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REMOTE MAINTENANCE for FACILITY EXPLOITATION

SPECIFICATION OF EFI FUNCTIONS

Optimal Maintenance Interval for Hydraulic String, Turbine and Generator (A3)

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PREFACE

This document gives a description of an analysis tools for optimal maintenance interval planning. Initially it is important to state that maintenance and refurbishment is done to maximise long term system performance. The tool is therefore based on an optimisation model which takes care of this perspective. The model minimises the sum of expected annual maintenance cost, loss due to wear mechanisms and expected costs caused by uncontrolled failure.

The model calculates optimal maintenance intervals for both hydraulic strings, turbines and generators. It also provides calculations for more detailed units in the production system.

This analysis function will retrieve data from the REMAFEX database, and will have the option to store results and inputs locally on a PC.

1. OBJECTIVE OF FUNCTION

This function provides calculations of optimal maintenance intervals for hydraulic string, turbine and generator. This tool will contribute in the planning process to make better decisions for maintenance and refurbishment by combining economical assumptions and evaluations with the technical state of the power production system.

The system provides documentation for decisions and will give the maintenance planner a tool, which speaks the important language of economy. Based on current knowledge, the planner can say that this recommended solution is the correct maintenance/refurbishment decision for the system being analysed. The model will calculate the expected maintenance cost following an optimal strategy, and also document the «invisible» costs of running the system at a lower efficiency level than a newly maintained/refurbished system would.

Analysis of turbine:

The function can analyse three different maintenance/refurbishment aspects of the turbine:

- Development in hydraulic efficiency. Wear is caused by cavitation and sand erosion which influence the turbines ability to transform the energy in the running water to rotating energy in the turbine.

- Development in volumetric efficiency. Sand in the labyrinth sealing will give increased leakage flow bypassing the turbine runner, and thereby give lower volumetric efficiency. (NB! Does not apply to Pelton turbines.)

- Probability of sudden failure due to mechanical ageing of different parts in the turbine. (Technical lifetime of equipment.)

These are all subjects of maintenance planning, and it is possible to combine these aspects of the decision problem in the system. The technical conditions under which the turbine is expected to run, will together with market assumptions be the basic input for the calculations. This includes seasonal variations in gross head and power output and how these variables influence the efficiency level.

Analysis of hydraulic string:

The user also has an option to analyse the hydraulic string. Even though the tunnel is to be specified in the system for energy calculations, we concentrate the maintenance and refurbishment analysis to the penstock. The following is being considered in the analysis:

- Development in head loss makes it possible to calculate and estimate the development of efficiency in the hydraulic string. The loss elements we consider is the singular losses due to geometry and loss due to friction. The singular losses normally have no detectable changes, so we focus at increase in the head loss due to friction development.

Analysis of generator:

In the model we assume there are no efficiency decrease in connection with the generator. However, we assume that the generator is monitored periodically to generate information to make optimal refurbishment decisions. The input to the model is the change in discharge level from the stator windings. These measurements have gives a quite difficult interpretation challenge. How does the discharge change affect the failure rate expectations ? Since major maintenance decisions are made based on such measurements, we will integrate this in the model.

Analysis of single components:

It will also be possible to do analysis upon single components. This is not the main focus for the system, but the option provides an opportunity to evaluate the risk connected to each component based on failure assumptions. These analysis is primarily worthwhile for parts of the hydropower system with a predictable ageing process. If we assume that the failure intensity increases over the years, it is possible to calculate a optimal maintenance interval for that component. These component specific analysis will not include calculations for efficiency development.

2. FUNCTION ENVIRONMENT

This function can optionally include both the Maintenance operator, Control operator and the Management operator. This depends on the data available, or the purpose of the actual analysis. The natural place for this system to be used, is at the management or maintenance operator level. It needs input both from market and production divisions in the company.

Table 1 Sequence of optional and necessary tasks to utilise the optimal maintenance function for Hydraulic string, Turbine and Generator.

Event	Request/Response (RQ/RS)	From	To
Technical data for turbine	RQ	Maintenance operator (M.O.)	Database
State of turbine (Efficiency level)	RQ	M.O.	Control Operator (C.O.)
Technical data for hydraulic string	RQ	M.O.	Database
State of hydraulic string (Head loss)	RQ	M.O.	C.O.
Technical data for generator	RQ	M.O.	Database
State of generator (Discharge level)	RQ	M.O.	C.O.
Evaluation of expected development of existing and/or alternative/new equipment	RQ	M.O.	C.O./ Management/ Database
Market assumptions	RQ	M.O./ Management	Market division/ Database
Maintenance costs	RQ	M.O.	Management
Production plans (expected)	RQ	M.O.	Database
Consequences of stop in system	RQ	M.O.	Management
Store input data	RQ	M.O.	Database
Run model alternatives	RQ	Function	Function
Present results for systems analysed:			
- optimal interval (t)	RS	Function	M.O.
- expected system state (η)	RS	Function	M.O.
- sensitivity analysis	RS	Function	M.O.
- economy	RS	Function	M.O.
Present conclusion (Essentially the same information as above)	RS	M.O.	Management

Internal events such as error messages, request for additional specification of task, i.e. limitation to sub-functions etc., are not included in the table above. The table just shows the main tasks to be considered before using the tool.

This sequence of tasks is meant as an example on how to organise the operation of this model. In general the data sources to be used should be the best possible ones. Some of the data should be localised in a central database, and others have more qualitative aspects which have to be taken into consideration. Some of the parameters have a highly uncertain nature (i.e. prices and failure rates), and these can be given as distributions or intervals.

3. INPUT DATA DEFINITION

This chapter gives an overview over the central parameters being used in the model. Some of them are optional, and it is not necessary to specify all these input data to analyse just parts of the system. During the development of the model, there might be some minor changes in this list. This list is also given as a more detailed table in appendix 1.

1. General technical data:				
1.1	n	Number of parallels in power station		(integer)
1.2	type	Type of production (river/magazine/energy)		(text)
1.3	Q	Maximum Flow	(m^3/s)	(real)
1.4	H	Gross head	(m)	(real)
2. Technical data for Hydraulic string:				
2.1	L_t	Length of tunnel	(m)	(real)
2.2	A	Tunnel cross section area	(m^2)	(real)
2.3	M	Manning number (Flow friction for tunnel)	(..)	(real)
2.4	L_p	Length of penstock(s)	(m)	(real)
2.5	D	Diameter of penstock(s)	(m)	(real)
3. Technical data for turbine(s):				
3.1	turbine	Type of turbine (Pelton/Francis/Kaplan)		(text)
3.2	P	Power output at maximum efficiency	(MW)	(real)
3.3	P_{max}	Maximum power output	(MW)	(real)
3.4	$\eta_t(P)$	Efficiency as function of power output	(%)	(real)
4. Technical data for generator(s):				
4.1	gtype	Type of generator		(text)
4.2	η_g	Generator efficiency	(%)	(real)
5. Measurements on penstock(s): *(Optional)*				
5.1	$\eta^{mp}(T)$	Measured hydraulic efficiency level *based on*	(%)	(real)
5.2	HL(T)	Head loss development *or*	(m)	(real)
5.3	R(T)	Roughness measurements	(mm)	(real)

6. Measurements on turbine(s): *(Optional)*

6.1	$\eta^{mt}(T,P)$	Measured hydraulic efficiency level (hydraulic efficiency)	(%)	(real)
6.2	$\Delta Q^{m}(T)$	Measured internal leaks in turbine (at best operational point) (volumetric efficiency)	(m^3/s)	(real)

7. Measurements on generator(s): *(Optional)*

7.1	gmon	Monitoring strategy (PDA/tan δ/others)		(text)
7.2	$dc^{m}(T)$	Measured discharge from windings	(pC)	(real)

8. Expected development for maintained/refurbished penstock(s): *(Optional)*

8.1	$\eta^{p}(t)$	Expected efficiency development	(%)	(real)

9. Expected development for maintained/refurbished turbine(s): *(Optional)*

9.1	$\eta^{t}(t)$	Expected efficiency decrease, new (hydraulic efficiency)	(%)	(real)
9.2	$\Delta Q(t)$	Expected development internal leaks, new (volumetric efficiency = 1 - $\Delta Q(t)/Q$)	(m^3/s)	(real)

10. Expected development for maintained/refurbished generator(s): *(Optional)*

10.1	dc(t)	Expected discharge from windings	(pC)	(real)

11. Assumptions about failure rates(exponential/weibull/empirically based): *(Optional)*

11.1	$f^{t}(t)$	Failure density - turbine		(real)
11.2	$f^{g}(t,dc)$	Failure density - generator (time and discharge)		(real)
11.3	f(t)	Failure density functions for components		(real)

12. Assumptions for maintenance action (penstock/turbine/generator/components):

12.1	C_p	Investment and labour - planned mainten.	(currency)	(real)
12.2	C_f	Investment and labour - unexpected failure	(currency)	(real)
12.3	DMT	Dismounting time for unit	(hours)	(real)
12.4	DLT	Delivery time for unit	(hours)	(real)
12.5	MT	Mounting time new unit	(hours)	(real)

13. Expected production plans for turbine(s):

13.1	plan(s)	Expected seasonal production plan	(MW)	(real)
13.2	new(s)	Expected alternative production plan *(option)*	(MW)	(real)
13.3	headvar(s)	Expected variations in the gross head *(option)*	(m)	(real)

14. Market assumptions:

14.1	m(s)	Expected price fluctuations *(option)*	(cur./MWh)	(real)
14.2	mLT(t)	Long term evaluation of market price	(cur./MWh)	(real)
14.3	r	Interest rate	(%/year)	(real)
14.4	ir	Inflation rate	(%/year)	(real)
14.5	tax	Company tax rate	(%)	(real)

4. OUTPUT DATA DEFINITION

Output from function:

1. Expected optimal maintenance/refurbishment interval, t^* (years).

2. Expected time to next maintenance/refurbishment based on the existing state of the turbine efficiency, head loss/roughness in penstock, discharge level in generator or age of unit, t^{next} (years).

3. For systems with efficiency decrease and efficiency measurements being performed regularly, the model calculates the level of efficiency at which the turbine or penstock should be refurbished or maintained, η^* (%).

4. Economical data for the optimal refurbishment plan. This includes
   1) expected annual refurbishment/maintenance cost (currency/year)
   2) expected annual production loss due to failure and efficiency decrease (currency/year)
   3) cost at the time of refurbishment/maintenance, planned or at an unexpected failure
   4) estimate of loss by doing refurbishment/maintenance too early or too late (currency)
   5) storage analysis; i.e. value of having the units stored locally

5. A full report of the input data.

6. Graphical presentation of the solution.

5. DYNAMIC BEHAVIOUR

This model is basically quite static. The user enters the data required, and the system calculates the correct maintenance decision based on this input. The use of the model however is subject to "dynamic thinking".

We propose the following of when to use this model in the maintenance planning:

1. When planning new hydropower plants it is important to think maintenance and strategies for refurbishment from the very beginning.

2. When efficiency measures of the turbine has been performed, and new information about the turbine system is inquired.

3. When new technology is being introduced in the market, i.e. new materials with significantly better deterioration rates to prevent cavitation. This will normally give an optimal strategy which requires an earlier *next* maintenance/refurbishment action.

4. When the expectations concerning the long term energy price changes.

5. For educational purposes to learn maintenance engineers and economists to see the connections between economy and technology in maintenance/refurbishment decision making. This system will be quite easy to use and is probably a good way of learning these relations.

6. DATA PROCESSING (ALGORITHMS)

In this section we give a brief description of the optimisation model concept. First we give a description of the system structure, and then we give a few comments about the model.

Overall program structure:

Figure 1 gives a brief overview of the data system which will be implemented.

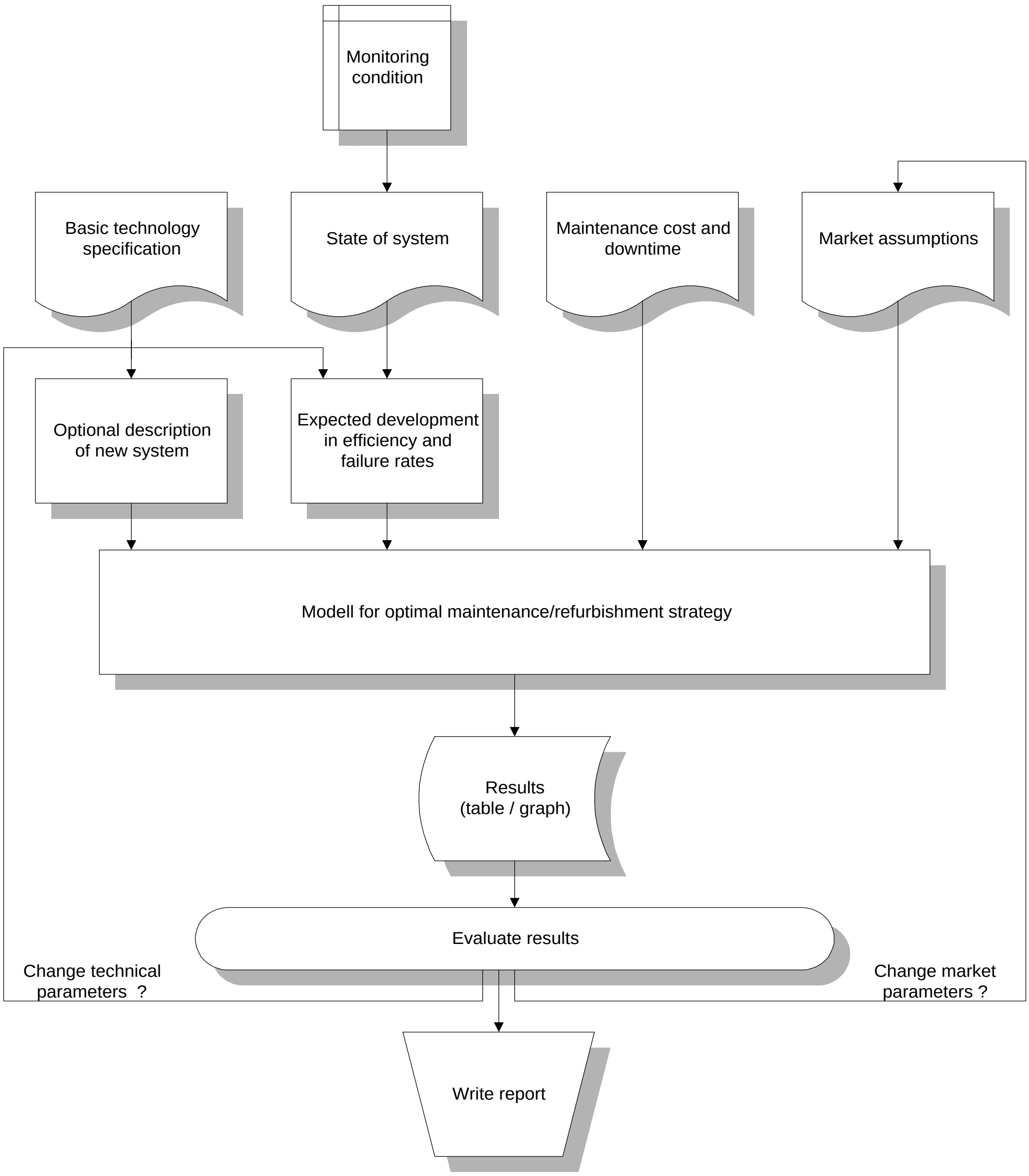

Figure 1. Overall program structure

The figure is a flow diagram for the system and gives an indication of the way to use it for decision making, by also doing sensitivity analysis for critical parameters.

The model:

The algorithmic part of the system is in the box «Model for optimal maintenance/ refurbishment strategy». It is a normal cost-minimisation model based on the input data from the boxes leading into it. A simplification of the model looks like this:

$$\min_{t^*}\left\{\left[\frac{C_{plan}}{e^{kt^*}}\left(1-\int_0^{t^*} f(t)dt\right)+\int_0^{t^*}\frac{C_{fail}\cdot f(t)}{e^{kt}}dt\right]\cdot\frac{k}{1-e^{-kt^*}}+\left[\overline{pP}\int_0^{t^{MTTR}}\frac{\eta_{new}-\eta(t)}{e^{kt}}dt\right]\cdot\frac{k}{1-e^{-kt^{MTTR}}}\right\}$$

This is a long term annuity model which gives the optimal maintenance interval. The solution of these integrals requires a numerical approach, since they normally are impossible to solve analytically. The model consists of three parts; the first part gives the cost of doing a planned maintenance operation, the second part gives the costs if an uncontrolled failure occurs, while the third part describes the production loss due to deterioration and loss of efficiency.

Modelling efficiency development:

Hydraulic efficiency in turbine:

$$\eta_h=\frac{T\omega}{\rho g Q H_e}$$

Reduction in the efficiency over time is estimated as

$$\eta_h(t)=\eta_2+(\eta_1-\eta_2)e^{-Kt}$$

at the best operational point. The power-dependent efficiency curve is estimated as a polynom, fitted to up to twelve registered values. At least two points must be given, - at the best operational point, and at the maximum power output . When running the turbines at other operational points than the best, we assume that the relative reduction due to wear is unchanged.

Volumetric efficiency in turbine:

$$\eta_v(t)=1-\frac{\Delta Q(t)}{Q}$$

Efficiency in penstock: (expressed by the Darcy-Weisbach formula)

$$\eta_p(t)=1-\frac{\Delta h(t)}{H_e},\Delta h(t)=\lambda(t)\frac{Lv^2}{D2g}$$ where λ(t) is an empirically based expression.

The model for the hydraulic efficiency development in the turbine will be modified and extended during this project.

Modelling failure density functions:

We will primarily apply the standard exponential distribution to describe stochastic failure, and the Weibull distribution to describe the risk of failure in components with a reduced reliability as a function of age.

Exponential: $f(t) = \lambda \cdot e^{-\lambda t}$

Weibull: $f(t) = \alpha\beta \cdot t^{\beta-1} \cdot e^{-\alpha t^{\beta}}$

The parameters in these distributions is explained in standard books of statistics. We will also apply the model in combination with empirical distributions, generated from statistical databases.

Impact of gross head variations:

It is known that variations in the gross head due to seasonal hydrological fluctuations will have impact on the best operational point, efficiency level and thereby on the optimal refurbishment decisions. /3/ In the models developed so far, this is not taken into account. Our ambition is to make it an *option* to integrate expected fluctuations in the head as input to the calculations. The changes needed in the model to implement this, is not finished yet.

7. INTERFACES

7.1. OPERATOR INTERFACE

The program system is a stand-alone module suitable for coding in the C++ language. The reason that the C++ language is recommended, is that we already have a prototype written in this language. The dialogue is to be implemented with Microsoft Visual C++ as a Windows95/NT-application.

All data into and out of the module are so far assumed to be held in standard binary i/o-format in C++. An integration into any specific database system should therefore be very easy.

The dialogue will be designed to give the operator an intuitive recognition of the underlying technical system. For the user to gain confidence in a system, this is a very important issue.

7.2. SYSTEM INTERFACE

This system is not dependent of other data systems, but it will be useful to integrate some of the functions with available databases. An example of this is estimation of failure rates to an underlying database with relevant statistics. (Ref. Project A2 «Procure Maintenance History and Statistics»)

8. ERROR MANAGEMENT

A general rule is that all input data should be subject to quality checking before they are entered into the model. The model in itself is very reliable, and it calculates the optimal solution based on the input. The problem is therefore the initial evaluation of the uncertain parameters. To prevent «wrong» input, it is necessary to prepare a «Users Guide», with examples of how to use the system in a proper way.

If there is data missing in the underlying database, there will be prompted a message on the screen, and produced an error file to document these problems.

9. CONSTRAINTS

For the mathematical model, there are no constraints on the input parameters, but we will test for negativity and zero in the central parameters which require positive numbers to make sense.

It is possible that we will limit the number of turbines in parallel to N. In the prototype N equals 3. At present we will also limit the system to one hydropower plant. At a later stage it might be possible to extend the system to simultaneously generate maintenance/ refurbishment plans for different plants owned by the same company.

At this point, we do not discuss complications regarding contracts of power delivery and safety aspects of running the hydropower system. These aspects will make the modelling of an optimal maintenance activity somewhat more complex, and is at present not included as restrictions in the model.

The state of the penstock system and the generator will also influence the refurbishment decision for the turbine, since these are dependent of each other. This dependence will initially be modelled quite roughly, but to begin with the purpose of this option is to reveal the principles of a correct maintenance strategy, with basis in measured and expected development in turbine/penstock efficiency and evaluation of failure probabilities for the turbine and generator.

10. HARDWARE AND SOFTWARE REQUIREMENTS

This model will primarily be implemented for PC with a requirement of having Windows95 or Windows NT installed. The hardware requirements for this system is given by the hardware required when using Windows95 / Windows NT.

For good system performance, a Pentium PC is recommended.

11. TEST PLAN

The purpose of the test is to assure that the system to be developed will benefit the process of making better maintenance and refurbishment decisions in a hydropower plant. The test will primarily be performed by applying the system on the two plants, which is chosen for test sites of REMAFEX, (France-Covas in Portugal and Salto de Soutelo in Spain.) In addition Statkraft will evaluate the system being developed, and have a role as testers, advisors and active discussion partners during the project.

Testing is a part of the quality process, and it should have focus both on 1) *the technical quality of the computer system*, 2) *the quality of the calculations performed by the model*, and 3) *the quality of the system as a part of the overall maintenance process in the hydropower company*.

1) The technical quality of the computer system is to be compared with the standards of Windows95/WindowsNT. The quality of the system interface should be measured by this standard, but is to some extent a subjective matter. In addition the software must be evaluated according to availability of onscreen help-functions and general system documentation. This evaluation can be done by any user or experienced developer.

2) The quality of the calculations is the main part of the system, and is a synthesis of economy and technology. The economic calculations will be tested and verified by researchers at SINTEF Industrial Management - Applied Economics. The technology specifications will be verified and tested by EFI, Kværner Energy and Statkraft. The main test for this part, however is the «on site» tests, and to what extent the results from the calculations is accepted as reliable and relevant.

3) The quality of the system as a part of the overall maintenance process is maybe the most difficult, but most important part of it. The question is how this system is functioning as a part of the total maintenance strategy in the power plant. This is a qualitative test, which will require the maintenance analyst to be educated in the REMAFEX concept. Testing this part is a general part of the REMAFEX project, but some systems will probably work better than others. This will also vary from one site to another, depending on interest and skill of the analyst.

As mentioned earlier, we have already developed a prototype which runs on PC (DOS) with manual input of data. The main model is implemented there, and it has been used for educational purposes at seminars held by the Norwegian Electricity Federation (EnFO). The concept has also been evaluated by Statkraft. This testing revealed the need of modifying the prototype model.

APPENDIX

Detailed specification of algorithms and software sub-modules will be developed during the project, and is at this point preliminary. The reference articles /1/ and /2/ gives an introductory overview over the details in the system.

REFERENCES

/1/ F. Rømo, M.W.Lund (SINTEF), T.K.Nielsen, H.Hulaas (Kværner):
«High head Francis turbines - optimal refurbishing time»
Paper presented at the conference «Uprating & refurbishing hydro powerplants »
in Nice, France. Conference Proceedings, Vol.III(1995)

/2/ A.O. Eggen, B.I. Langdal, F. Rømo, T.K. Nielsen, M. Laulo:
«Beslutningsstøttesystemer for vedlikeholdsplanlegging
Modell av vannvei, turbin og generator» (1996)
(In Norwegian)

/3/ F.O.Rasmussen:
«Hydraulisk optimal drift av vannkraftsystemer» (1994)
(Hydraulic optimal operation of hydropower systems)
(In Norwegian) (STF67 A94023)

APPENDIX 1 - INPUT DATA TABLE FOR FUNCTION

FUNCTION: OPTIMAL MAINTENANCE INTERVAL FOR HYDRAULIC STRING, TURBINE AND GENERATOR (A3)

Item	**Hydraulic string, turbine and generator**
Domain	**Refurbishment/Maintenance planning**
User Need	**To generate optimal refurbishment plans**
Function	**Optimal maintenance interval for hydraulic string, turbine and generator**

No.	System	Subsystem	Parameter	State	Type	Unit of measure	Range	Alarm value	Trip value	Remarks	Data label
1.	**Power station**		**Number of parallels in power station**		Numeric		Site dependent **N** = [1, 8]		None	configured, Remafex DB	_PS_#NUMP
2.	**Power station**		**Type of production**		Numeric		Site depend. (Magazine=0/ River=1)		None	configured, Remafex DB	_PS_#TYPE
3.	**Power station**		**Maximum Volume flow**		Numeric	m^3/s	[0, Q_{imax}]		None	configured, Remafex DB	_PS_#MFLW
4.	**Power station**		**Gross head**		Numeric	m	>0		None	acquired,	_PS_#GHED
5.	**Hydraulic string**	**Tunnel**	**Length**		Numeric	m	>0		None	configured, Remafex DB	_HY_TL_#LENG
6.	**Hydraulic string**	**Tunnel**	**Cross section area**		Numeric	m^2	>0		None	configured, Remafex DB	_HY_TL_#CSEC
7.	**Hydraulic string**	**Tunnel**	**Manning Number**		Numeric		>0 [20, 50]		None	configured, Remafex DB	_HY_TL_#MANN
8.	**Hydraulic string**	**Penstock**	**Length**		Numeric	m	>0		None	configured, Remafex DB	_HY_PE_#LENG
9.	**Hydraulic string**	**Penstock**	**Diameter**		Numeric	m	>0		none	configured, Remafex DB	_HY_PE_#DIAM
10.	**Hydro-electric set**	**Turbine**	**Type**		Numeric		(0=Pelton/1=Kaplan /2=Francis)		none	configured, Remafex DB	_HS_TU_#TYPE
11.	**Hydro-electric set**	**Turbine**	**Power output at max efficiency**		Numeric	MW	>0		none	configured, N data Remafex DB	_HS_TU_#PMEF
12.	**Hydro-electric set**	**Turbine**	**Maximum power output**		Numeric	MW	>0		none	configured, N data Remafex DB	_HS_TU_#PMAX

13.	**Hydro-electric set**	**Turbine**	**Efficiency as function of power**		Numeric	%	>0		none	calculated, N series, Remafex DB	_HS_TU_#EPOW
14.	**Hydro-electric set**	**Generator**	**Type**		char				none	configured, Remafex DB	_HS_GE_#TYPE
15.	**Hydro-electric set**	**Generator**	**Efficiency**		Numeric	%	>0		none	configured, N data Remafex DB	_HS_GE_#EFF
16.	**Hydraulic string**	**Penstock**	**Measured hydraulic efficiency level**		Numeric	%	>0		none	(Based on 17 or 18) configured	_HY_PE_#MEFF
17.	**Hydraulic string**	**Penstock**	**Head loss development**		Numeric	m	>0		none	acquired, time series, Remafex DB	_HY_PE_#MHLO
18.	**Hydraulic string**	**Penstock**	**Roughness measurements**		Numeric	mm	>0		none	acquired, time series, Remafex DB	_HY_PE_#MROU
19.	**Hydro-electric set**	**Turbine**	**Measured hydraulic efficiency**		Numeric	%	>0		none	acquired, N time series, Remafex DB	_HS_TU_#MHEF
20.	**Hydro-electric set**	**Turbine**	**Measured internal leaks**		Numeric	m^3/s	[0,->)		none	acquired, N time series, Remafex DB	_HS_TU_#MILE
21.	**Hydroel set**	**Generator**	**Monitoring strategy**		char		(PDA/ tanδ/ A/ B)		none	configured	_HS_GE_#STRM
22.	**Hydro-electric set**	**Generator**	**Measure discharge from windings**		numeric	pC	[0,->)		none	acquired, N time series, Remafex DB	_HS_GE_#MDSC
23.a	**Hydraulic string**	**Penstock**	**Expect. roughness development**		Numeric	mm	[0,->)		none	assumptions about future development	_HY_PE_#EREF
23.b	**Hydro-electric set**	**Turbine**	**Expected hydraulic efficiency develop.**		Numeric	%	[0,->)		none	assumptions about future development	_HS_TU_#EHEF
24.	**Hydro-electric set**	**Turbine**	**Expected internal leaks develop.**		Numeric	m^3/s	[0,->)		none	assumptions about future development	_HS_TU_#EILE
25.	**Hydro-electric set**	**Generator**	**Expected discharge from windings**		numeric	pC	[0,->)		none	assumptions about future development	_HS_GE_#EDSC
26.	**Hydro-electric set**	**Turbine**	**Failure density**		Numeric x3		Contains up to 3 unrestr. param.		none	tuned (acquired)	_HS_TU_#FAIL
27.	**Hydro-electric set**	**Generator**	**Failure density**		Numeric x3		---«---		none	tuned (acquired)	_HS_GE_#FAIL
28.	**Hydro-electric set**	**Turbine/ Generator**	**Failure density**		Numeric x3		---«---		none	tuned (acquired) (failure density for components)	_HS_#COMFAIL
29.	**Hydraulic string**	**Penstock**	**Investment and labour planned**		numeric	currency	[0,->)		none	configured, Remafex DB	_HY_PE_#INVP
30.	**Hydraulic string**	**Penstock**	**Investment and labour corrective**		numeric	currency	[0,->)		none	configured, Remafex DB	_HY_PE_#INVC

31.	**Hydraulic string**	**Penstock**	**Dismounting time for unit**		numeric	hours	[0,->)		none	configured, Remafex DB	_HY_PE_#TDIS
32.	**Hydraulic string**	**Penstock**	**Delivery time for unit**		numeric	hours	[0,->)		none	configured, Remafex DB	_HY_PE_#TDEL
33.	**Hydraulic string**	**Penstock**	**Mounting time for new unit**		numeric	hours	[0,->)		none	configured, Remafex DB	_HY_PE_#TMOU
34.	**Hydro-electric set**	**Turbine**	**Investment and labour planned**		numeric	currency	[0,->)		none	configured, N data, Remafex DB	_HS_TU_#INVP
35.	**Hydro-electric set**	**Turbine**	**Investment and labour corrective**		numeric	currency	[0,->)		none	configured, N data, Remafex DB	_HS_TU_#INVC
36.	**Hydro-electric set**	**Turbine**	**Dismounting time for unit**		numeric	hours	[0,->)		none	configured, N data, Remafex DB	_HS_TU_#TDIS
37.	**Hydro-electric set**	**Turbine**	**Delivery time for unit**		numeric	hours	[0,->)		none	configured, N data, Remafex DB	_HS_TU_#TDEL
38.	**Hydro-electric set**	**Turbine**	**Mounting time for new unit**		numeric	hours	[0,->)		none	configured, N data, Remafex DB	_HS_TU_#TMOU
39.	**Hydro-electric set**	**Generator**	**Investment and labour planned**		numeric	currency	[0,->)		none	configured, N data, Remafex DB	_HS_GE_#INVP
40.	**Hydro-electric set**	**Generator**	**Investment and labour corrective**		numeric	currency	[0,->)		none	configured, N data, Remafex DB	_HS_GE_#INVC
41.	**Hydro-electric set**	**Generator**	**Dismounting time for unit**		numeric	hours	[0,->)		none	configured, N data, Remafex DB	_HS_GE_#TDIS
42.	**Hydro-electric set**	**Generator**	**Delivery time for unit**		numeric	hours	[0,->)		none	configured, N data, Remafex DB	_HS_GE_#TDEL
43.	**Hydro-electric set**	**Generator**	**Mounting time for new unit**		numeric	Hours	[0,->)		none	configured, N data, Remafex DB	_HS_GE_#TMOU
44.	**Hydro-electric set**	**Turbine/ Generator**	**Number of components defined**		numeric		**M** = (0,100)		none	Remafex DB, (optional,export from A3-function)	_HS_#COMNUM
44.a	**Hydro-electric set**	**Turbine/ Generator**	**Component name**		char	Text label	Max 30 characters for M components		none	Remafex DB, (optional,export from A3-function)	_HS_#COMNAME
44.b	**Hydro-electric set**	**Turbine/ Generator**	**Investment and labour planned**		numeric	Currency	[0,->)		none	configured , M*N data, Remafex DB, (optional,export from A3-function)	_HS_#COMINVP
45.	**Hydro-electric set**	**Turbine/ Generator**	**Investment and labour corrective**		numeric	Currency	[0,->)		none	configured , M*N data, Remafex DB, (optional,export from	_HS_#COMINVC

										A3-function)	
46.	**Hydro-electric set**	**Turbine/ Generator**	**Dismounting time for unit**		numeric	Hours	[0,->)		none	configured , M*N data, Remafex DB, (optional,export from A3-function)	_HS_#COMTDIS
47.	**Hydro-electric set**	**Turbine/ Generator**	**Delivery time for unit**		numeric	hours	[0,->)		none	configured , M*N data, Remafex DB, (optional,export from A3-function)	_HS_#COMTDEL
48.	**Hydro-electric set**	**Turbine/ Generator**	**Mounting time for new unit**		numeric	hours	[0,->)		none	configured , M*N data, Remafex DB, (optional,export from A3-function)	_HS_#COMTMOU
49.	**Power station**		**Expected seasonal production plan**		numeric	MW	[0,->)		none	configured, time series, Remafex DB, Max 365 data	_PS_#PLNE
50.	**Power station**		**Expected alt. Production plan**		numeric	MW	[0,->)		none	tuned data (optional)	_PS_#PLNA
51.	**Power station**		**Expected seasonal variation in gross head**		numeric	m	[0,->)		none	configured, time series, Remafex DB, Max 365 data. (optional)	_PS_#GHVR
52.	**External**	**Market**	**Expected price fluctuations**		numeric	currency/ MWh	[0,->)		none	configured (optional)	_EX_#PFLU
53.	**External**	**Market**	**Long term develop-ment market price**		numeric	currency/ MWh	[0,->)		none	configured (assumptions)	_EX_#PLTM
54.	**External**	**Market**	**Interest rate**		numeric	%/year	[0,->)		none	configured, Remafex DB	_EX_#RINT
55.	**External**	**Market**	**Inflation rate**		numeric	%/year	[0,->)		none	configured, Remafex DB (optional)	_EX_#RINF
56.	**External**	**Legislation**	**Company tax rate**		numeric	%	[0,->)		none	configured, Remafex DB (optional)	_EX_#CTAX