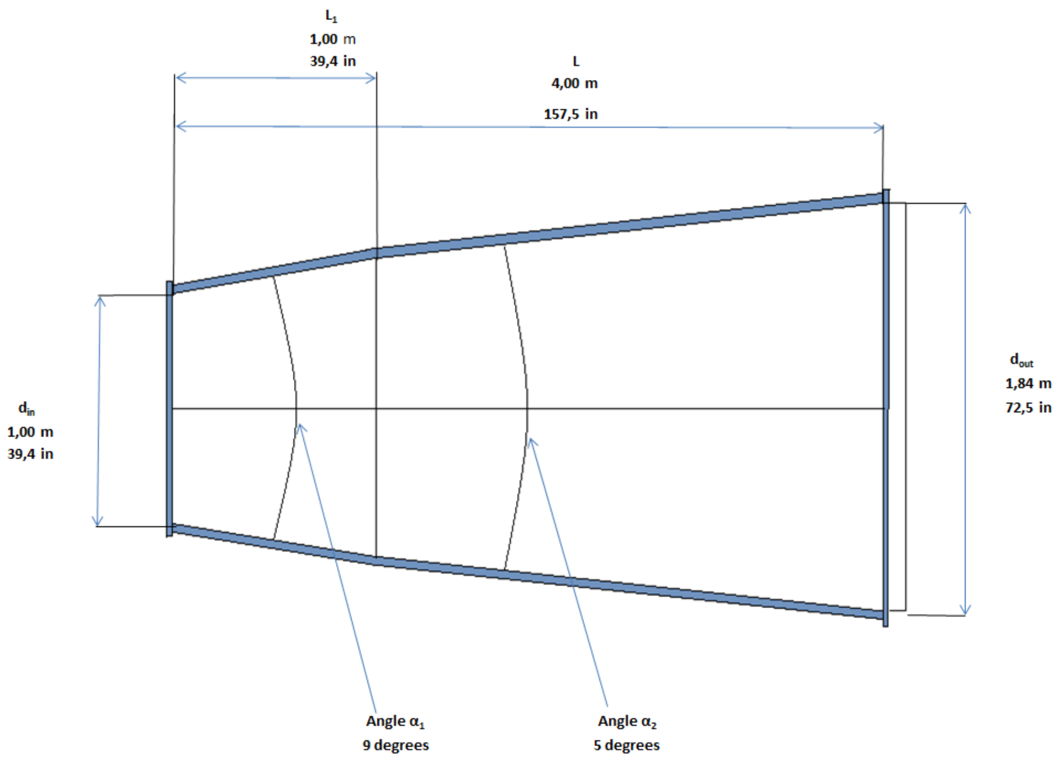


Figure 5. Proposed Draft Tube Dimensions

The turbine converts the water force into torque that is applied to a generator, which converts the torque into electrical energy. The theoretically available energy in a pressurized penstock can be expressed as:

$$P\ [kW] = H[m] \cdot Q\ \left[{m^3}/{s}\right] \cdot g$$

Where

- H is the net head (level difference between upstream and downstream water level minus the dynamic head loss in the penstock)
- Q is the water flow through the turbine

- g = 9.81 m/s^2

The turbine efficiency η_T is the ratio of actual power output of the turbine vs. available power according to the equation above. The turbine efficiency, η_G, is the ratio of actual power output of the generator vs. input power from the turbine. The overall efficiency of the turbine and generator set is: $\eta_{tot} = \eta_T \cdot \eta_G$. Thus, the estimated power output from the power plant is:

$$P_{est}\,[kW] = H[m] \cdot Q\,\left[{}^{m^3}/{}_{s}\right] \cdot\, g\, \cdot\, \eta_{tot}$$

5 TURBINE BACKGROUND

5.1 Turbine Types

Several different turbine technologies exist and depend mainly on the available head (input pressure to the turbine). The range of recommended turbine technologies corresponding to available head is illustrated in Figure 6.

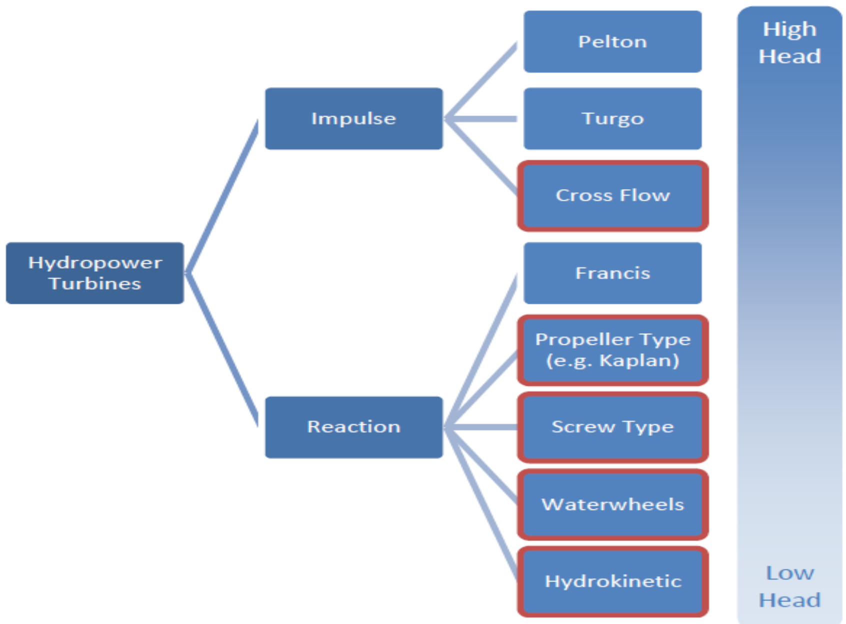


Figure 6. Types of Hydropower Turbines (Applegate Group, Inc., 2011)

In the low to medium head range (10-50 meters), turbine types to consider are:

- Kaplan turbines (several versions are available)
- Cross flow turbine
- Francis turbine

The various turbine types have different operational characteristics, typically reflected in their efficiency curve, which depicts the relationship between turbine efficiency vs. turbine flow. Figure 7 depicts efficiency curves for various small hydro turbines.

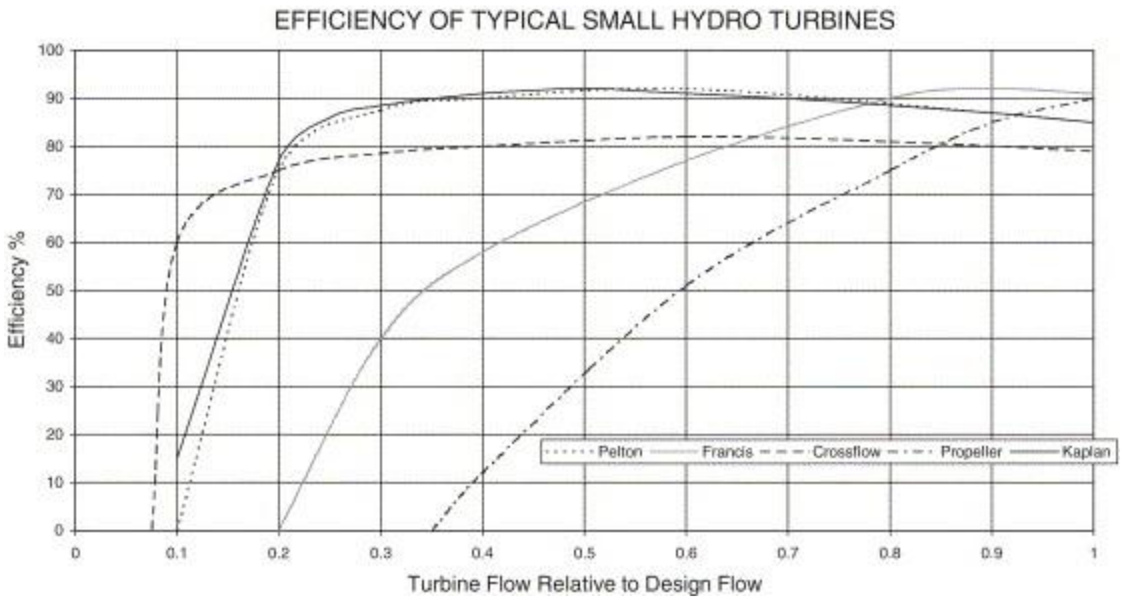


Figure 7. Efficiency Curves for Small Hydro Turbines

The curves show the varying adaptability of the different turbine types to changes in the water flow. NOTE: The turbine type here named “Propeller” is a Kaplan with fixed runner blade pitch.

5.2 Kaplan Turbine Types

The most commonly used turbine type for low to medium head is the Kaplan turbine. Compared to the Crossflow turbine, which is not able to exploit the entire head difference because its runner wheel operates out of the water, the Kaplan turbine can exploit the entire head.

In order to adapt to different types of sites, a variety of Kaplan turbine types and installation methods have been developed. The basic Kaplan turbine is shown in Figure 8, and has two means to change the water inflow and modify its characteristics.

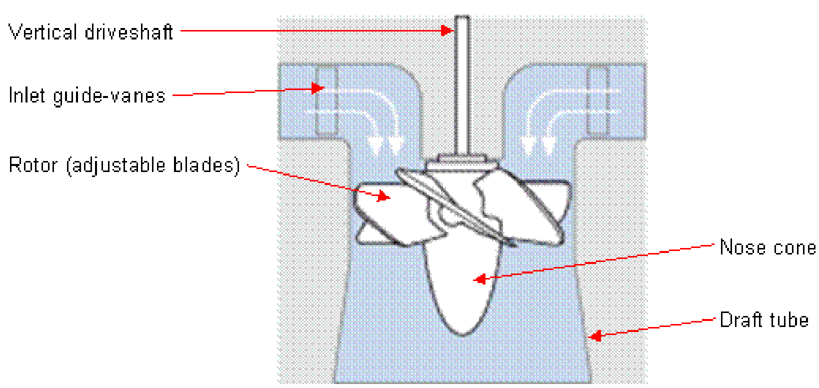


Figure 8. Kaplan Turbine (Renewables First Ltd.)

1. Inlet guide vanes (also called wicket gates) can be opened and closed to regulate the amount of flow that can pass through the turbine. When fully closed, they will stop the water flow completely and bring the turbine to rest. Depending on the position of the inlet guide-vanes, they introduce differing amounts of 'swirl' to the flow, and ensure that the water hits the rotor at the most efficient angle for the highest efficiency.
2. The rotor blade pitch can be also adjustable - from a flat profile for very low flows, to a heavily pitched profile for high flows (see Figure 9). This adjustability of both inlet guide-vanes and rotor blades means that the flow operating range is very wide (a characteristic from the inlet guide-vanes) and the turbine efficiency is high and the efficiency curve is very flat (a characteristic from the adjustable rotor blades allowing optimum alignment of the blade to the oncoming flow).

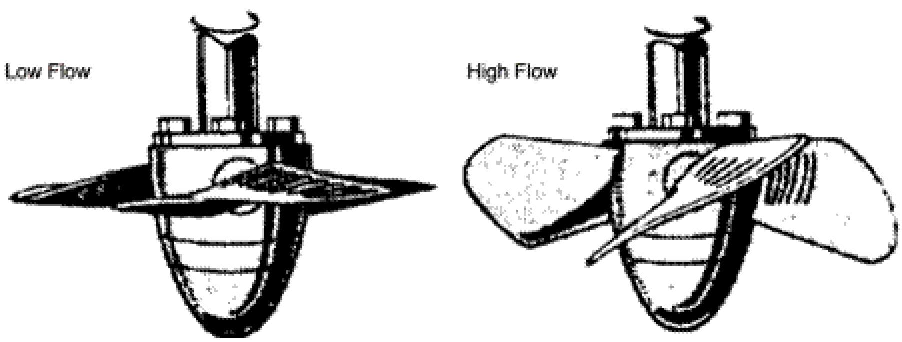


Figure 9. Kaplan Turbine Rotor Blade Positions (Renewables First Ltd.)

There are variants of Kaplan turbines that have only adjustable inlet guide-vanes or adjustable rotor blades, which are known as semi-Kaplans. Although the performance of semi-Kaplans is compromised when operating across a wide flow range, they can be a cost-effective choice for applications where the variation in flow is small. Figure 10 below shows how the efficiency varies across the operating flow range for a full-Kaplan (curve A), a semi-Kaplan with adjustable blades (curve B) and a semi-Kaplan with adjustable inlet guide-vanes (curve D). It also shows the efficiency curve for a propeller–type turbine (a Kaplan with fixed blades and fixed inlet guide-vanes [curve C]).

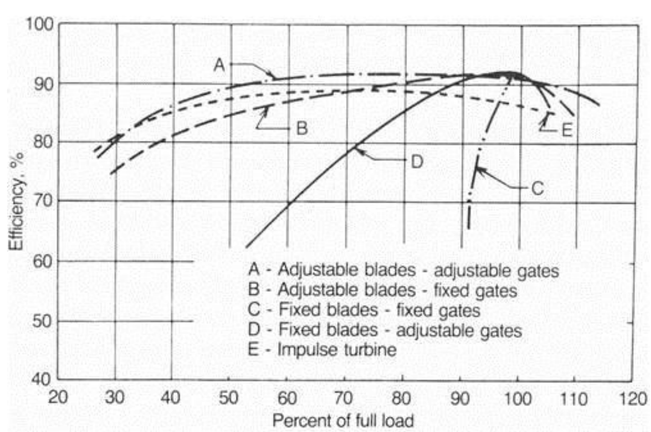


Figure 10. Kaplan Turbine Efficiency Curve Comparison (Renewables First Ltd.)

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6 Turbinator® Technology

6.1 Overview

The Turbinator® developed by CleanPower AS is an axial flow semi-Kaplan turbine, with adjustable guide vane and fixed runner wheel blades, and with an integrated permanent magnet (PM) generator. The generator is efficiently cooled from the process water, and the machine is sealed from the environment. In most climatic conditions, it can be installed outdoors without a powerhouse.

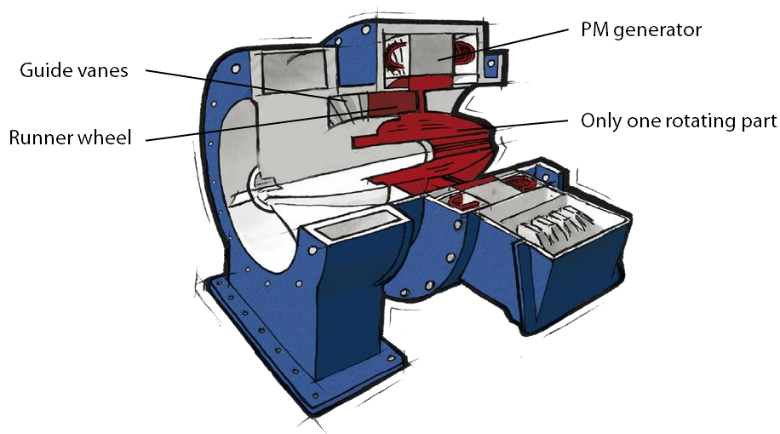

Figure 11. The Profile of Turbinator®

The main features are:

- Compact, easy to install in confined locations
- In-pipe installation: flange in/flange out
- Powerhouse not needed
- Low maintenance: Robust construction with only one rotating part
- Short lead time

6.2 Turbinator Design Process

Each Turbinator products' design is the result of extensive dialogue with the customer to ensure it meets the specific needs for each installation. Physical site requirements and parameters are combined with a set of design criteria to establish a framework that references model-tested experience to suggest a set of physical characteristics of the turbine. The generator's design is based in close concert with the design of the turbine.

6.3 Turbinator Design

The appeal of the Turbinator is its unique component integration and the resulting ease of installation and maintenance. The low head axial turbine and generator are designed and situated together such that the entire unit is very compact and manageable to install. The simplicity of its design is the single rotating generator and turbine assembly combined in an adequately sized housing that contains all moving parts and can be installed with ease.

The generator employs permanent magnetized synchronous generator technology that utilizes permanent magnets as opposed to coils to impose an excitation field. This type of technology reduces the need for slip rings and brushes in the construction of the turbine and generator combination. The Turbinator product design allows for installation at sites capable of producing 100 kW to 3 MW.

The Turbinator housing is designed and constructed to standard specifications; making it compatible with standard runners and generators.

Two and three-dimensional computational tools are used to develop optimum shaped and sized turbine blades. These resources are also beneficial in assessing the generator's performance for various sized applications and virtually constructing the various parts to ensure adequate fit. Figure 12 depicts detailed finite element analysis of magnetic fields in the generator.

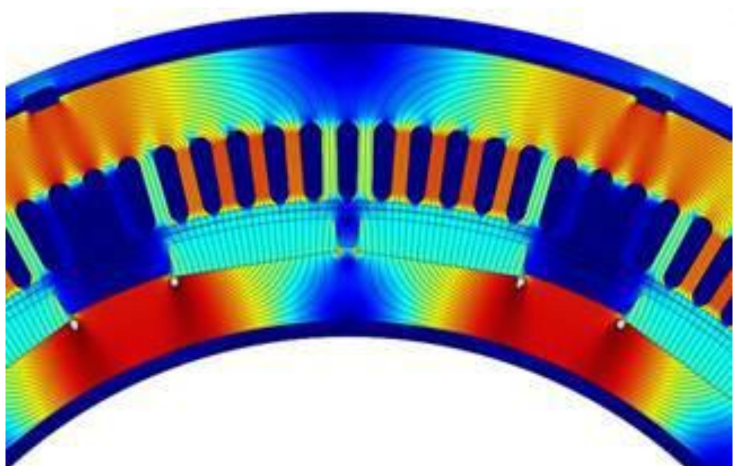

Figure 12. Magnetic Field Modeling Using FEA for Generator

6.4 Turbinator Efficiency

Due to the axial configuration, the turbine efficiency curve in Figure 13 is steeper than curve D in Figure 10.

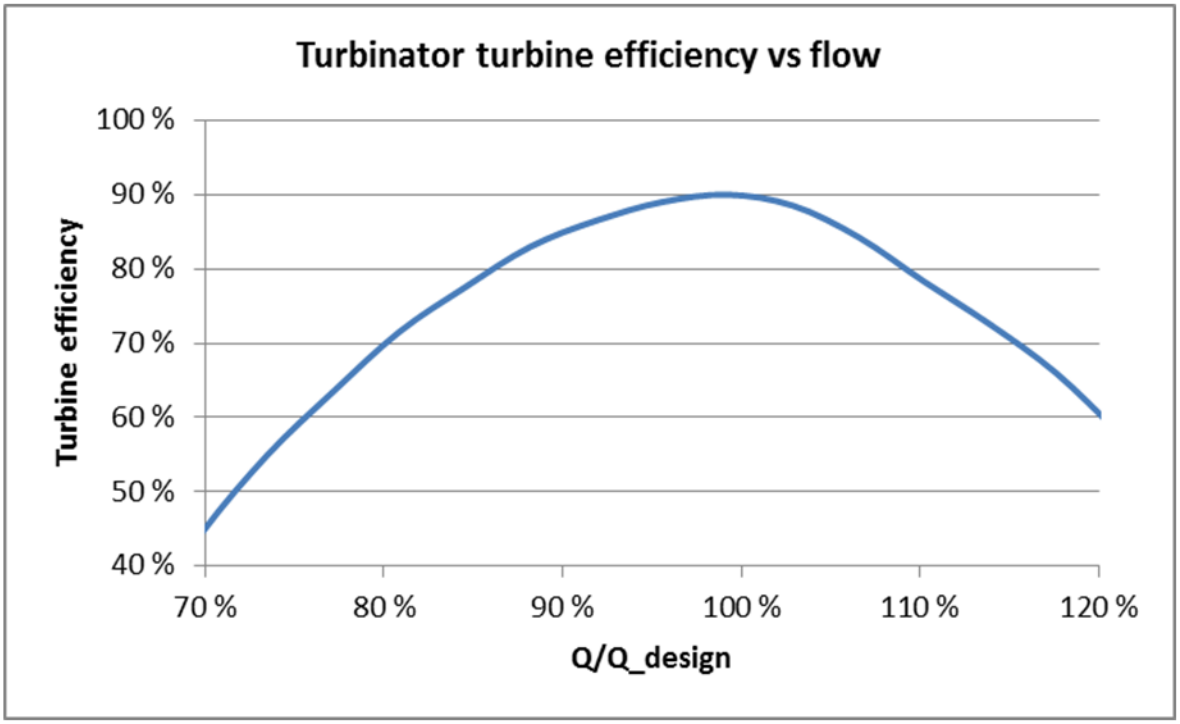

Figure 13. Turbinator Efficiency vs. Flow

NOTE: This is turbine efficiency only, and does not include the generator losses.

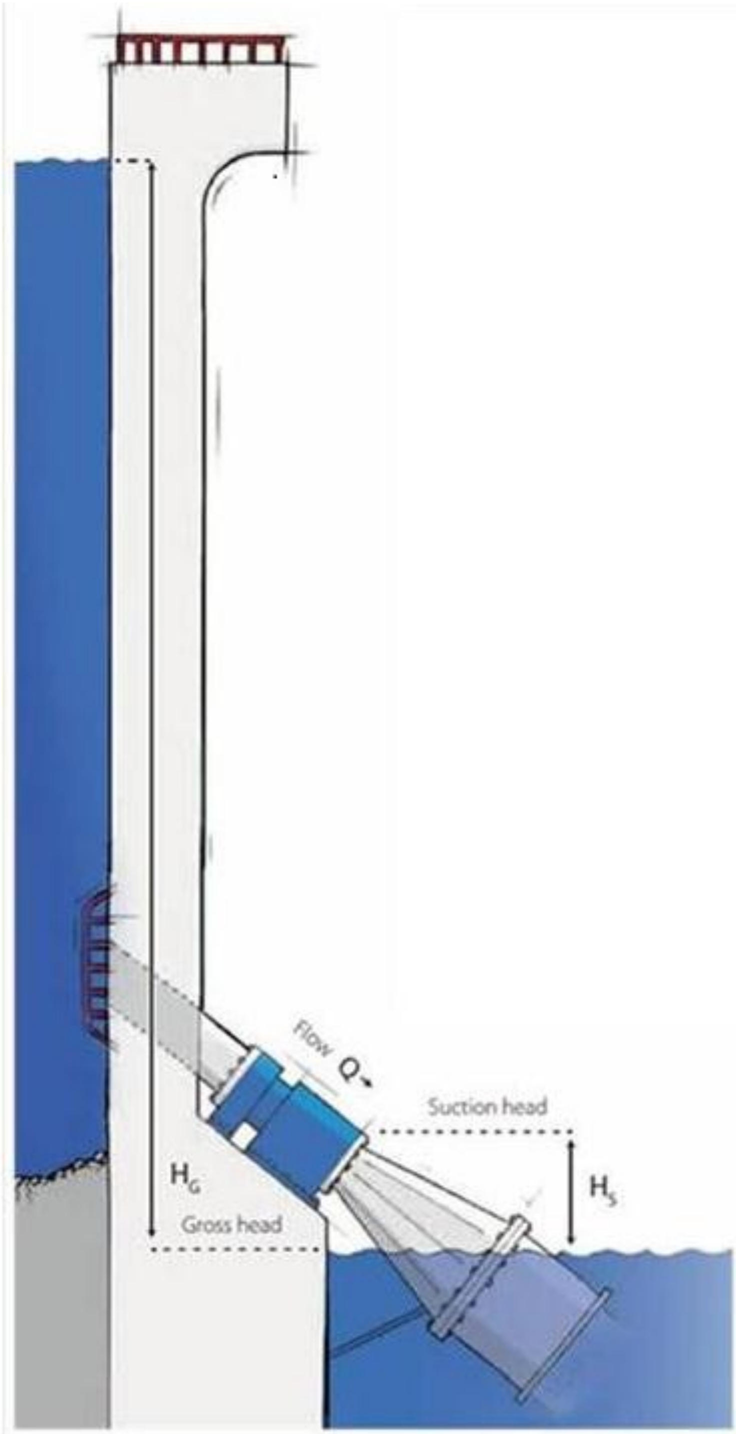

Figure 14. Physical Depiction of Parameters

Considering that the generator has a 5% loss:

Turbinator total efficiency (turbine + generator): > 80%

The parameters used for configuring a Turbinator for a given site installation are (see Figure 14):

Gross head, H_G
The vertical distance between reservoir / intake water level and downstream tailrace water level.

Net head, H_N
Gross head minus dynamic head loss in the system. The head loss increases as the pipe diameter decreases.

Flow, Q
The volume of water passing the turbine per unit time.

Suction head, H_S
The vertical distance between tailrace water level and the upper point of the outlet side of the Turbinator, corresponding to the location of the lowest pressure. The Turbinator must be configured appropriately to avoid cavitation, a potentially destructive hydrodynamic process that occurs in intermittent low pressure zones, typically at the outlet of the runner wheel.

Site elevation
Information of the site elevation (height above sea level) is considered as the decreased air pressures at high altitudes could potentially affect the onset of cavitation.

6.5 Typical Installation

Figure 15 shows the main components of a typical installation. The components consist of:

- The Main valve opens and closes the water flow
- The plant control system which includes:
  - Turbinator monitoring and control
  - Main valve control (electrically actuated valve assumed)
  - Power switching to grid
  - Power protection circuitry
  - Synchronization
  - Ready for remote access and monitoring via internet
  - Oil circulation system
- The downstream draft tube ensures a continuous water string down to the tailrace (downstream) water outlet level.
- The Turbinator which converts hydraulic energy into electrical energy

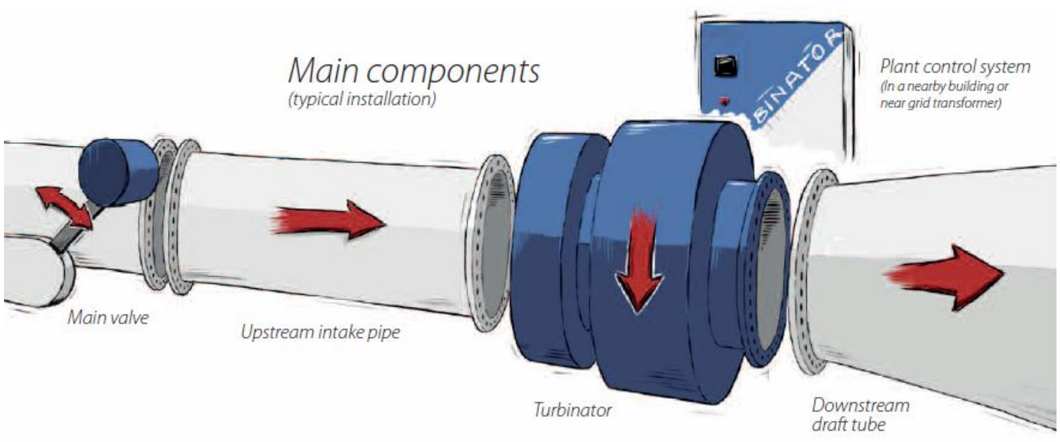

Figure 15. Main Components of a Turbinator Installation

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7 SUMMARY OF HEGSET DAM PROJECT

7.1 Pilot Installation at Statkraft Dam 2010

Following four years of prototype construction and testing at CleanPower AS' test facility in Kristiansund, Norway (Figure 16), the first Turbinator® was constructed and installed in 2010 as a pilot installation at the Statkraft-owned 'Hegset Dam' in the Nea River in Tydal near Trondheim, Norway. The pilot installation utilizes the flow released for environmental purposes, and has an installed capacity of 280 kW. Nominal net head is 24 meters (78.7 feet) and the nominal flow 1.2 m^3/s (42.4 cfs). The installation demonstrates the feasibility of installing a small hydropower plant at the toe of the dam. The Turbinator's ability to survive total submersion has been proven due to the occurrence of heavy flooding at this project.

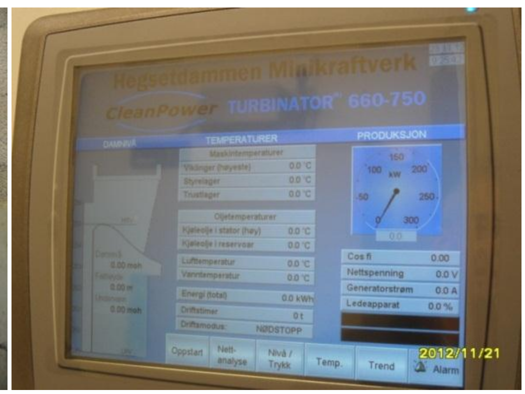

Photo showing first water through the turbine, before the downstream reservoir had reached its normal level to submerge the draft tube outlet.

Figure 16. First Pilot Turbinator Application, Monitoring System, Control Panel, and Turbinator, Hegset Dam 2010

7.2 Summary of the Monitoring and Results at Hegset Dam

The following graphics in Figures 17 and 18 depict visual aid tools used at the Hegset Dam for monitoring the performance and operation of the Turbinator.

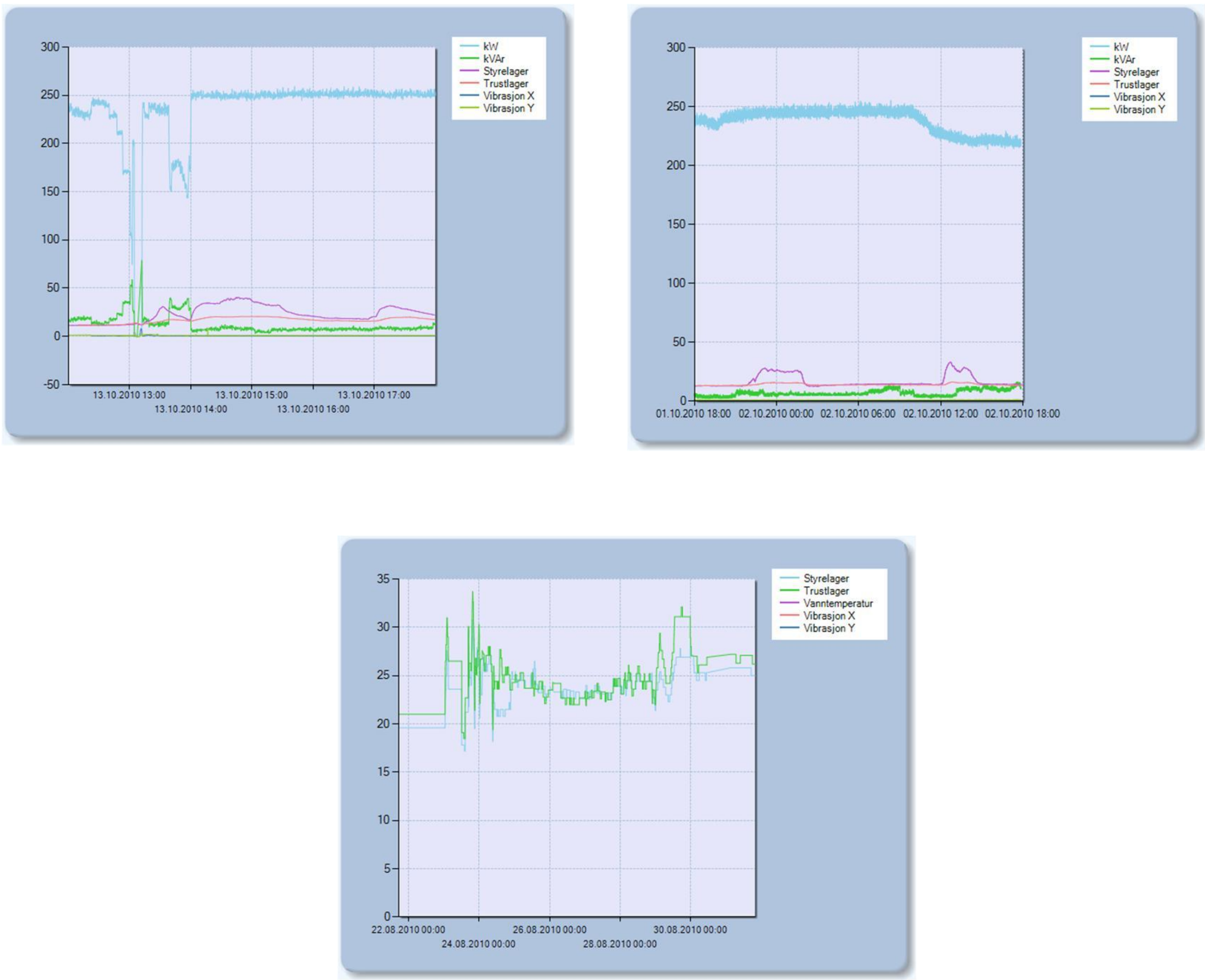

Figure 17. Typical Performance Monitoring Metric Plots Associated with the Operation of the Turbinator

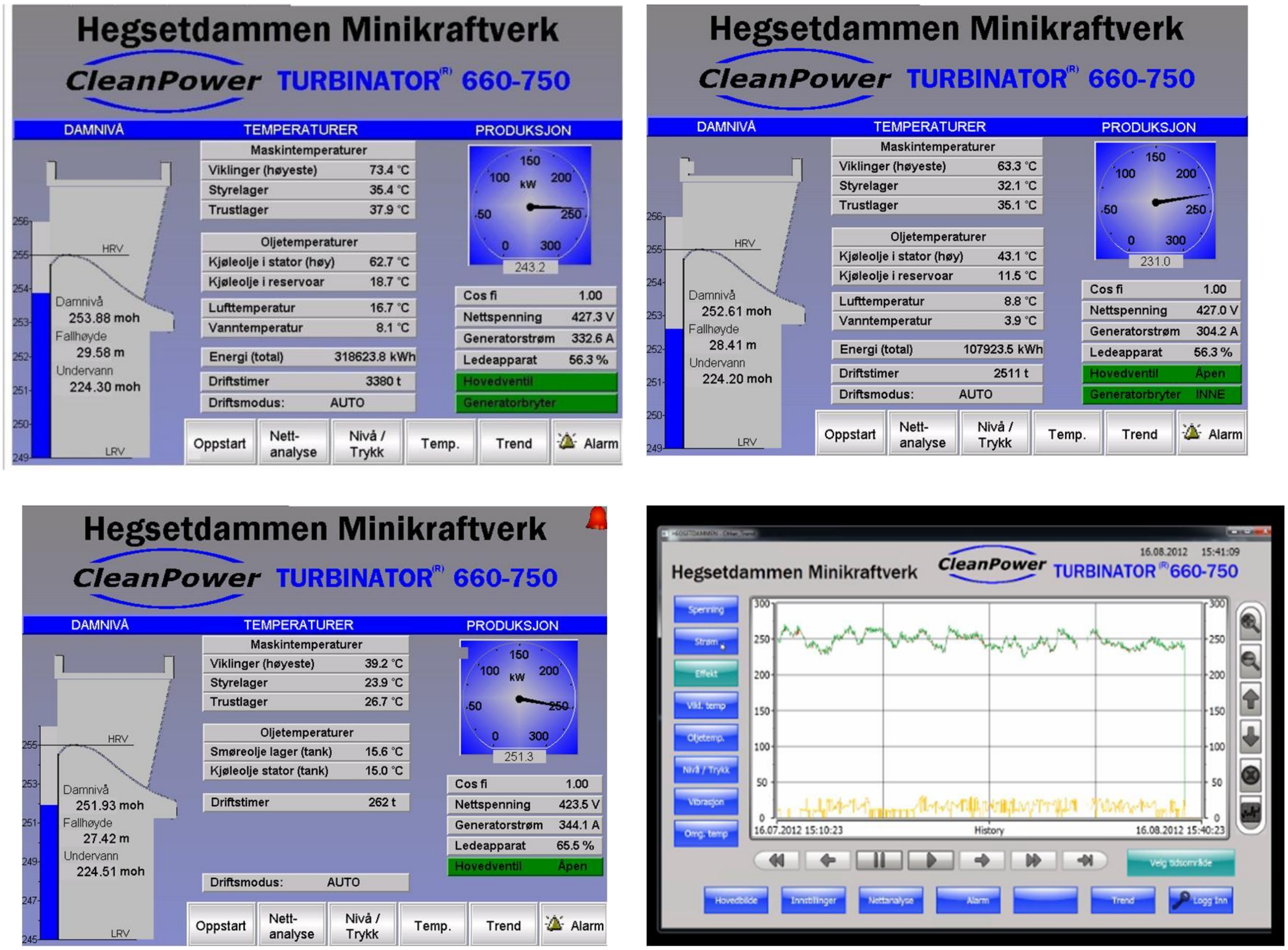

Figure 18. Typical Information Interfaces Associated with the Operation of the Turbinator

8 SUMMARY OF TJELDBERGODDEN PROJECT

8.1 Background

The largest methanol factory in Europe is located at Tjeldbergodden in Norway (Figure 19), and utilizes piped-in natural gas from offshore reservoirs located mainly at the Draugen field. Sea water is used as process cooling water at the methanol plant. Using the Turbinator technology, the methanol plant cooling water is used to generate power before being discharged back to the sea. The construction of a 450 kW hydropower plant was completed by the end of 2012, and it is expected that generation will start early 2013. The plant is expected to produce an estimated annual generation of 3.3 GWh. The power produced will be used for seawater pumping by an on-site land-based fish farming facility.

Figure 19. Tjeldbergodden Methanol Plant

Tjeldbergodden runner wheels were made at a local molding company, Oshaug Metall AS. Figure 20 shows a fabrication mold at Oshaug Metall AS.

Figure 20. Molding Factory for the Turbinator Runner Wheel, Norway

8.2 Summary of Second Application of the Turbinator Technology: Tjeldbergodden Project

- Energy recovered from Statoil methanol plant cooling water pumps (Figure 21 schematic)
- Produced power will be delivered locally to an on-site fish farming installation
- Production: 3.3 GWh/year (annual consumption of 165 Norwegian households)
- Public investment support: $800,000
- Ongoing project, in operation early 2013

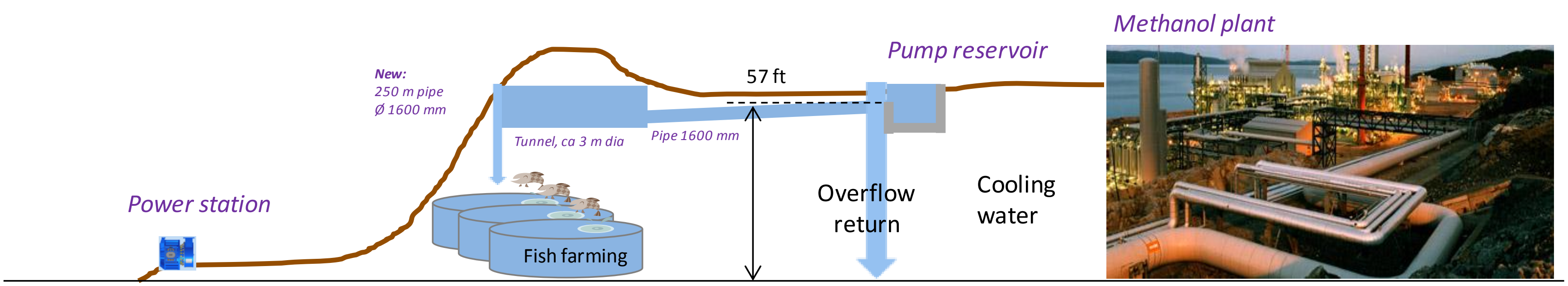

Figure 21. Schematic Layout of the Tjelbergodden Project and Project-Related Photos

Figure 22. Construction of the Tjeldbergodden Turbinator

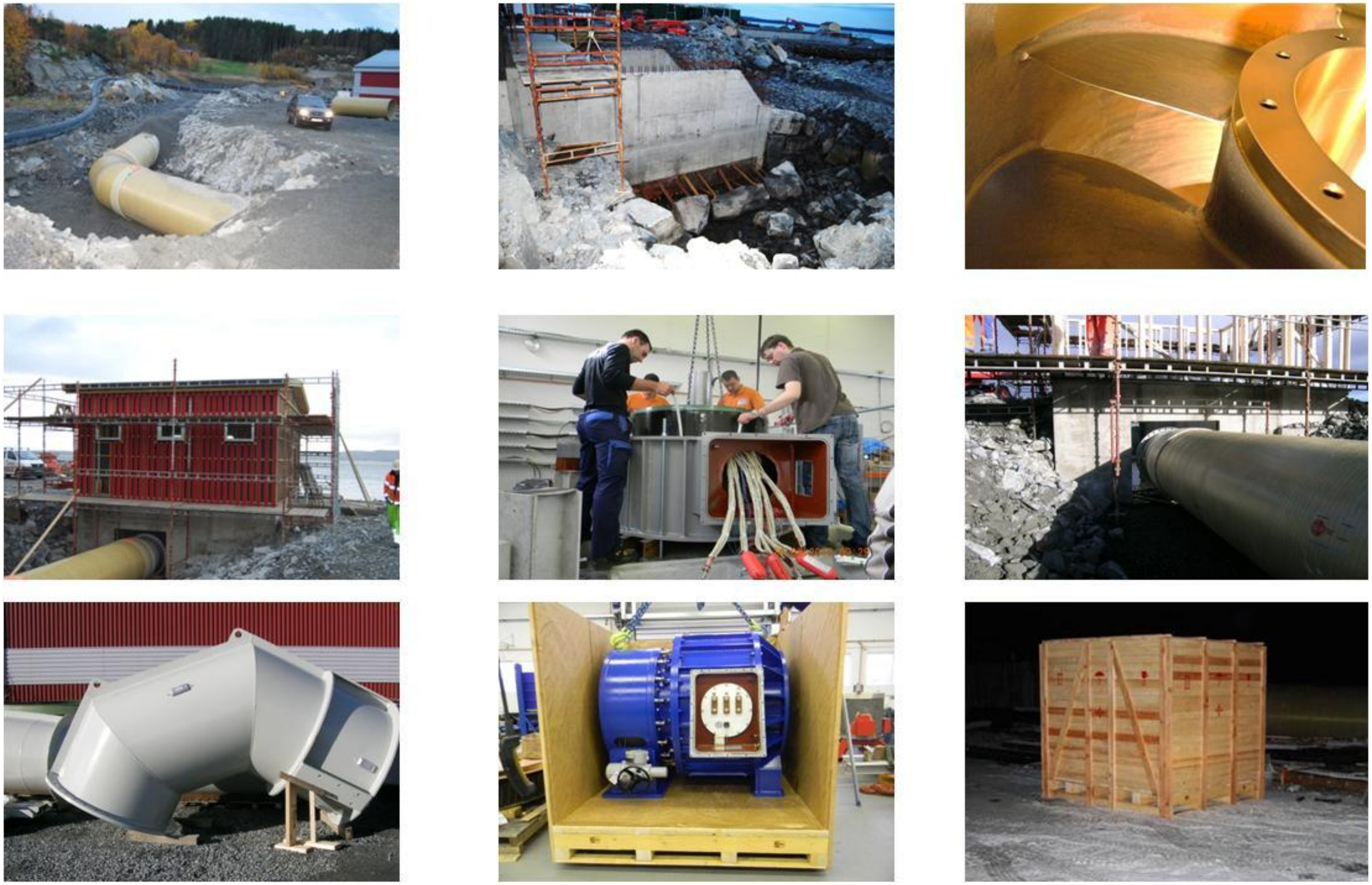

Figure 23. Construction of Tjeldbergodden Energy Recovery Plant

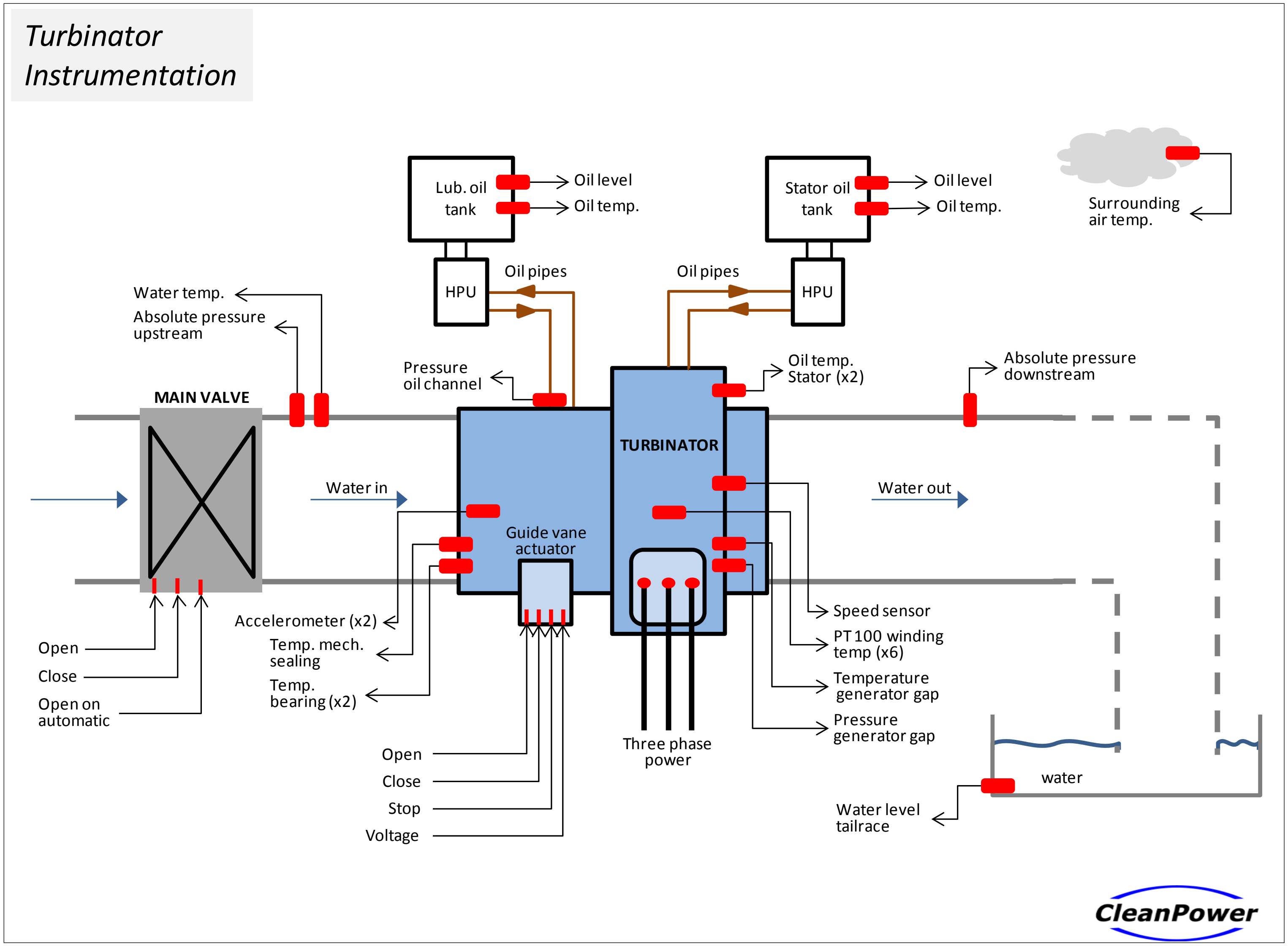

Figure 24. Layout of the Turbinator Monitoring Instrumentation

Figure 25. Installation of the Control Panels and the Second Turbinator Application, Tjeldbergodden, 2012

9 CONCLUSION AND RECOMMENDATIONS

Oak Ridge National Laboratory (ORNL) is a partnering entity in the EBD proposal and received funds through the FY2011/12 AOPs to support EBD's effort by evaluating the design, manufacture, and deployment outcomes in Norway for the Turbinator technology as a pre-requisite for deployment in the U.S. An ORNL assessment and evaluation of the Turbinator was the primary reason for the November 2012 trip to Kristiansund, Norway. Based on the visit, discussions with designers and operators, and first-hand observations of the Turbinator in use at a similar site, ORNL concludes that the technology is appropriate and ready for deployment to the EBD site in Oregon. This conclusion was communicated via email to EBD on November 23, 2012, along with a recommendation that EBD releases funds to CleanPower to initiate fabrication of Turbinator equipment for the Oregon site.

It is understood that there are critical deadlines associated with Turbinator installation at the Oregon site that are related to seasonal irrigation operations that may negatively impact the ability for the EBD team to accomplish a successful demonstration for the period of performance according to the scope of the DOE awarded project. During the trip to Norway, CleanPower AS staff indicated that it would require seven to eight months from order to delivery and about one month for installation. Given that the irrigation season begins April 15 for the Oregon deployment site, and since the irrigation season ends on October 15, it is unlikely that the installed technology can be demonstrated during the 2013 irrigation season.

EBD may have encountered challenges with their site-specific design and permitting process that prevented them from ordering equipment. In any case, it is recommended that a follow-up discussion should be made as soon as possible to confirm the status of EBD's effort and their intent to pursue the order and funding for manufacturing the Turbinator equipment.

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- Trygve Siira, Sales
- Kristin Skoglund, Project Manager (MSc)

<u>CleanPower Board of Directors:</u>

- Chairman: Reidar Bjerkestrand, CEO in regional investment fund.
- Knut Hansen, CEO at NEAS (regional power utility company)
- Nils Erik Pettersen, CEO of local energy consultancy company
- Sivert Sande, Board member

Statkraft:

- Per Morten Aunemo, Regional head of Statkraft power plants, Trondheim region

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12 ACRONYMS

DOE	Department of Energy
EBD	Earth By Design
FAT	Factory Acceptance Tests
FOA	Funding Opportunity Announcement
kW	Kilowatt
LCOE	Levelized Cost of Energy
MW	Megawatt
ORNL	Oak Ridge National Laboratory
PM	Permanent Magnet
PPA	Power Purchase Agreement
WWPP	Wind and Water Power Program

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APPENDIX A: GENERAL SPECIFICATION OF THE TURBINATOR TECHNOLOGY

CleanPower

TURBINATOR™

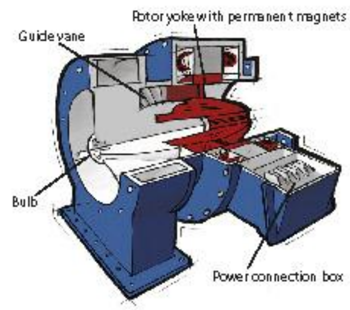
Technical specifications

The TURBINATOR™

The Turbinator™ is an axial flow, fixed-blade Kaplan turbine with a direct drive synchronous permanent magnetized generator (PMG).

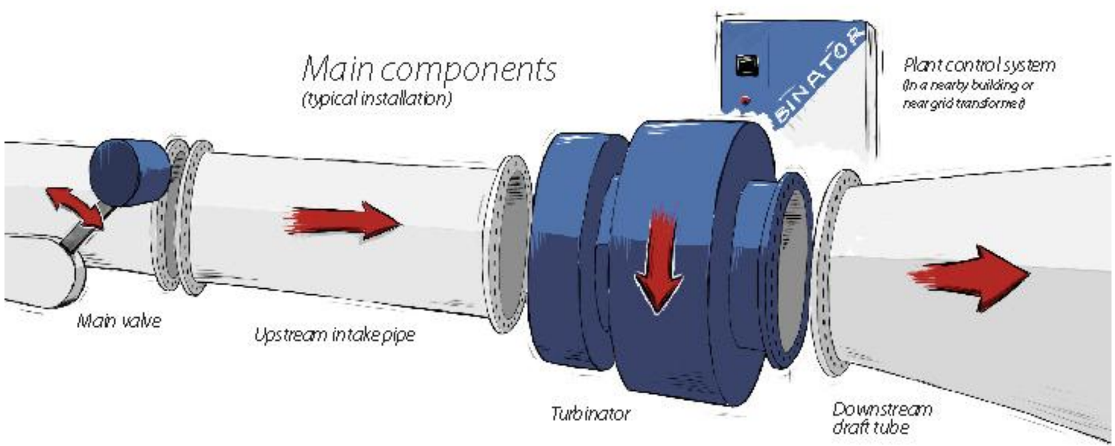
Using patented technology, it has only one rotating part and is a robust and cost-efficient alternative to a traditional and more complex Kaplan installation.

The integrated PMG gives a compact unit with high energy density and small footprint, and a sealed machine that does not require a protecting power house.



Easy installation – no power house – reduced civil works

The Turbinator™ is a sealed (IP68) unit that does not need a power house, which significantly reduces the site civil works. This reduces both site investment and construction time. The unit generates at low voltage (440 or 690 V) and is directly switched into the grid transformer.



Site configuration

The Turbinator™ comes in six sizes. Within each size the runner wheel geometry, rotational speed and generator rating are configured to match the site requirements. The main input data needed for configuring the Turbinator configuration are: ***Net head***, ***nominal flow*** and ***suction head need*** (see illustration). In addition, statistical flow data for the site are useful to optimally select the design point.

CleanPower has a close dialogue with the customer throughout the project, from initial contact and request through to installation and commissioning, and for after sales service needed during the life cycle.

Assess the power potential of your site!

The potential energy can easily be approximated with the following formula:

$$P[kW] = Q[m^3/s] \cdot H_N[m] \cdot g[m/s^2] \cdot \eta$$

or

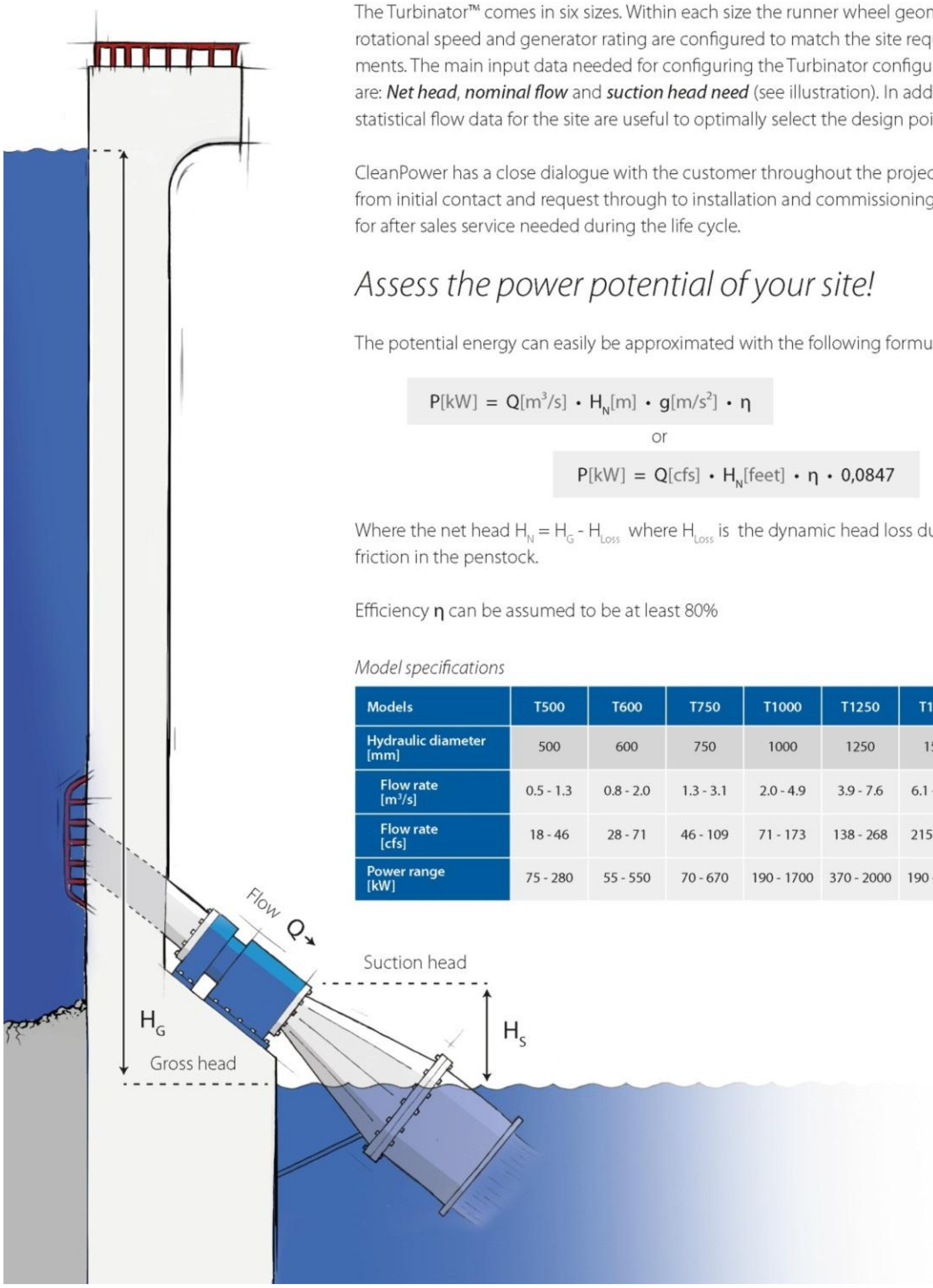
$$P[kW] = Q[cfs] \cdot H_N[feet] \cdot \eta \cdot 0{,}0847$$

Where the net head $H_N = H_G - H_{Loss}$ where H_{Loss} is the dynamic head loss due to friction in the penstock.

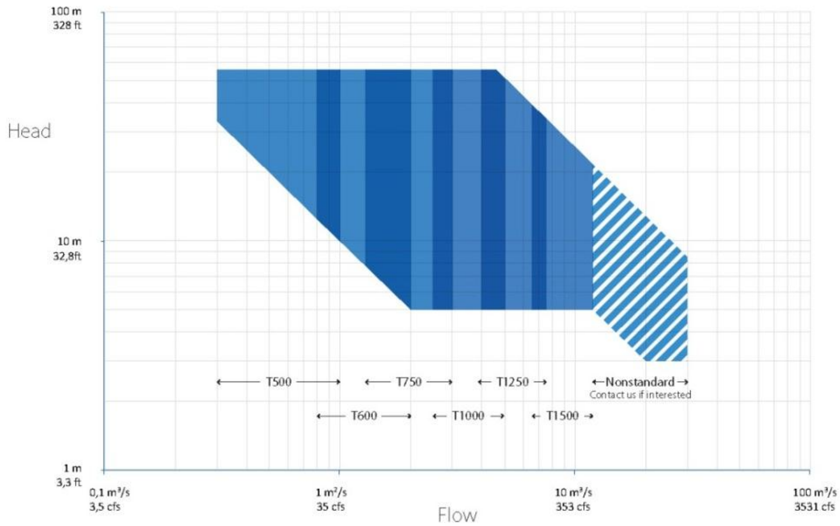
Efficiency η can be assumed to be at least 80%

Model specifications

Models	T500	T600	T750	T1000	T1250	T1500
Hydraulic diameter [mm]	500	600	750	1000	1250	1500
Flow rate [m³/s]	0.5 - 1.3	0.8 - 2.0	1.3 - 3.1	2.0 - 4.9	3.9 - 7.6	6.1 - 11.9
Flow rate [cfs]	18 - 46	28 - 71	46 - 109	71 - 173	138 - 268	215 - 420
Power range [kW]	75 - 280	55 - 550	70 - 670	190 - 1700	370 - 2000	190 - 3300



Model size map



General specifications

Standard power range	100 - 3000 kW
Total efficiency	≥80% (turbine + generator)
Flange dimension	PN6 (DIN-EN 1092-1)
Surface treatment	Double layer epoxy paint
Maintenance	Programmed revision according to O&M manual at three year intervals
Life span	Up to 50 years
CE-marked	Yes
IP-class	IP68
UL Certification	Power and controls

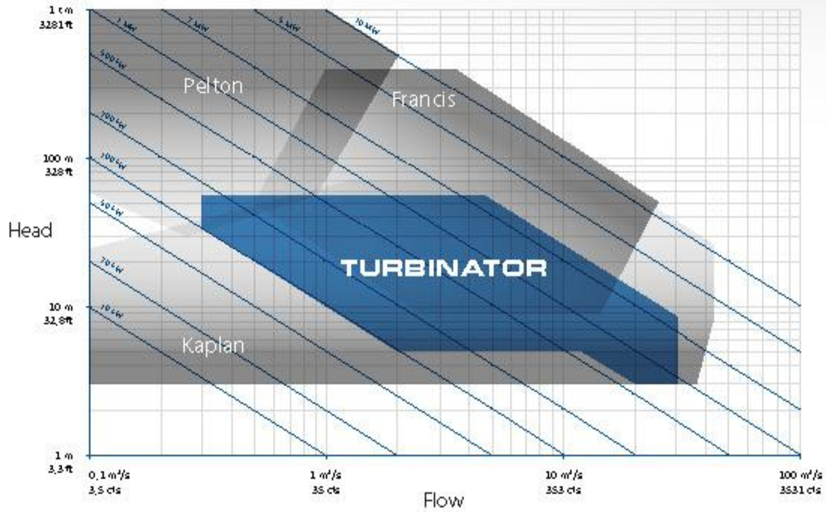
Grid interface

Grid voltage	400 - 690 V
Grid frequency	50 or 60 Hz 3-phase
Power factor	cos φ > 0.95 at full load

Options

Main valve	**Foundation steelwork**
Inlet pipe	**Installation supervision**
Draft tube	**Commissioning**

Turbinator™ vs other turbine technologies



The Turbinator is a low complexity alternative to a traditional small hydropower plant. Its robust construction with only one rotating part ensures a reliable installation with low maintenance costs.

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