SOME TECHNIQUES USEFUL FOR RENOVATION, MODERNIZATION AND UPGRADATION OF HYDRO POWER STATION

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Workshop on “Renovation, Modernization, Uprating & Life Extension of Hydro Power plant- Diverse Issues & Handling Strategies ”

Introduction

- **RM&U requirements**

-Rrefurbishment of the old hydro power stations is the most economical way of enhancing the installed capacity in a much shorter time and efficient way.

- Normal life of Hydropower plant → **30-35 years**
- Normal Modernization process → **15-20 years**
- Uprating possible if available hydropower potential is more or existing generating unit efficiency is low.

Modernization can be performed simultaneously with Renovation to improve the reliability of Hydropower station.

RM&U Assessment

- For **RM&U**, followings may be considered
  - Assessment of existing and available unit efficiency
  - Wear and tear of the components
  - Mechanical/Electrical/Hydraulic failure
  - Modern equipment
  - Wide range for turbine operations
  - Reliability in operations
  - Optimization and flow field study of the plant
  - Pay-back period
  - Power potential studies
  - Socio-economic Issues

Performance assessment

- **Some of the Methods** (as per **IEC 60041**)

Discharge measurement	**Uncertainty**
– Current meter	± 1% to ± 2.3%
– Pitot tubes	± 1.5% to ± 2.5%
– Pressure-time	± 1.8% to ± 2.3%
– Tracer method	± 1% to ± 2%
– Weir	± 1.7% to ± 3%
– Transit-time	± 1% to ± 1.5%

Hydraulic efficiency Measurement

– Thermodynamic method	± 0.2% to ± 0.6%

Our experience of Efficiency Measurement

- **Current-meter Method:** Used for many station in India, particularly for open channel flow measurement.

  Problem – large uncertainty in discharge measurement.

Maximum uncertainty in Unit Efficiency Measurement: **± 4%**

48 current-meters used

Parameter	Uncertainty(%)
Discharge	±3.082
Head	±0.394
Power	±0.735
Unit efficiency	±3.193

Eff. at rated load = 89.06 ± 3.193%

Our experience of Efficiency Measurement

- **Thermodynamic Method (IEC 41)**

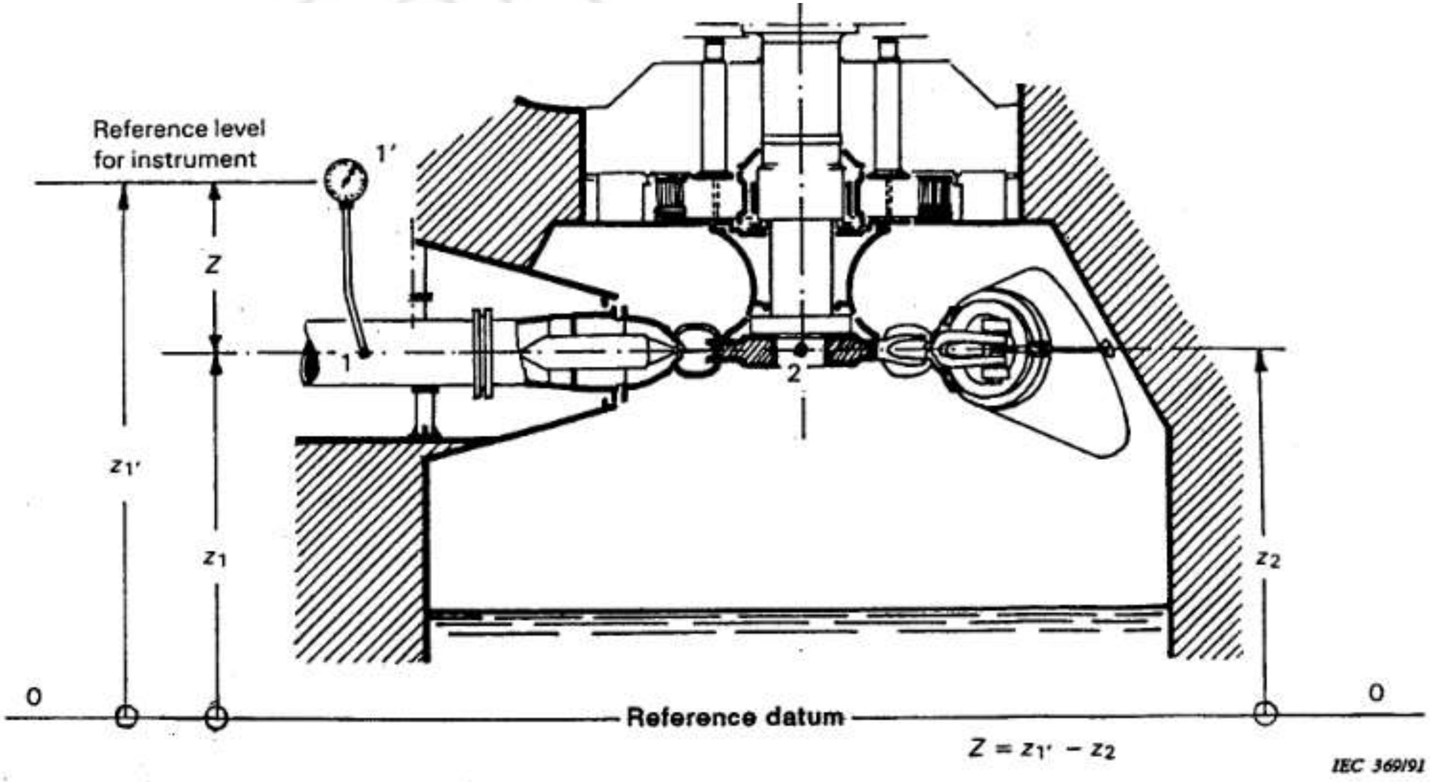
Principle

- ✓ The thermodynamic method results from the application of the principle of conservation of energy
- ✓ Governs on first law of thermodynamics
- ✓ Transfer of energy between water and the runner/impeller through which it is flowing.
- ✓ Recommended for specific hydraulic energies in excess of 1000 J/kg (or 100 m head).
- ✓ Specific mechanical energy at the runner/impeller is determined by the ***pressure, temperature, velocity, and thermodynamic physical properties*** of water

Cont.... Thermodynamic Method

- Specific Hydraulic Energy is calculated as:

$$E = \bar{g}H = \frac{(p_{1'} - p_{2'})}{\bar{\rho}} + \bar{g}(z_1 - z_2) + \frac{v_1^2 - v_2^2}{2}$$



Cont…. Thermodynamic Method

Specific Mechanical Energy (E_m):

- Mechanical power transmitted through the runner/impeller.
- It is calculated with the help of thermophysical properties of water striking through jet at runner.

$$E_m = \bar{\alpha}\left(p_{abs11} - p_{abs20}\right) + \overline{C_p}\left(\Theta_{11} - \Theta_{20}\right) + \frac{v_{11}^2 - v_{20}^2}{2} + g\left(z_{11} - z_{20}\right) + \delta E_m$$

- ***Hydraulic efficiency:***

$$\eta_h = \frac{E_m}{E \pm \frac{\Delta P_h}{P_m} E_m}$$

Discharge calculation:

Discharge is not measured but it is calculated as iteratively

$$Q = \frac{P_{el}\eta_{gen} + P_{mechloss}}{\rho E \eta_h}$$

Turbine runner, Thermowell and vessel

- **Thermodynamic Method**: Two power plants in Himachal

Inspection of Pelton Turbine

Eliminate direct measurement of discharge

Total uncertainty of efficiency measurement = ± 1 %

Thermo-well Probe and Vessel

Thermodynamic Method

Insulated Thermo-vessel Assembly

SBE 38 Seabird Thermometer

Inlet pressure measurement

Data Acquisition

Our experience of Unit Efficiency Measurement

- **Bassi hydro power station (4x15 MW)**

✓ Before and after RM&U

✓ For the measurement of discharge in the individual penstocks, an ultrasonic transit-time flow-meter (UTTF) with clamp-on type ultrasonic transducers was used for the following reasons:

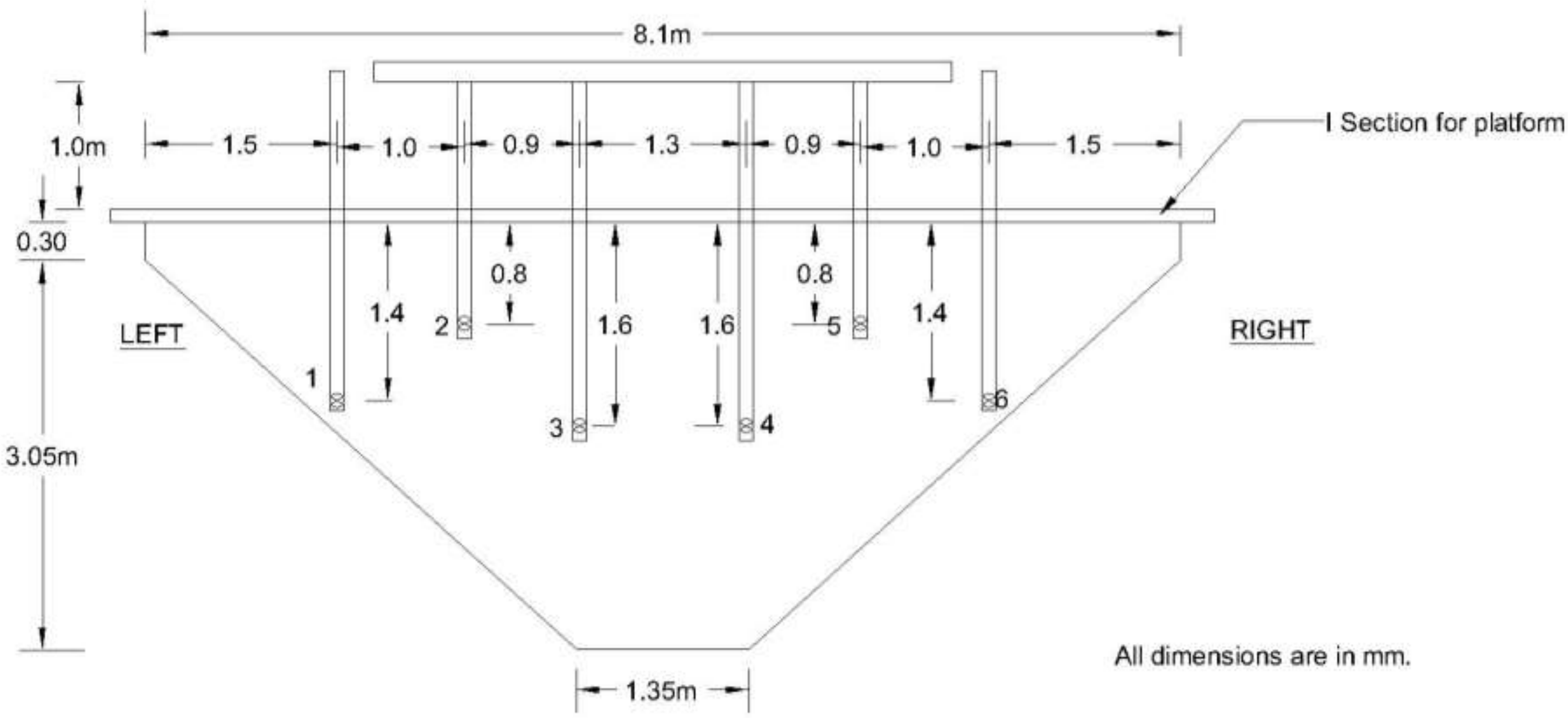
  – To avoid puncturing of the old penstocks to install intrusion-type ultrasonic transducers.

  – To save the time and cost of drilling holes and installing intrusion-type transducers.

  – Lower cost of clamp-on type UTTF as compared to intrusion-type UTTF.

✓ It was decided to use a battery of propeller current meters (PCMs) movable / fixed to a mounting frame to evaluate the discharge capacity.

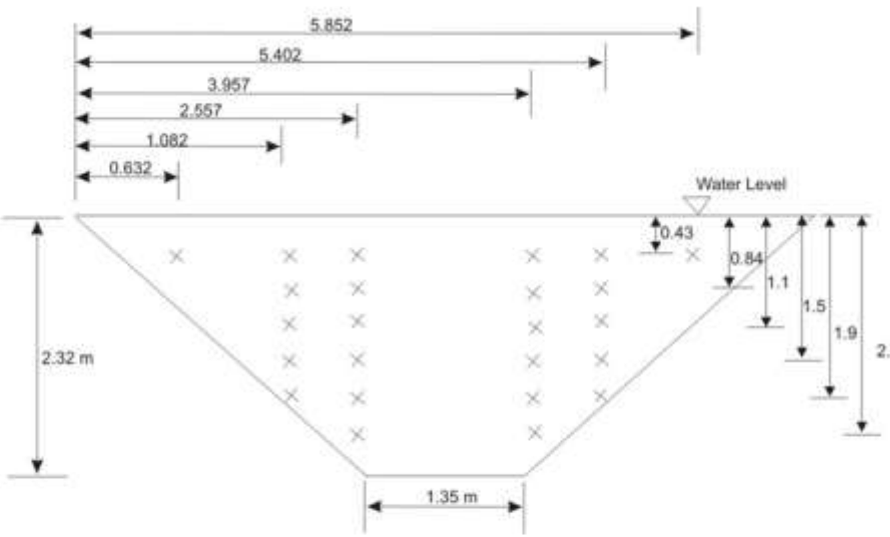
Discharge Measurement in power channel



Discharge Measurement in power channel

The discharge in the power channel was also measured simultaneously using acoustic instruments, namely a Horizontal-beam and a Vertical-beam acoustic Doppler current profiler (ADCP).

Matrix of discharge measurement points
(All dimensions are in meters)



✓Discharge through the power channel:
24.193 m^3/s

Total uncertainty of discharge measurement= ± 2.345%

Performance assessment

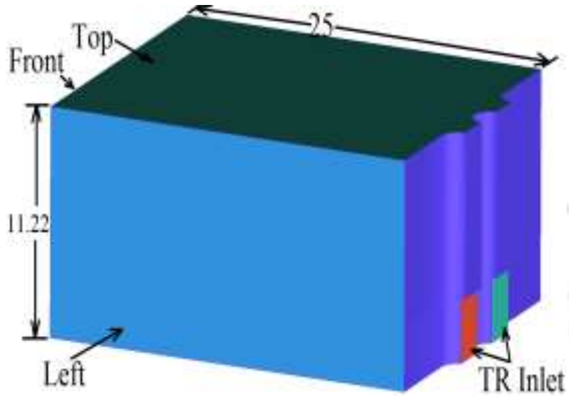
- **Pre-renovation unit efficiency**

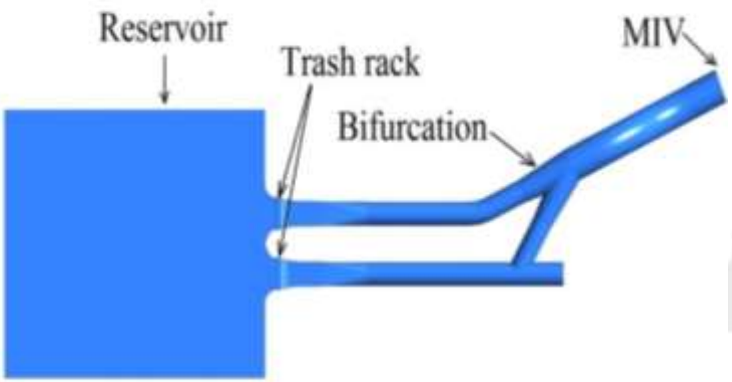
Generating Unit	Net head (m)	Average discharge (m^3/s)	Power output (kW)	Unit efficiency (%)
1	338.787	6.010	14431.8	**72.41**
2	341.007	6.044	15598.2	**77.31**
3	339.238	6.112	14368.2	**70.74**
4	336.683	5.523	14568.0	**79.98**

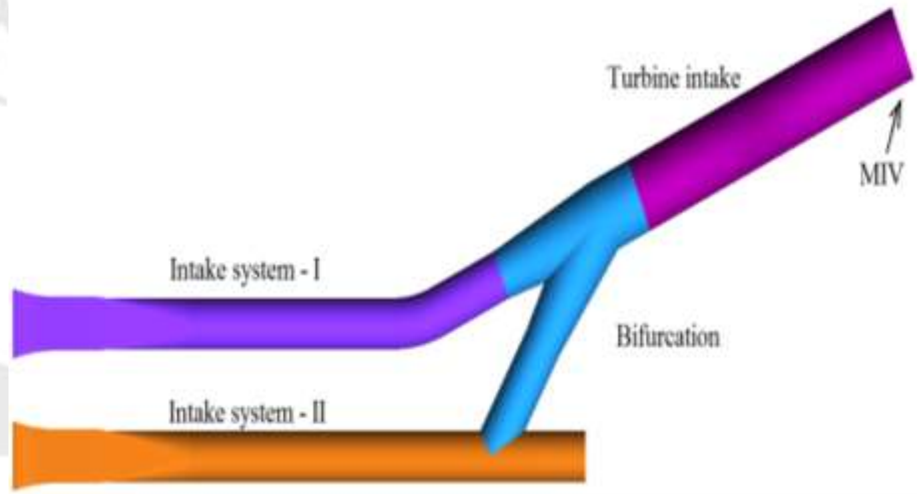
- **Post-renovation unit efficiency (Unit 1)**

Quantity	Load on unit		
	100%	**80%**	**60%**
Averaged discharge (m^3/s)	5.634	4.504	3.380
Net head (m)	341.470	343.146	344.509
Electrical power output (kW)	16560.3	13302.9	9986.7
Unit Efficiency (%)	**87.77**	**87.76**	**87.46**
Generator efficiency as evaluated earlier (%)	98.43	98.28	97.96
Turbine Efficiency (%)	**89.17**	**89.30**	**89.28**

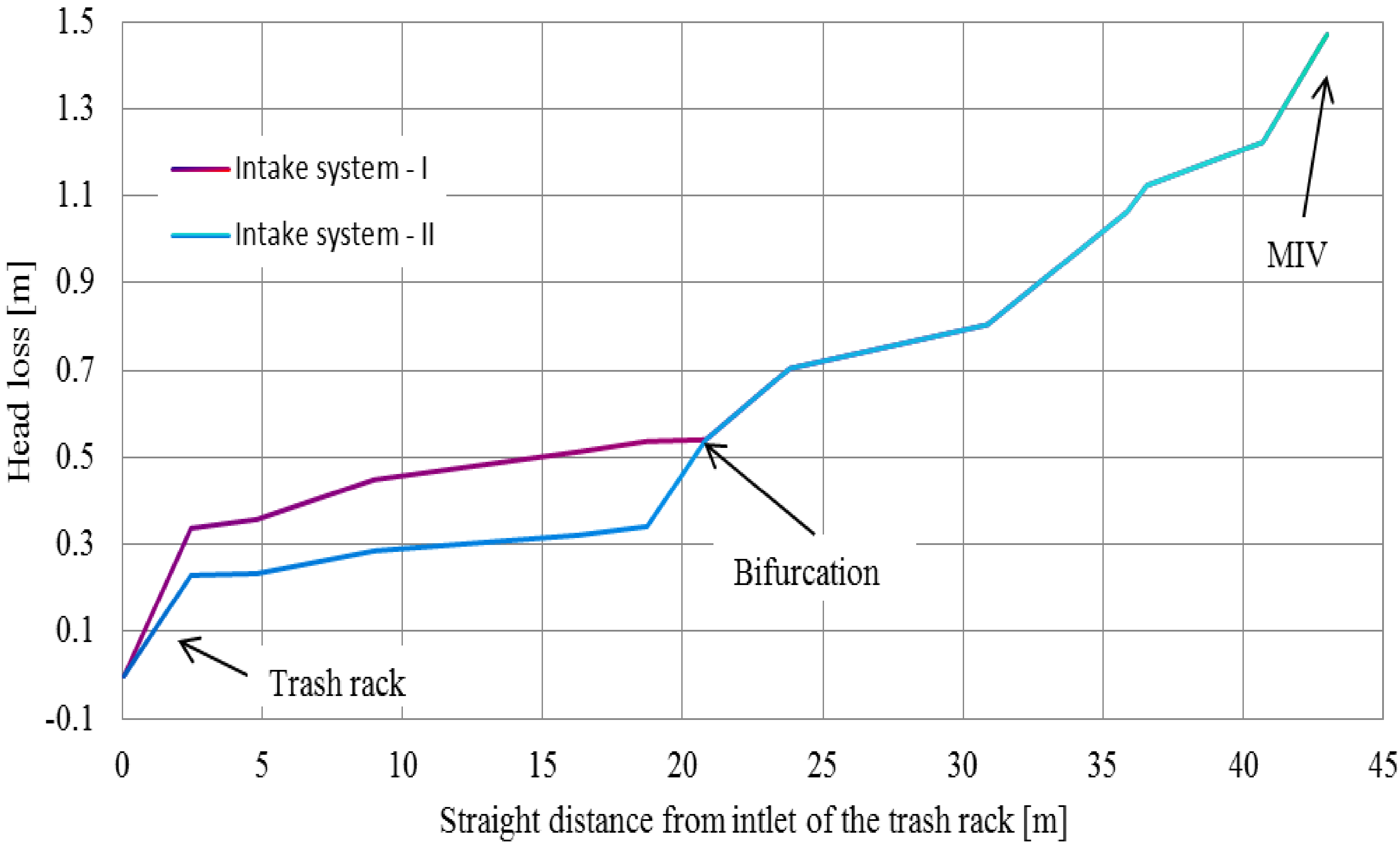
CFD Analysis of Hydro Power Stations



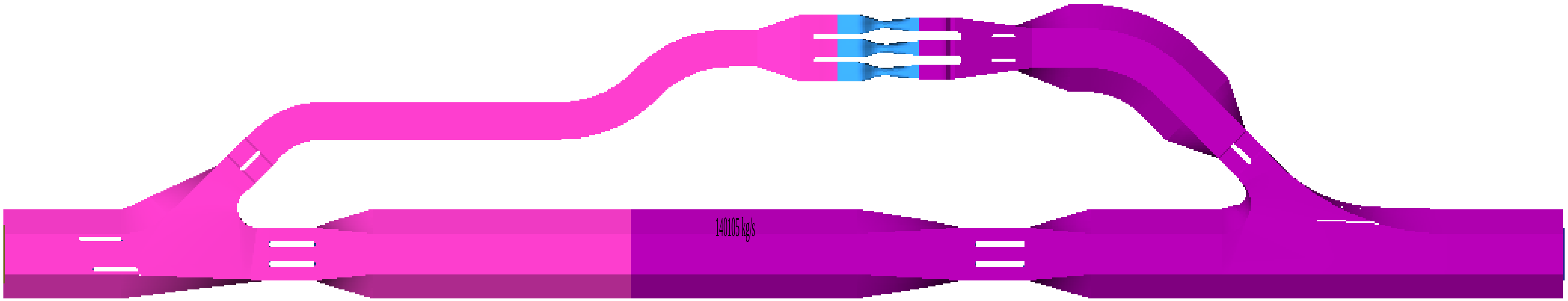




Head loss Analysis



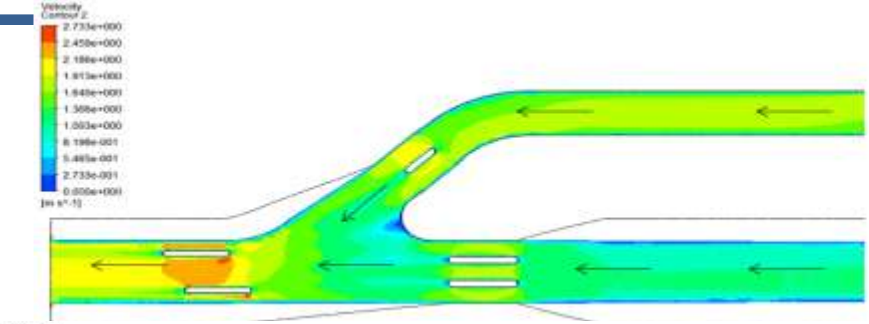
CFD analysis of canal based project

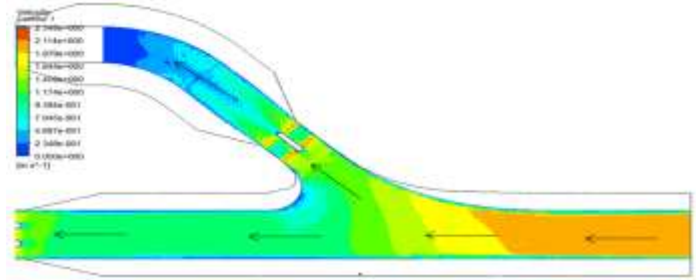


Description	U/S	D/S, MBC	D/S, TRC
Full Supply Discharge (m^3/s)	136.120	136.120	66.000
Full Supply Level (m)	69.581	66.581	64.581
Bed Level (m)	65.431	62.431	60.431
Full Supply Depth(m)	4.15	4.15	4.15
Bed Width	10.43	10.43	9.5
Side Slope (H:V)	1.50	1.50	0.00
Height of Fall (m)		3.00	5.00

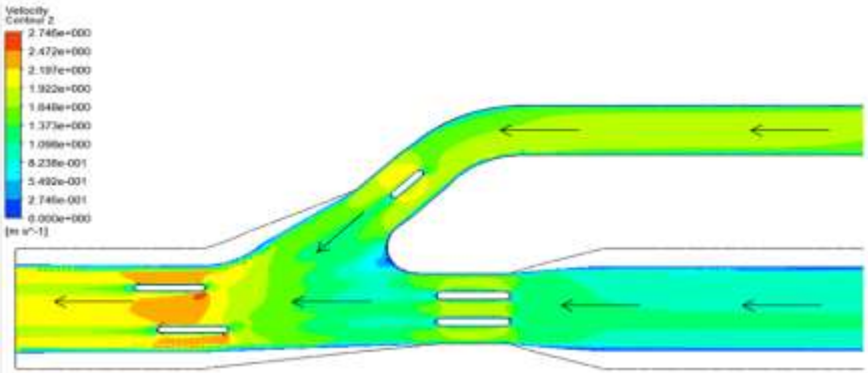
Mesh Size (m)	Total Elements No.	Skewness	Orthogonal Quality
0.5	3035663	0.698	0.386
0.75	2104794	0.684	0.412
1	976498	0.699	0.381

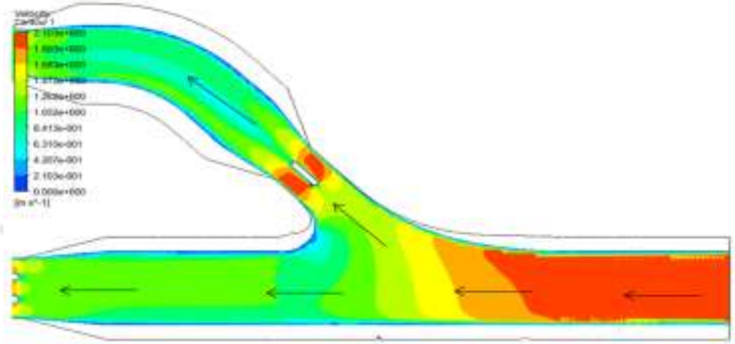
Velocity contours at different water depths



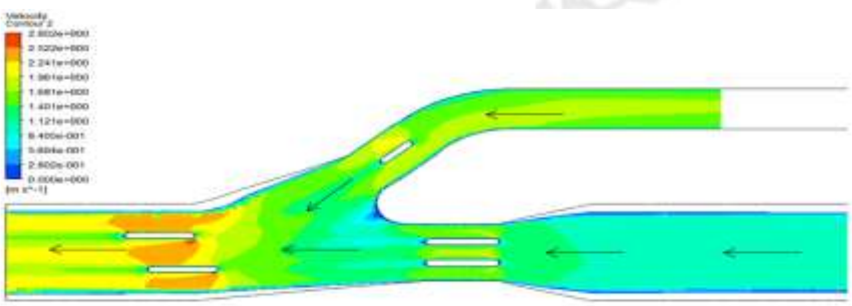


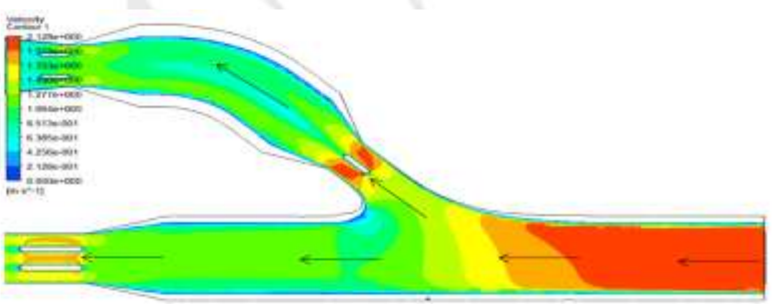
1 m depth





2 m depth





3 m depth

Flow rate = 140.105 m^3/s

CFD Analysis for Additional Unit

- **Flow field investigation in Power Channels**

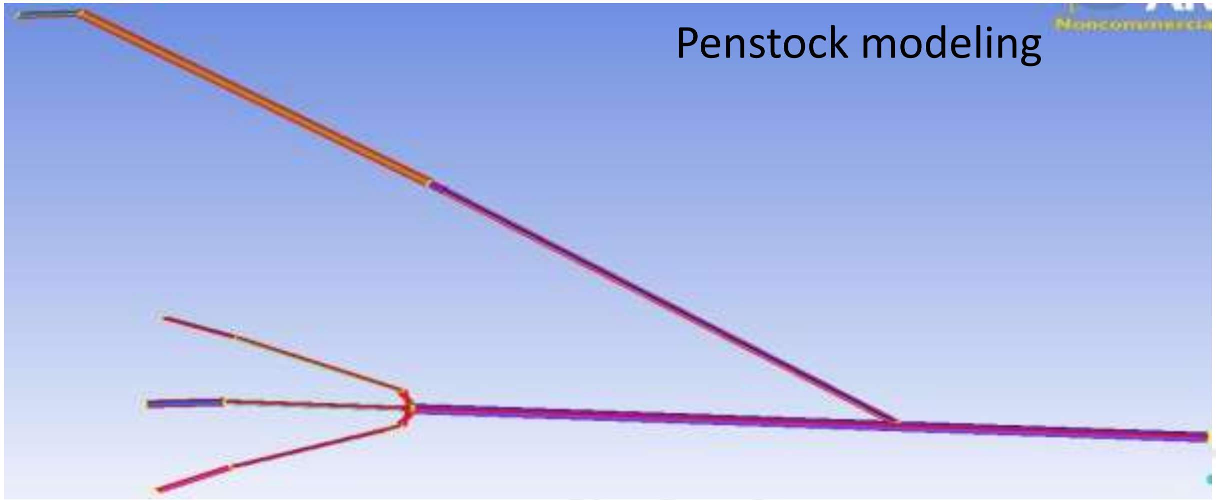
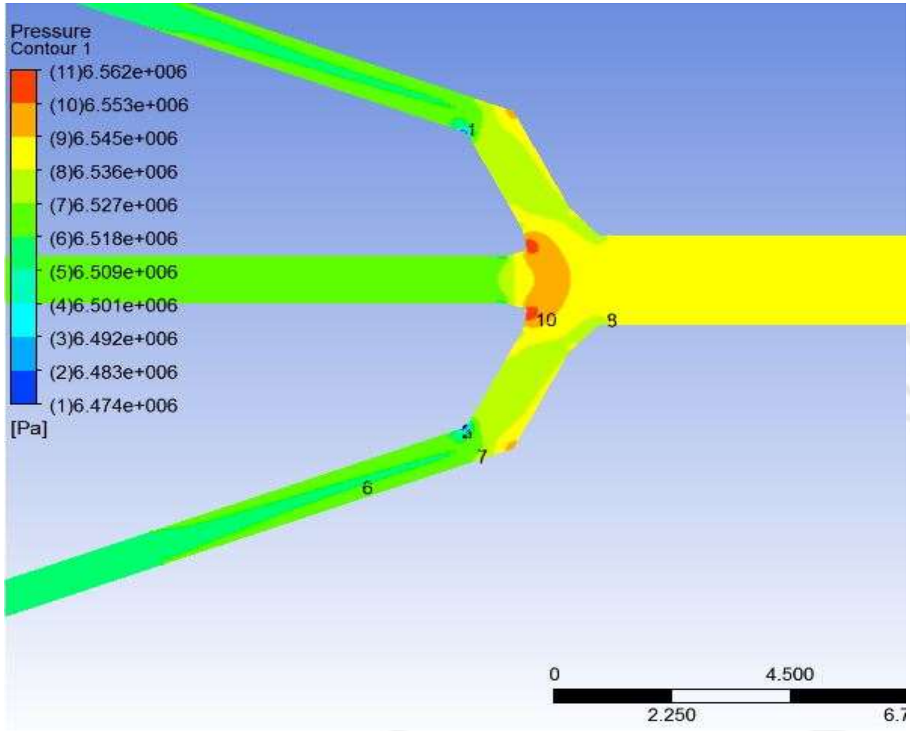


Table: Load Pattern for Numerical Simulation on new layout

Case No.	Load at Unit I	Load at Unit II	Load at Unit III	Load at Unit IV
1	Rated load	Rated load	Rated load	Rated load
2	40% load	40% load	Rated load	Rated load
3	40% load	40% load	80% load	Rated load

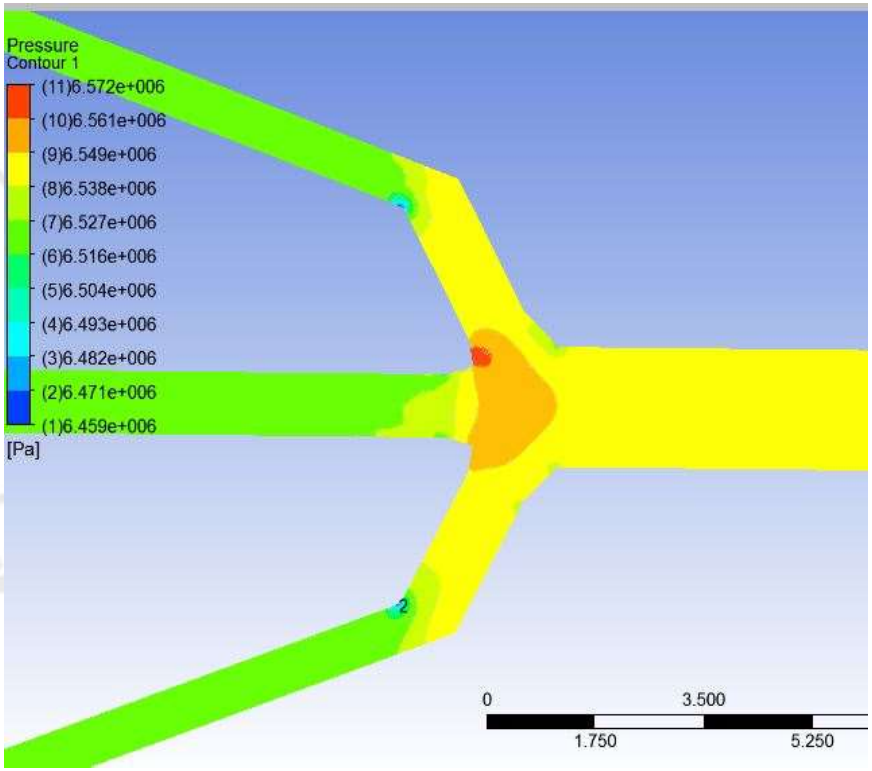
CFD Analysis of Trifurcation

Pressure and velocity contours at trifurcation (Old and new Layout at rated load)



Old Layout

New Layout

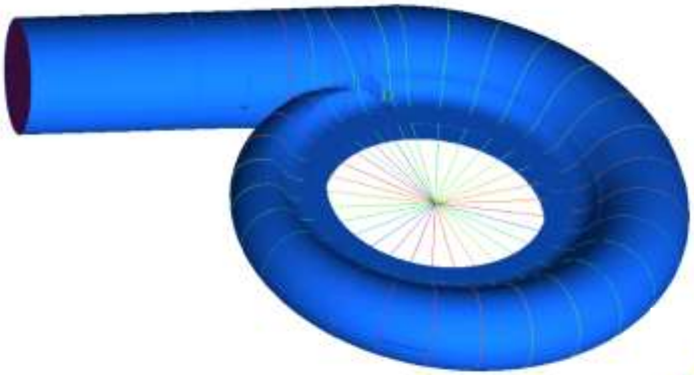


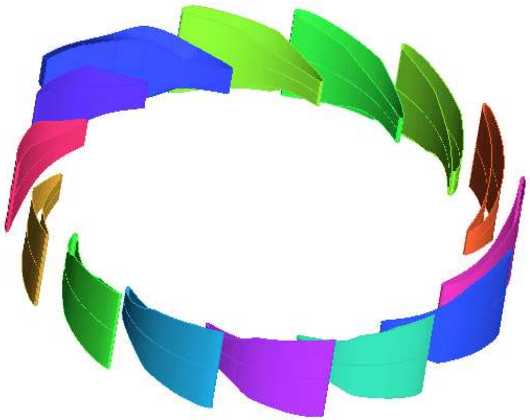
CFD Analysis for RM&U

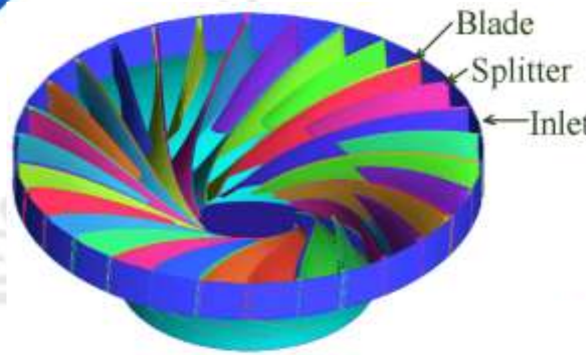
Outcomes of CFD Investigations

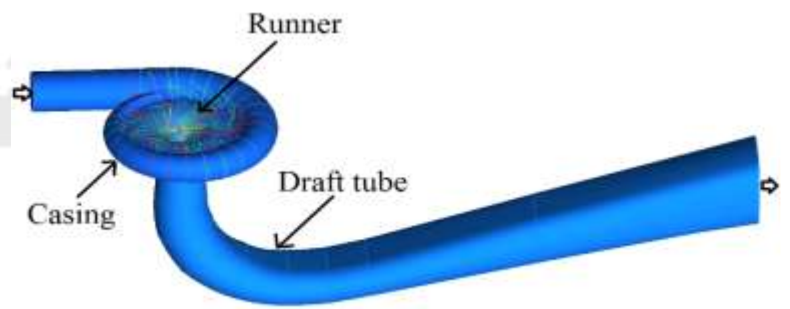
- ✓ It is found that the bifurcation is not being made according to standard practices and is the source of the problem for downstream units.
- ✓ The velocities in 1.5 km long penstock is very high (of the order of 9 m/s) compared to the recommended 3-5 m/s.
- ✓ It is therefore recommended that a separate penstock line be laid for unit IV (i.e. 50 MW) which will eliminate the problem and reduce the intake discharge to each of the turbine for same power generation due to lesser head losses.

Flow field investigation in turbines



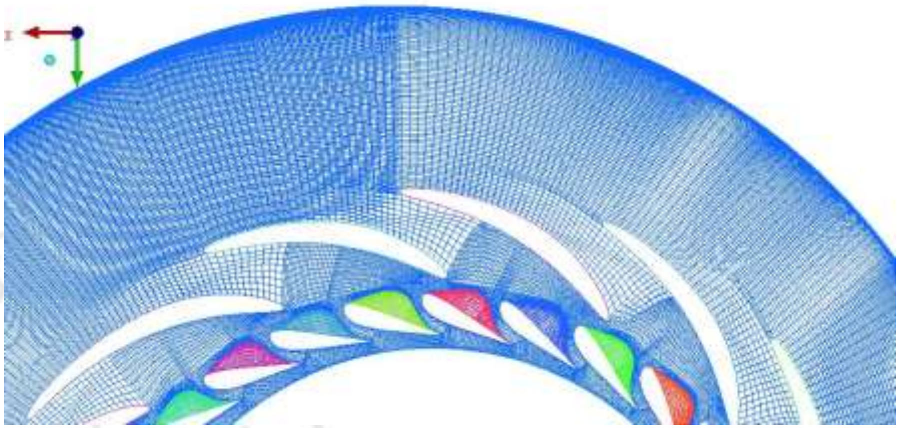


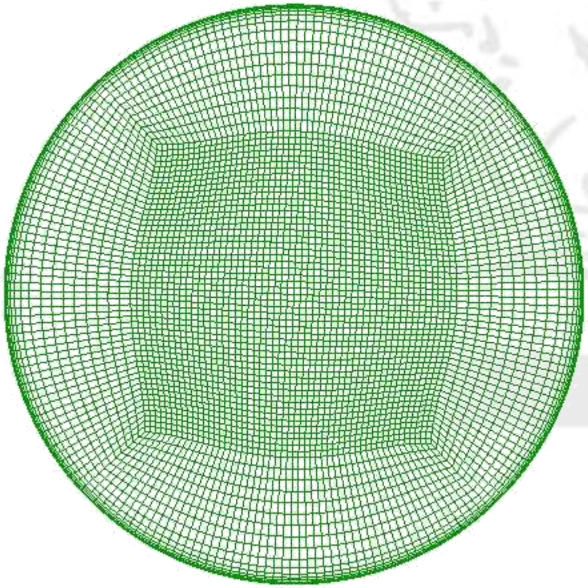


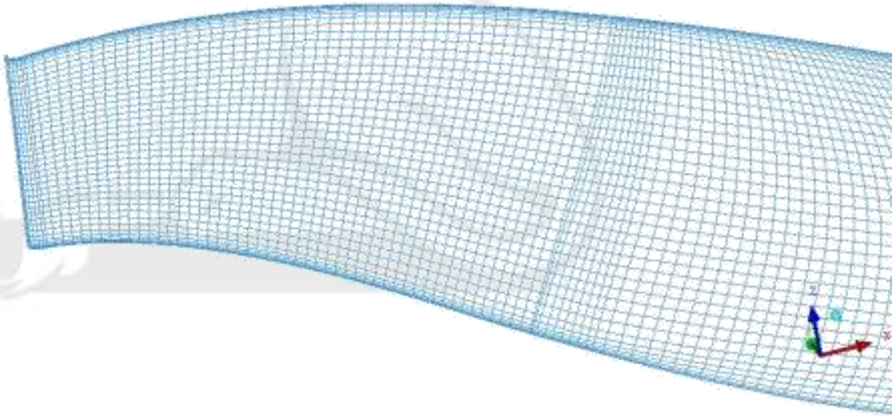


CFD Analysis of Turbine

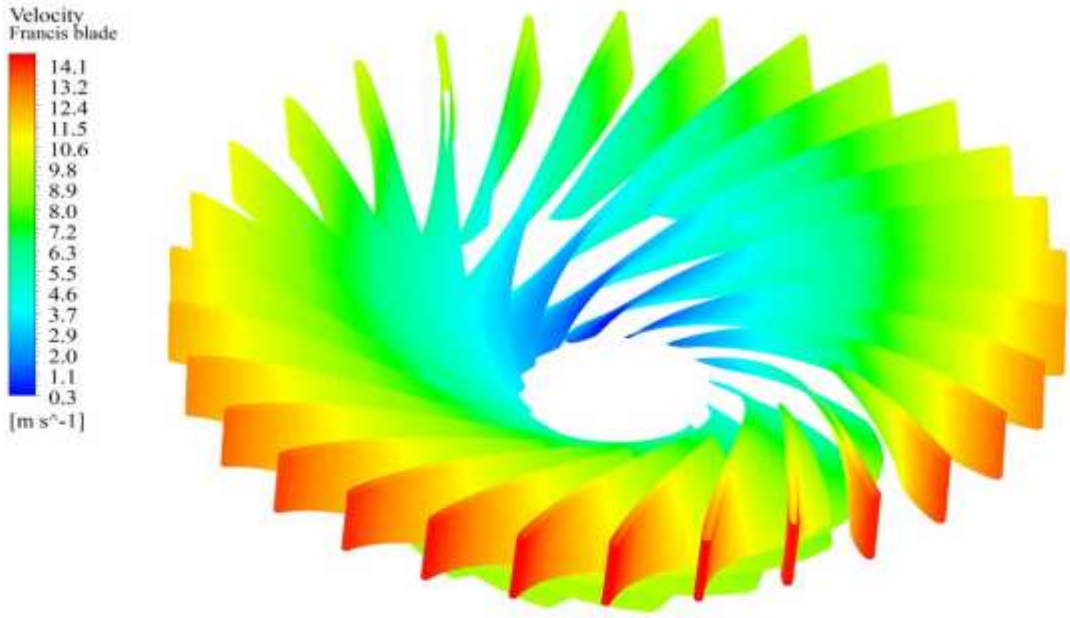
- **Meshing**

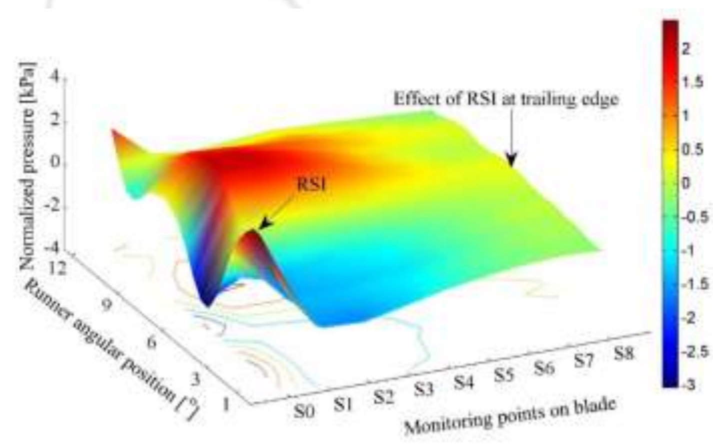






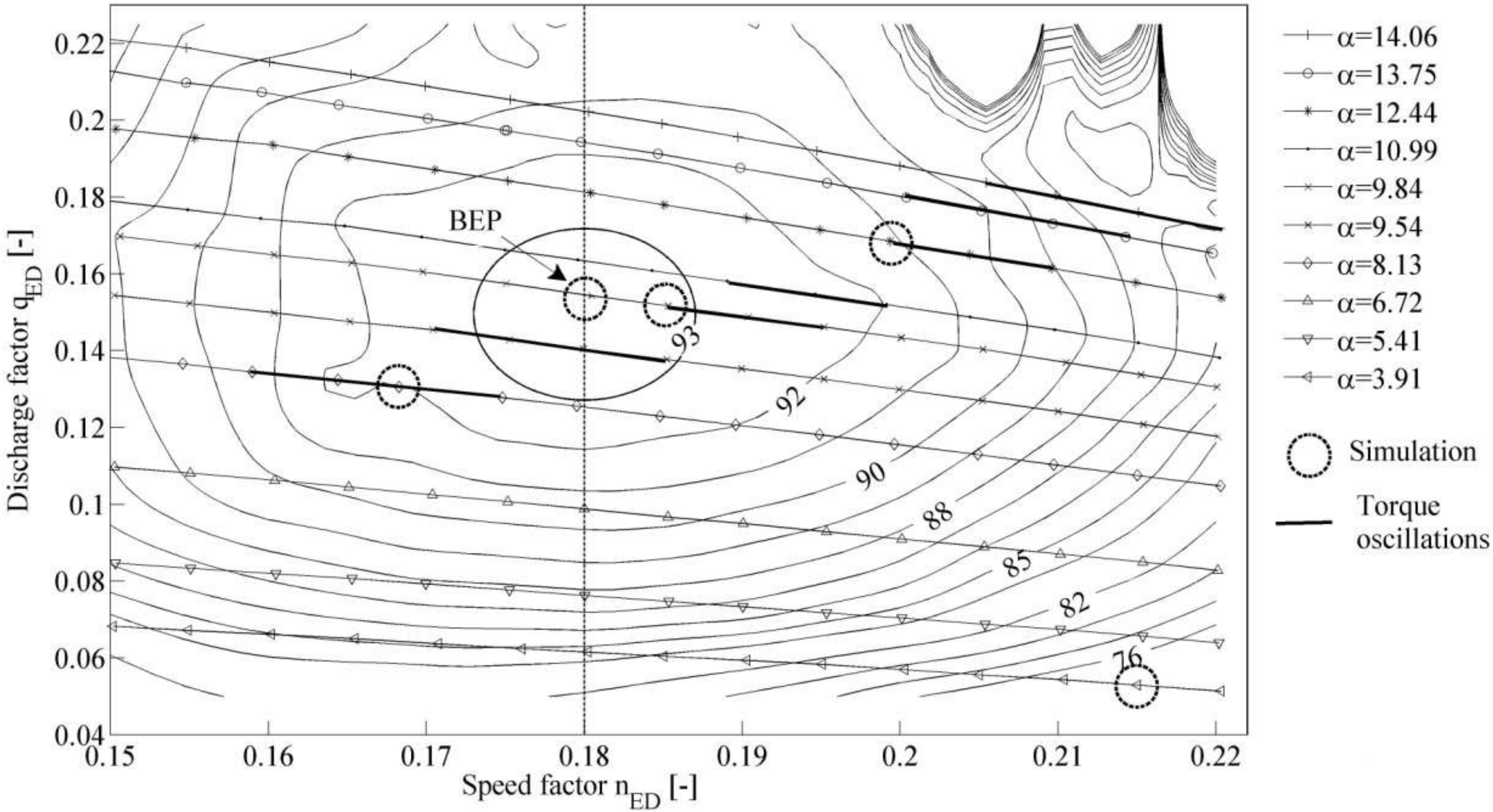
Velocity variation on runner blades with runner revolution





CFD Analysis for operating points

- **Hill chart helpful for best operating condition**



6.3 Numerical simulation (1): Numerical hydraulic efficiency

Difference:

1. Part load:

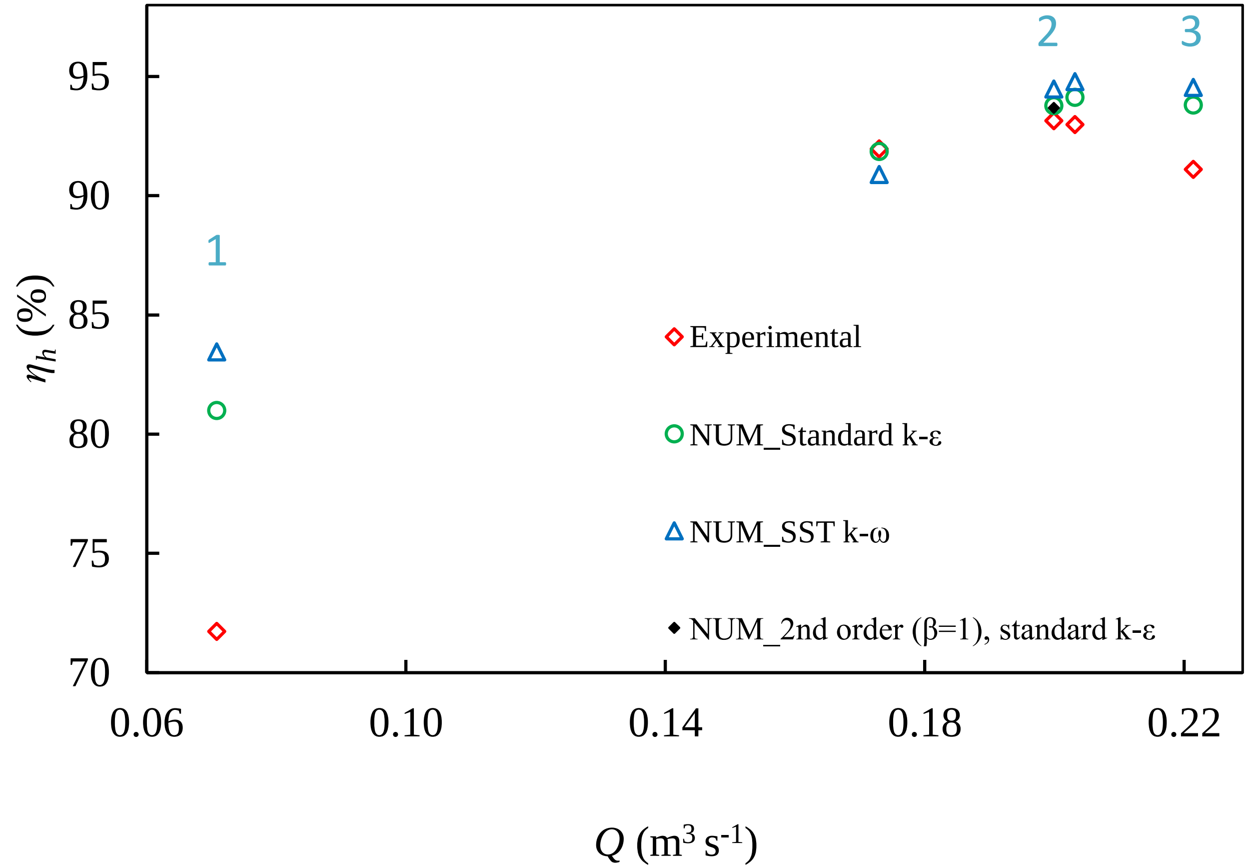
11.44% (standard *k-ε*)
14.05% (SST *k-ω*)

2. BEP load:

0.85% (standard *k-ε*)
1.58% (SST *k-ω*)

3. High load:

2.87% (standard *k-ε*)
3.64% (SST *k-ω)*



$$\eta_h = \frac{T \cdot \omega}{\Delta p' \cdot Q} \quad [-]$$

Efficiency hill diagram

Estimation of Erosion wear

- **Laboratory Test Rig**

Small scale bench test rig for evaluating erosion wear

- Pot diameter = 800 mm
- Pot height = 533 mm

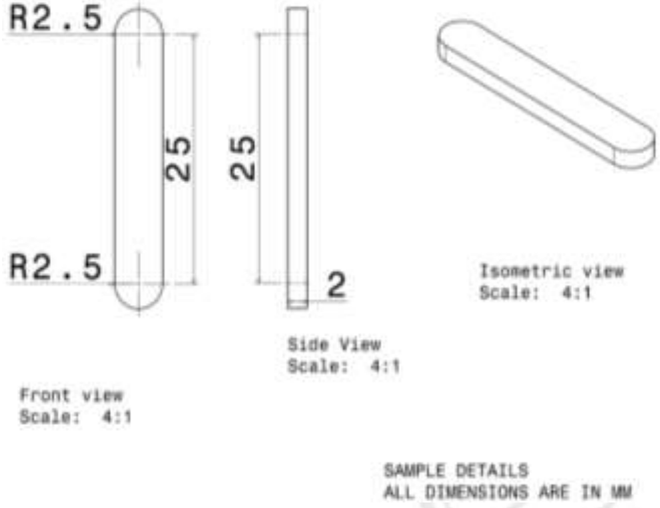
Unique features:

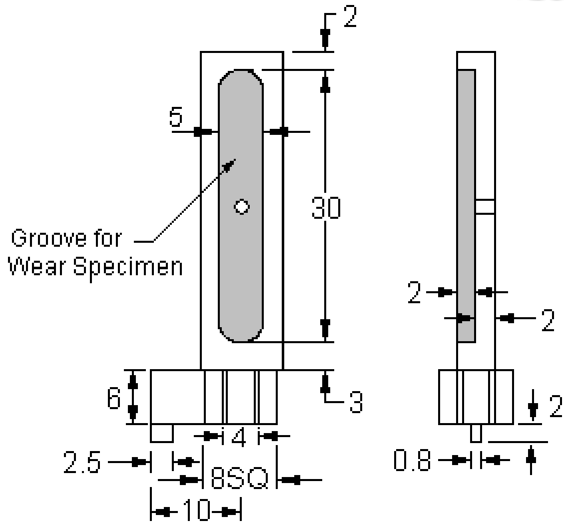
- Separate arrangements for suspending the solid particles in the pot and rotating the wear specimens at different speeds.

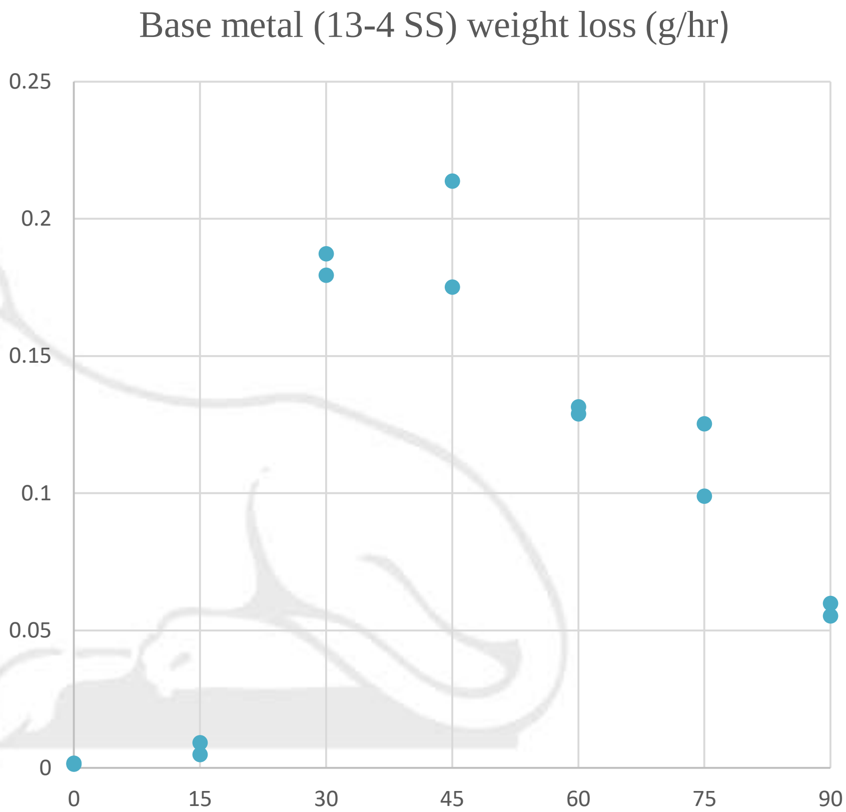
- Test speed range = 0 - 32 m/s
- Solid concentration = 0-10% by wt
- Solid particle size = 0 – 2 mm
- Impingement angle (fix) = 0-90 degree

Estimation of Erosion wear

- **Wear specimens and variation of weight loss**

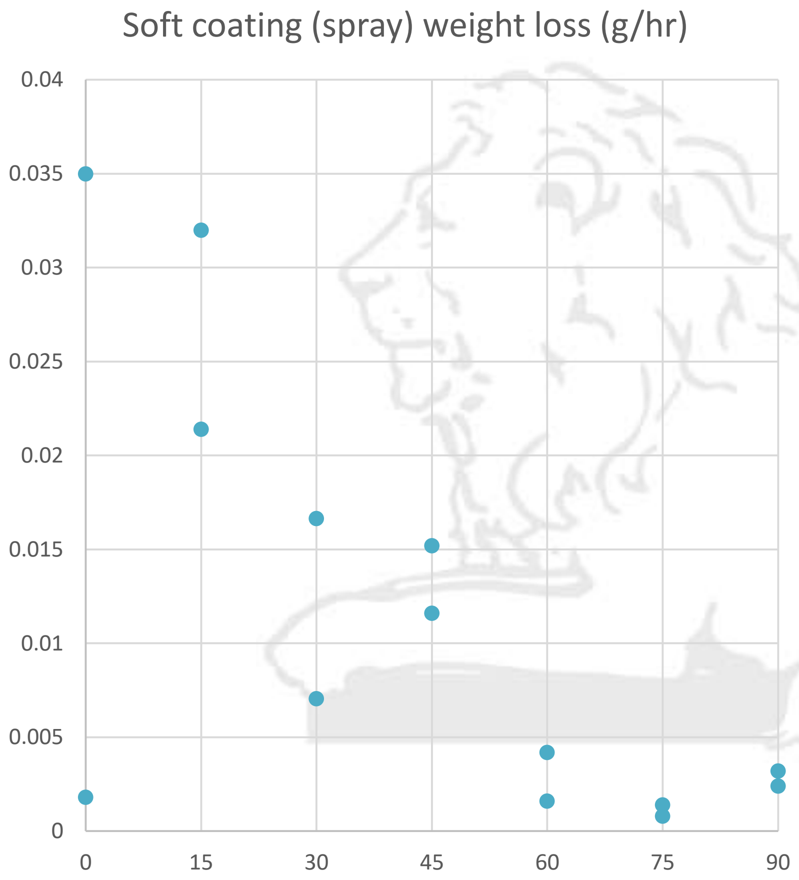


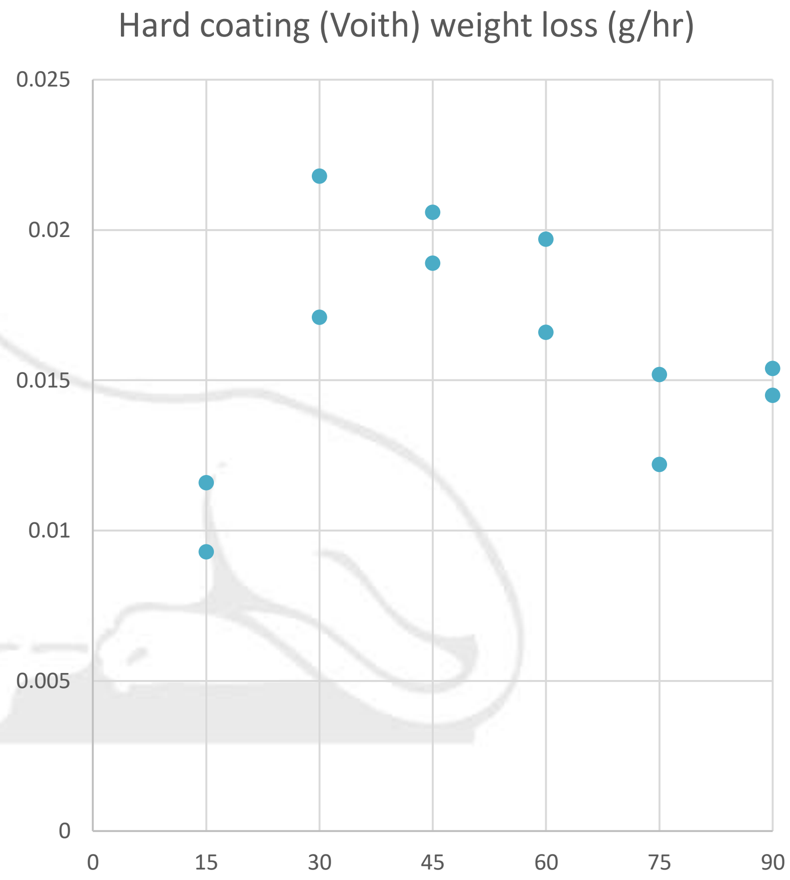




Estimation of Erosion wear

- **Comparison of two coating materials**





Transient operations

- To allow for Increased reliability of the power grid, runner life, and safe operations of hydropower plant, RM&U process are needed to focus on:
  - Consequences of the transient and more about the pressure loading on the hydraulic turbine.
  - The dynamic stresses on the runner blades and guide vanes during transient operations considering the present trend of electricity market.
  - Optimization of the guide vane sequence with old and new runner may extend the life and reliability of the turbine.

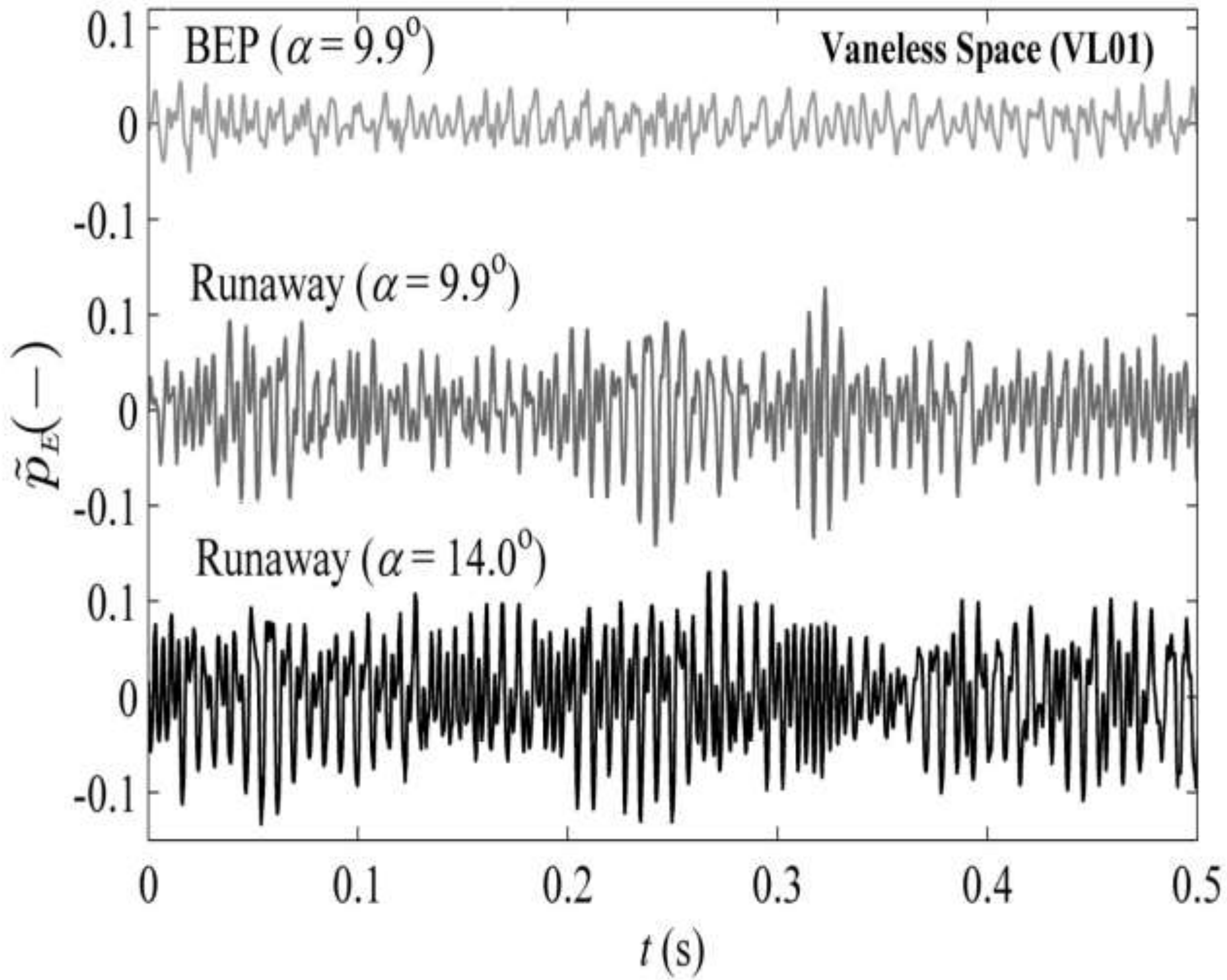
Runaway characteristic : Operating point

The pressure pulsations are corresponding to the rotor stator interactions in the vaneless space

$$\bar{p} = \frac{\sum_{1}^{N} \tilde{p}_i}{N} \quad [\mathrm{kPa}]$$

$$\tilde{p}_E = \frac{(\tilde{p} - \bar{p})}{(\rho \cdot E)_{bep}} \quad [-]$$

Amplitudes of the blade passing frequency were more than two times that of observed during BEP.



Load rejection and acceptance: Pressure loading

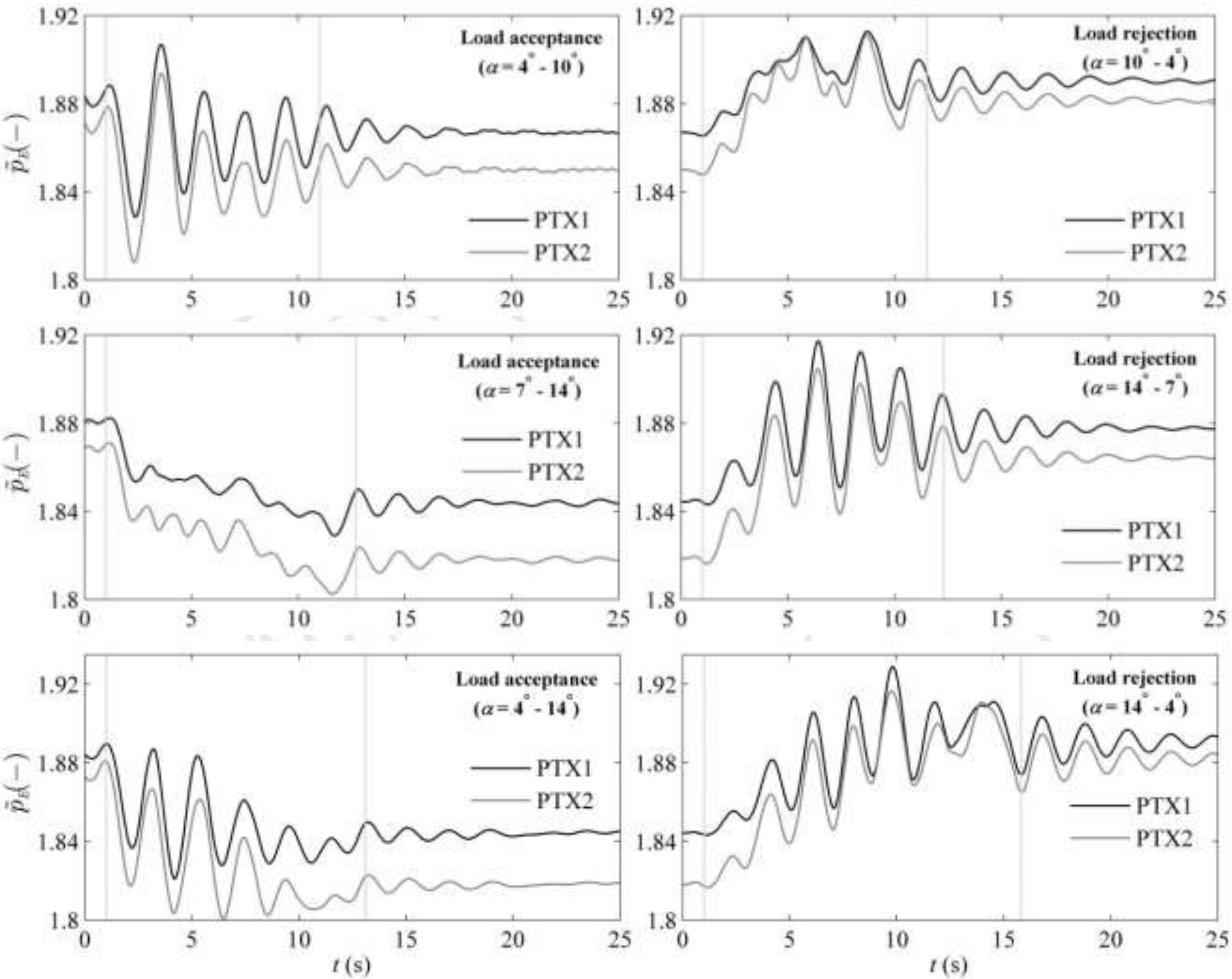


Fig. Transient pressure variation at the turbine inlet locations PTX1 and PTX2 during load acceptance and load rejection

Load rejection and acceptance: Pressure loading

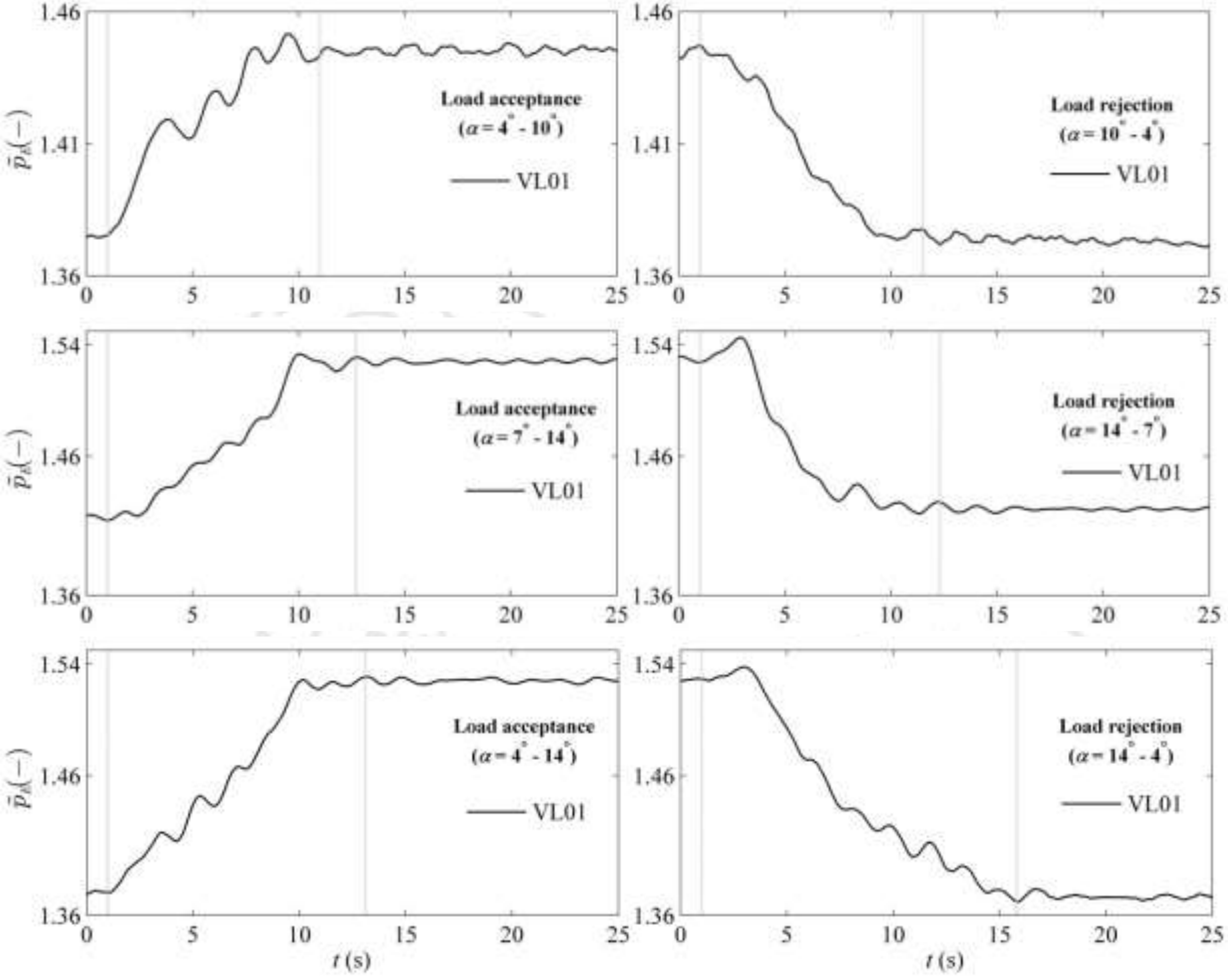


Fig. Transient pressure variation in the vaneless space (VL01) during load acceptance and load rejection

Load rejection and acceptance: Pressure loading

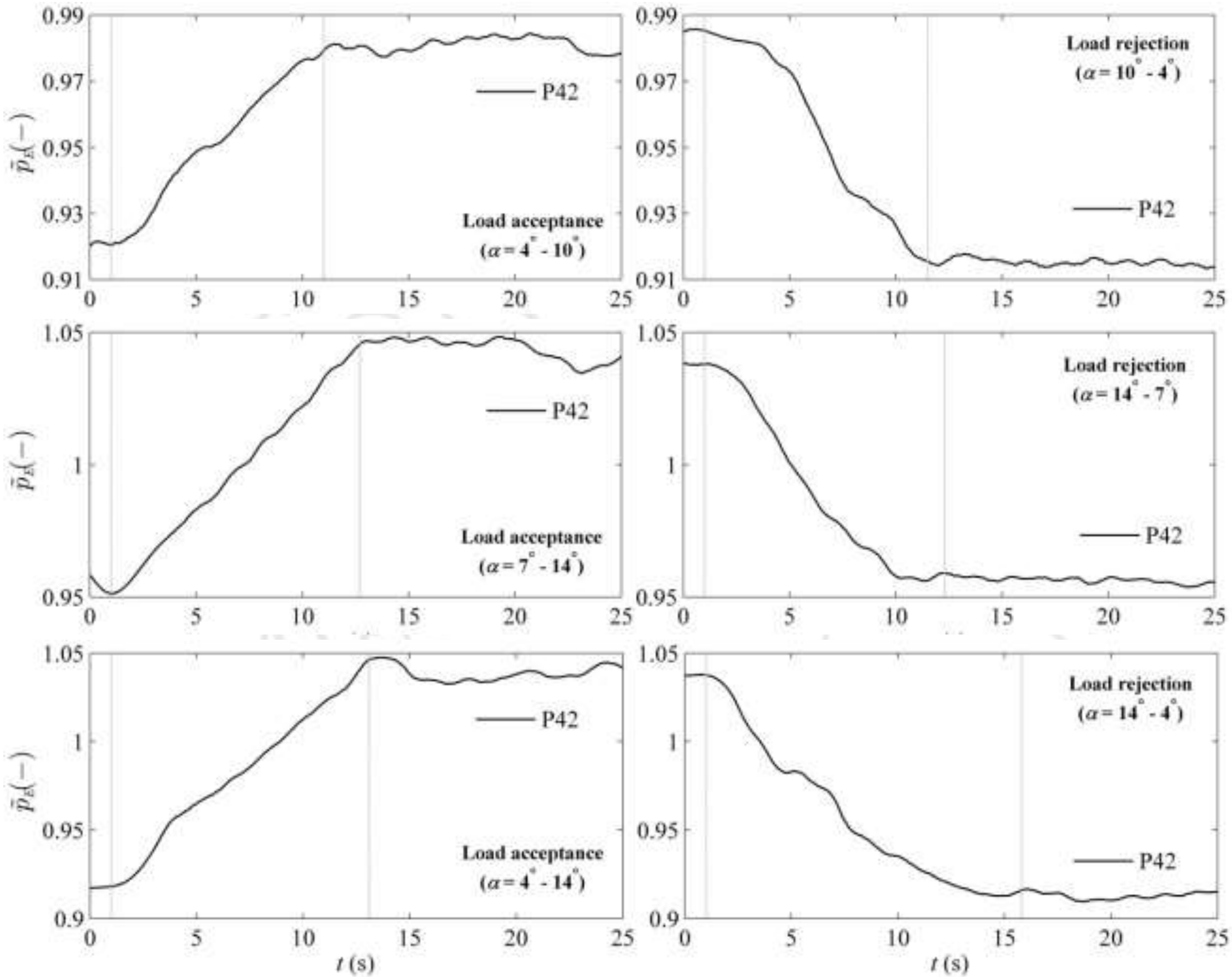


Fig. Transient pressure variation in the runner (P42) during load acceptance and load rejection

Load rejection and acceptance: Pressure loading

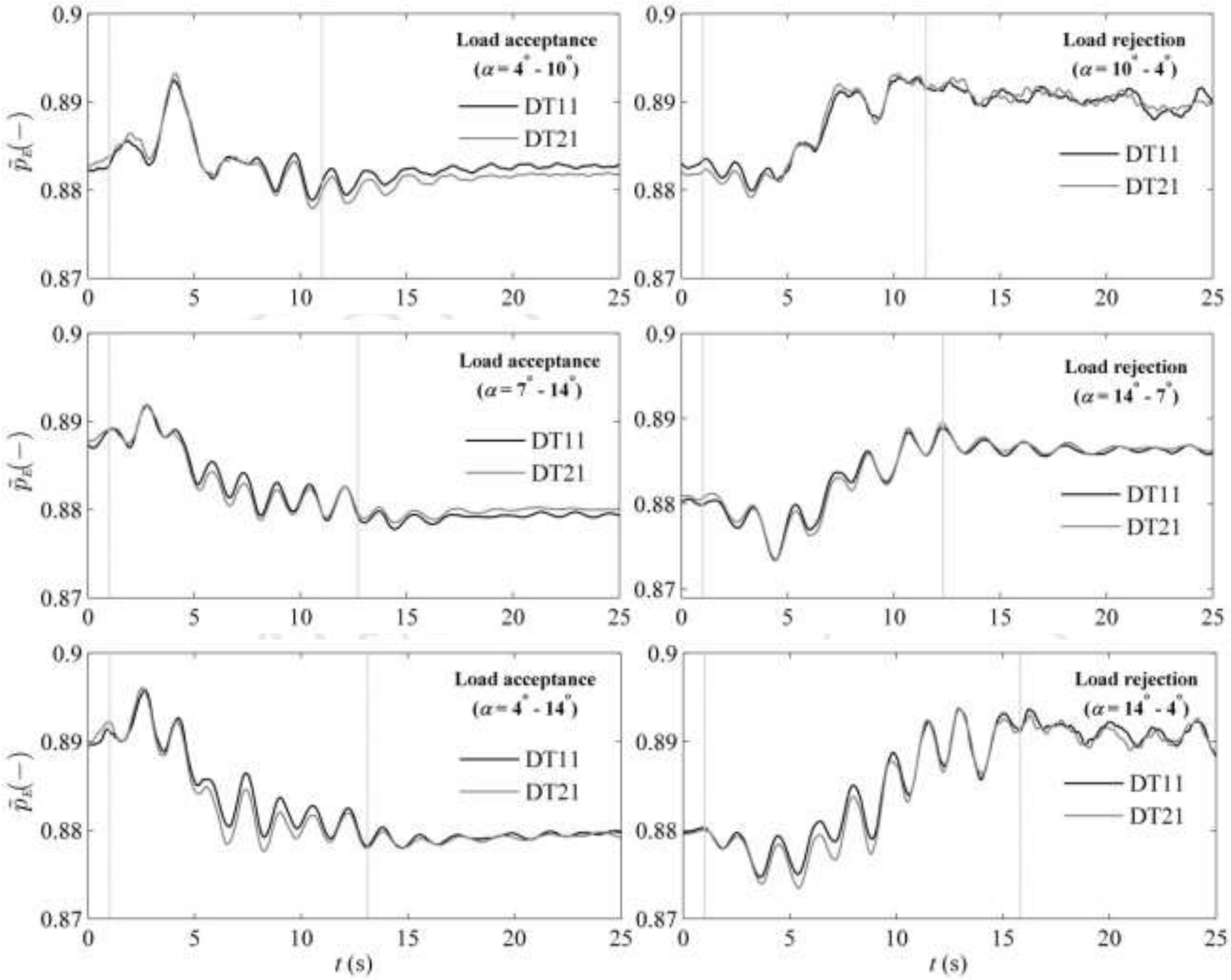


Fig. Transient pressure variations in the draft tube during load acceptance and load rejection

Startup: Pressure loading

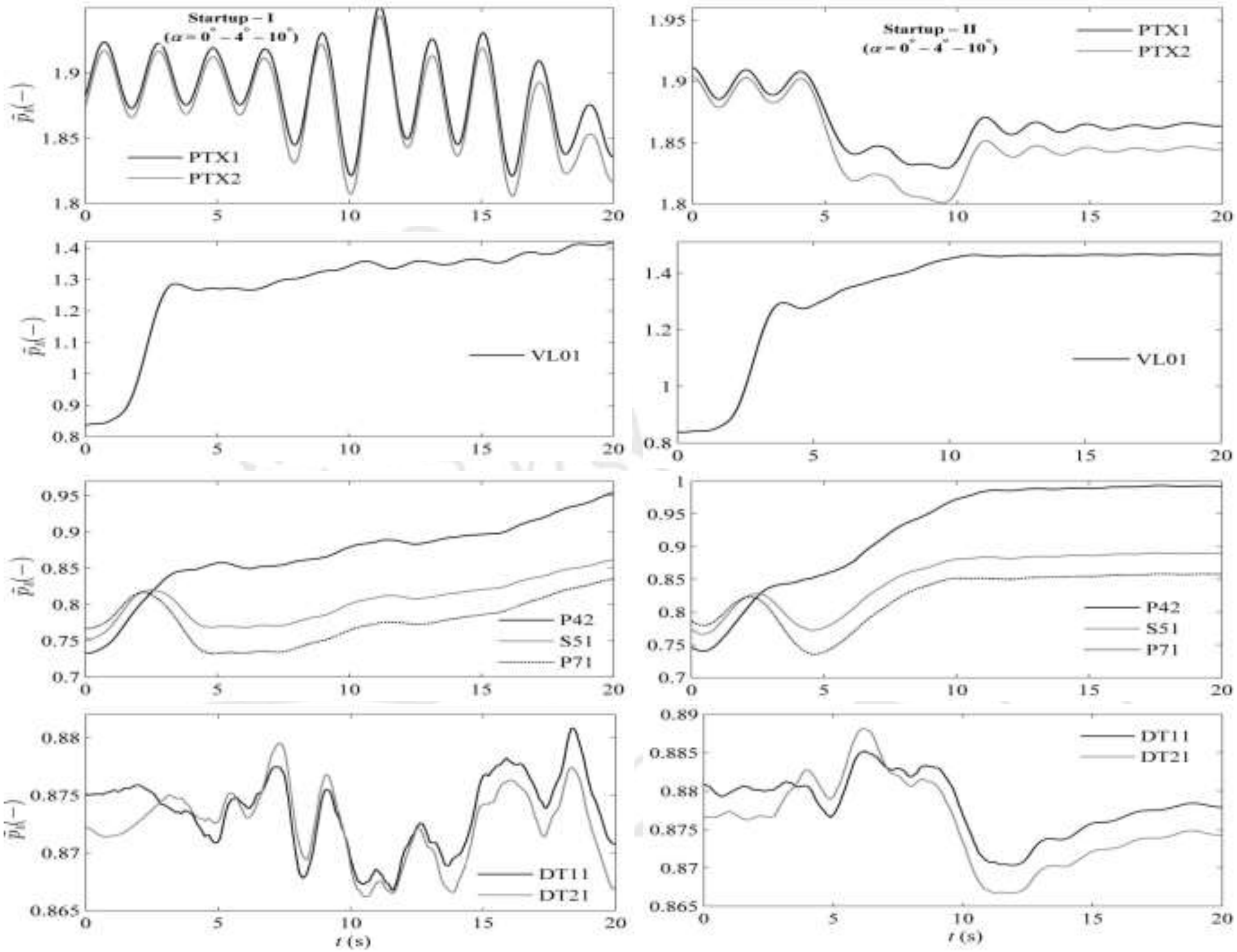


Fig. Transient pressure variation at the turbine inlet (PTX1 and PTX2), vaneless space (VL01), runner (P42, S51, and P71), and draft tube (DT11 and DT21) during the startup – I and II of the case 0 – 4 – 10

Startup: Pressure loading

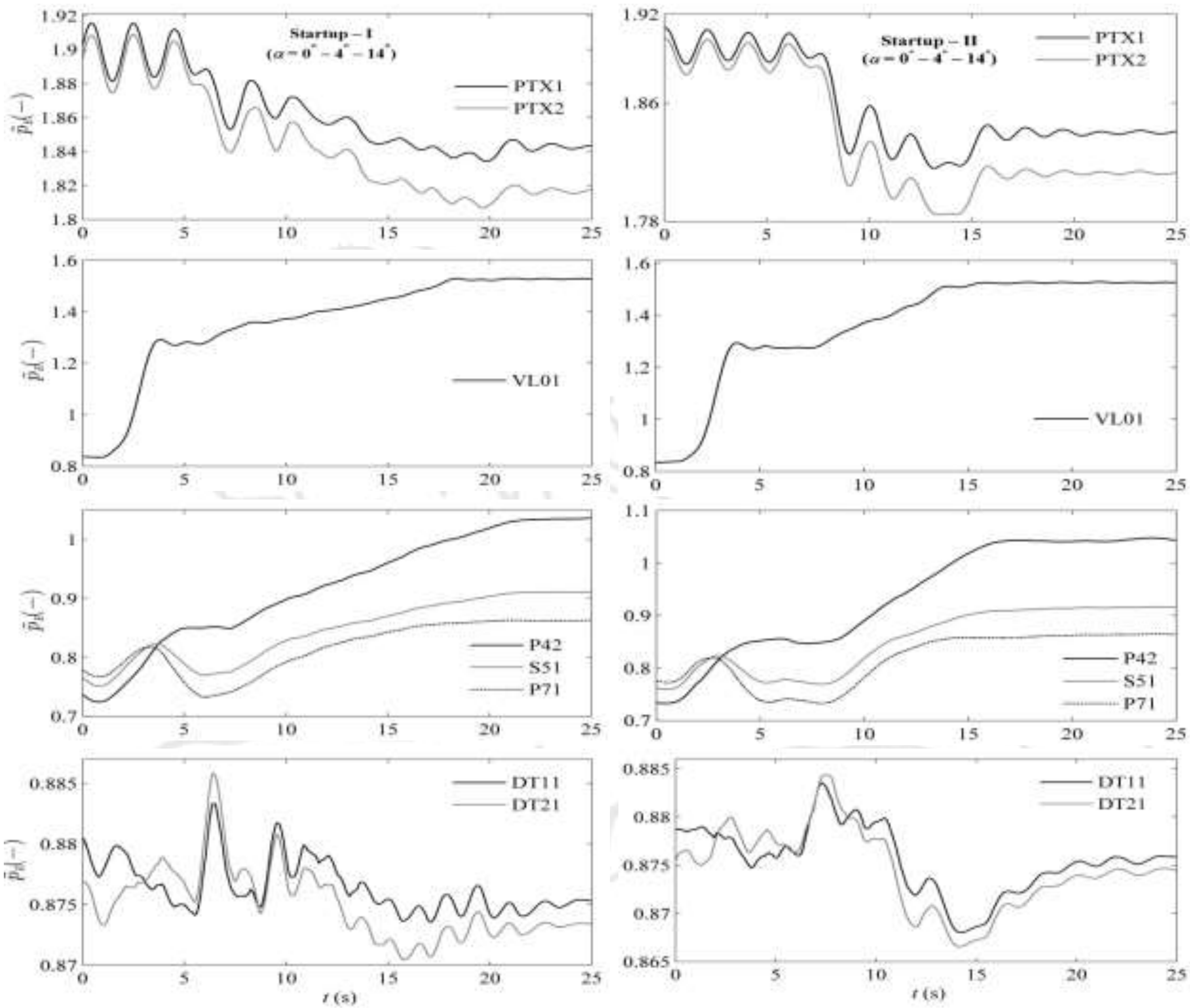


Fig. Transient pressure variation at the turbine inlet (PTX1 and PTX2), vaneless space (VL01), runner (P42, S51, and P71), and draft tube (DT11 and DT21) during the startup – I and II of the case 0 – 4 – 14

Concluding Remarks

In the present scenario the gap between the demand and supply, and the need of flexibility in grid network can be relaxed by RM&U of the old hydropower stations.

Some issues to be addressed:

- Pre and post efficiency measurements
- Evaluation of hydropower potential
- CFD analysis for optimizing the performance and design
- Transient operation capability to meet the current trend
- Turbine selection for wide operating range
- Evaluation of relative erosion behavior of material in a small bench test rig.