

6th Edition
Hydropower Plant
Digitalization Forum

**Session: advanced condition
monitoring and predictive
maintenance**

**Peculiarities of Condition
Monitoring in Small Hydro**

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Predictive maintenance



Advanced condition monitoring: the latest SCADA model



CONCLUSIONS

- Big plants → Big Money → Big Data
- Small plants → Small Money → Small Data

What are we talking about?

An example Italy (2016)

<i>Installed capacity</i>	<i>Nr.</i>		<i>Capacity (MW)</i>		<i>Energy (GWh)</i>	
$P \leq 1 \text{ MW}$	2.745	92%	769	18%	2.639	25%
$1 \text{ MW} < P \leq 10 \text{ MW}$	872		2.626		8.175	
$P > 10 \text{ MW}$	303	8%	15.246	82%	31.618	75%
<i>Total</i>	3.920	100%	18.641	100%	42.432	100%

Source: GSE 2017

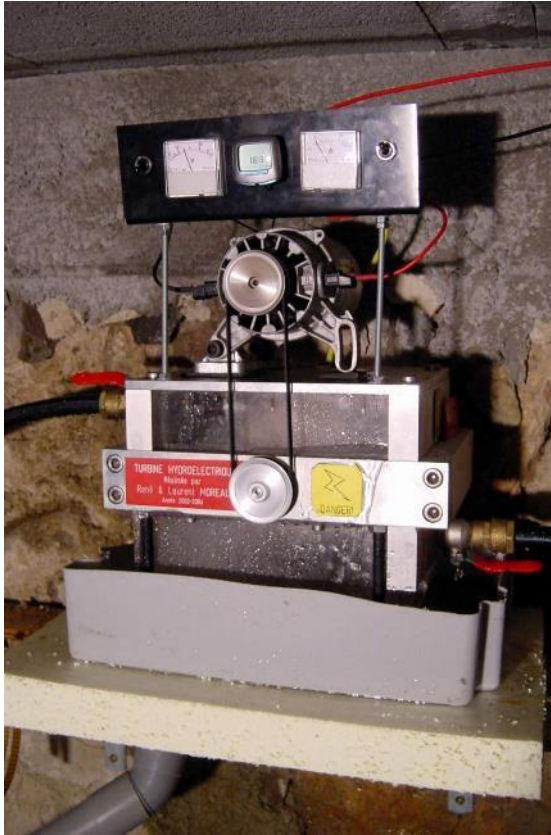
What are we talking about?



Semenza SHPP: $P = 6,8 \text{ MW}$ – $H_g = 8,0 \text{ m}$ – $Q_{\max} = 85 \text{ m}^3/\text{s}$



What are we talking about?



Pico hydro: 300 W

Risk based maintenance

a) run to failure: operation till the next fault

b) maintenance based only on the current plant condition

c) preventive maintenance

d) predictive maintenance

All the maintenance works generally advisable to avoid the failure

Attempt to predict which works are really crucial for a reliable operation

Risk based maintenance



Run to failure operation

No control on rivets and
penstock shell in 70 years

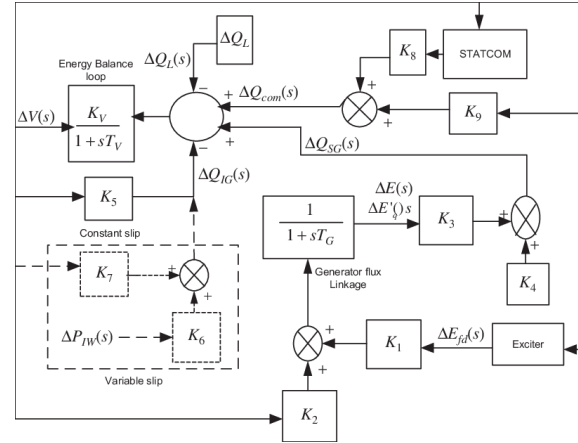
Predictions



50% success

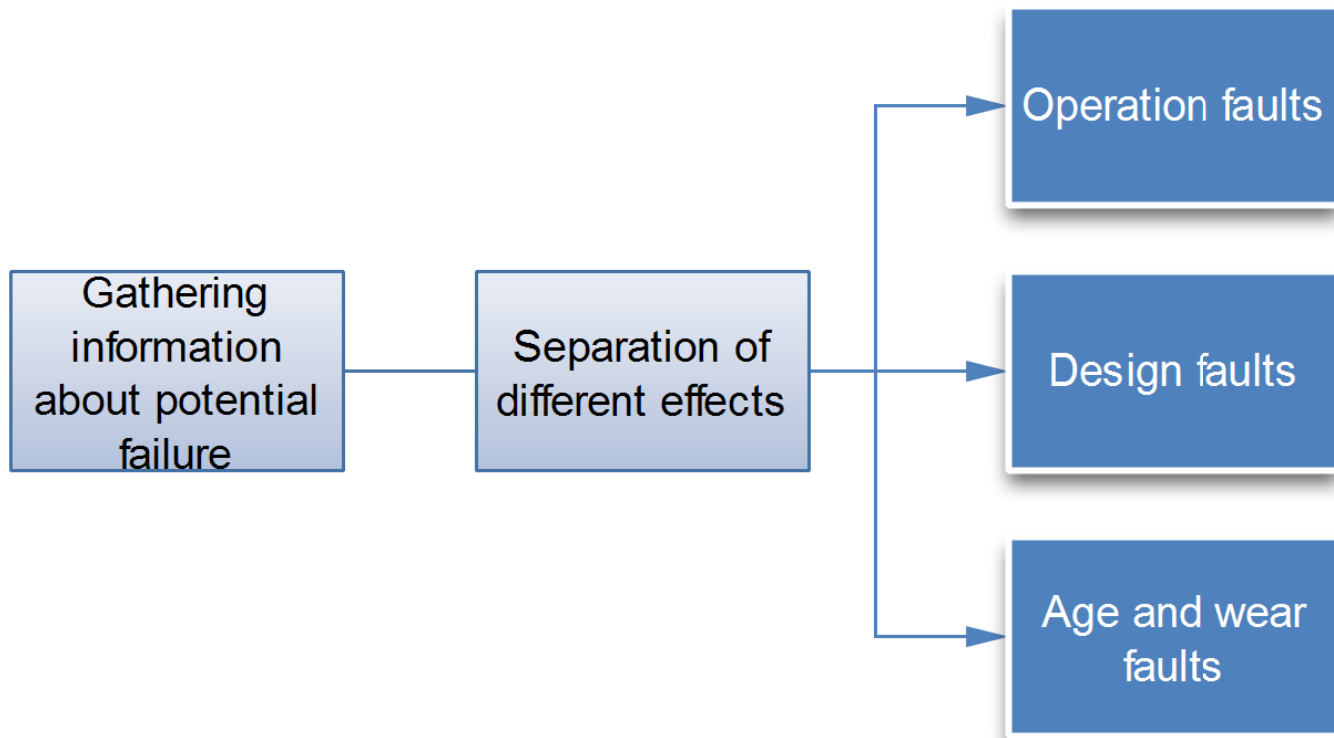
$$\frac{\partial u_i^+}{\partial t^+} + u_j^+ \frac{\partial u_i^+}{\partial x_j^+} + Re^{-1} = -\frac{\partial p^+}{\partial x_i^+} + Re^{-1} \frac{\partial^2 u_i^+}{\partial x_j^+ \partial x_j^+}$$

$$\sum_{i=1}^N \sum_{j=1}^N \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j) = \sum_{i=1}^N \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^N \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$



50% failure

Predictions



Predictions



Degradation
due to age

Incorrect
operation

Original sin



Predictions



Poor condition monitoring



Poor maintenance procedures
for the air vent

Why predictive maintenance and condition monitoring for SHPs

Low spot market prices

high costs of complex expert systems
could be incompatible with the plant size

Reduction
of O&M
cost
needed

Reduction of the
insurance premiums
or of the extension
of the covered risks

A new approach to PM & CM is
needed

**not ONLY referred to EM
equipment**

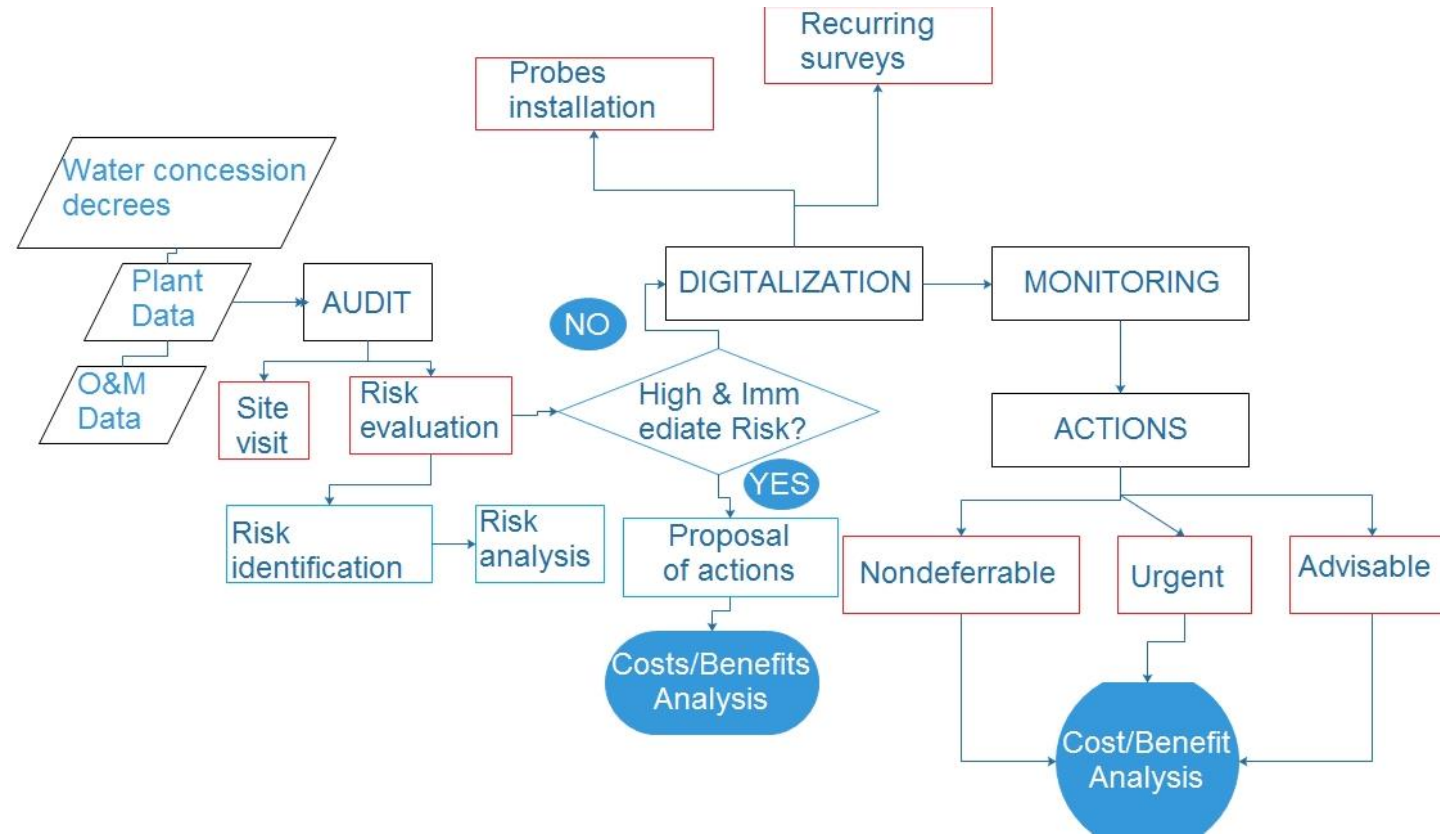
What hinders widespread diffusion of PM & CM in SHP sector?

- cost intensive (esp. for owners of a single plant)
- difficulty to monetize the benefits of the method
- lack of historical data for small plants



- tailor-made solution
- step by step implementation process
- low initial costs
- possibility to extend the system once the owner has experimented the pros of the predictive maintenance

General methodological approach



Plant audit
Identification of the risks
Identification of the parameters to monitor
Implementation of the monitoring system
Check of the parameters trend
Maintenance program

Risk identification

Part of the plant	Component	Type of risk	Event	Effect on plant operation	Plant outage?	Expected duration	Predictable	Prev./Predict. measure	Monitoring (if any)
Dam/Weir Intake works Headrace channel Forebay Penstock Powerhouse Tailrace channel	Civil works	Hydraulic							
		Geotechnical							
		Structural							
	Hydraulic works	Mechanical							
		Hydraulic							
		Electrical							
	Automation	Hardware							
		Software							
	Operation	Human Error							
		Procedures violation							



Risk analysis and risk management

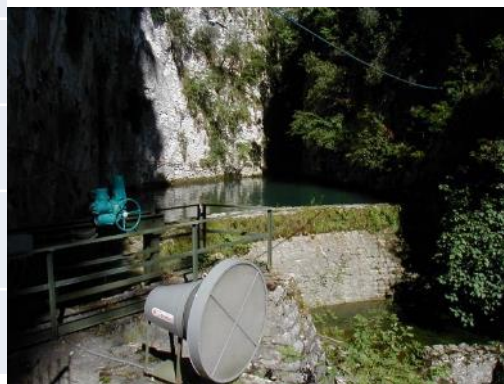
<i>Probability</i>	<i>P</i>	<i>Damage</i>	<i>D</i>
highly probable	4	extremely serious	5
plausible	3	serious	4
unlikely	2	medium	3
improbable	1	low	2
		minimum	1

Risk analysis and risk management

$R = P \cdot D$	Action
$R \geq 12$	an urgent measure (either a maintenance works or a modification of the operation)
$12 > R \geq 8$	a risk management measure
$8 > R \geq 4$	
$4 > R \geq 1$	no measure needed

Case study

<i>Location:</i>	Northern Italy
<i>Commissioning:</i>	1906
<i>Rated flow:</i>	1,32 m ³ /s
<i>Gross head:</i>	119,50 m
<i>Nr of units:</i>	2
<i>Type of units:</i>	Francis Horizontal
<i>Installed capacity:</i>	1,4 MW
<i>Pondage:</i>	20.000 m ³
<i>Penstock:</i>	DN 800 mm, riveted



Case study

Major refurbishments

<i>Turbines</i>	1996
<i>Generators</i>	1996
<i>Automation</i>	2018
<i>HPUs</i>	2018
<i>Trafos</i>	2014-2017
<i>Gates drivers</i>	1996
<i>Penstock shell and joints</i>	Wall Thickness check & Minor repairs in 1996



Case study

PARAMETERS FOR THE RISK EVALUATION							
INLET VALVE		EFFECTS ON	EVENT	CONSEQUENCES	P	D	R
Type of valve	Butterfly						
Nominal diameter	800						
Drive	Hydraulic-dead weight	Probability	Valve fails to close	Flow not interrupted	1	1	1
Overspeed Detection System	Yes	Damage	Impossibility to stop flow in case of failure	Flow not interrupted in case of penstock failure	3	4	12
Type of system of overspeed detection (Differential/Paddle/US only at the inlet)	Paddle	Probability	Interruption of flow in case of failure	Flow not interrupted in case of penstock failure	3	4	12
Last check of the efficiency of OSD	2018	Probability	=		1	1	1
Type of air vent (Pipe/Air valve)	Pipe	Probability	Air vent clogged or insufficient	Collapse of the penstock due to vacuum	1	2	2
Diameter of air vent	250	Probability	=	=	1	1	1
Last check of air vent if mechanical (air valve)	2018	Probability	=	=	1	1	1
Ice Prevention system on air vent	None	Probability	=	=	2	1	2

Case study

PARAMETERS FOR THE RISK EVALUATION							
UNIT VALVE		EFFECTS ON	EVENT	CONSEQUENCES	P	D	R
Drive	Hydraulic/Spring	Probability	Fast closure	Waterhammer	1	2	2
Nominal time of closure	44	Probability	=	=	1	2	2
Year of last check of time of closure	Unknown	Probability	=	=	2	2	4
Time of closure - last check	Unknown	Probability	=	=	2	2	4
Possibility of regulating the time of closure	Yes	Probability	=	Uncontrolled waterhammer	1	2	2
Possibility of closure under uncontrollable and very small times	Yes	Probability	=	Uncontrolled waterhammer	1	2	2
Maximum overpressure due to waterhammer at the device section	55 (46%)	Probability	=	Waterhammer	1	2	2

Case study

PARAMETERS FOR THE RISK EVALUATION							
GATES AT THE WEIR		EFFECTS ON	EVENT	CONSEQUENCES	P	D	R
Drive	Electric	Damage	Gates fail to open during floods	Intake flooding	4	2	8
Power supply	Private line from the ph	Probability	=	=	4	2	8
Source of power	MV Grid	Probability	=	=	4	2	8
GATES AT THE INTAKE							
Drive	Electric	Damage	Gates fail to close during floods	Intake flooding	4	2	8
Power supply	Private line from the ph	Probability	=	=	4	2	8
Source of power	MV Grid	Probability	=	=	4	2	8

Case study

		DAMAGE			
P R O B A B I L I T Y	L	20	15	10	5
	I <td>16</td> <td>12</td> <td>8</td> <td>4</td>	16	12	8	4
	T <td>12</td> <td>9</td> <td>6</td> <td>3</td>	12	9	6	3
	Y <td>8</td> <td>6</td> <td>4</td> <td>2</td>	8	6	4	2
		4	3	2	1

Risk analysis and risk management

$R = P \cdot D$	Action
$R \geq 12$	an urgent measure (either a maintenance works or a modification of the operation)
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$4 > R \geq 1$	
	no measure needed

Urgent measure: installation of a differential system to detect overspeed

Monitoring actions

1. more frequent check of the time of closure of the unit valve
2. check wall thickness of the penstock shell
3. provide an emergency power supply (Diesel generator?) to weir and intake gates

CONCLUSIONS

Condition monitoring in a wider sense can't refer only to EM equipment
Static equipment can fail as the dynamic one and even more

A global model of the whole plant is fundamental, especially for SHPs

Site-specificity of SHPs makes difficult the causation between monitored parameters and failures and the statistical analysis

Nonetheless, a frequently updated knowledge of the plant condition allows to regularly check the residual value of the asset, that plays an important role in the balance of the Company.

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THANK YOU FOR THE ATTENTION