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TITLE :	SPECIFICATION OF IBERDROLA FUNCTIONS: "CALCULATE HYDROELECTRIC SET, TURBINE AND GENERATOR EFFICIENCY (S29)"
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CONTENTS

0. OBJECTIVE OF THE FUNCTION

The objective of the function is to calculate and report the hydroelectric set, turbine and generator efficiency, as well as cooling losses in turbine and generator and raw head losses in pipes for efficiency valuation.

For this purpose the function will estimate the real efficiencies of the different items of the installation (water gallery, forced pipe, branchs, turbine, generator) according to the plant instrumentation and they will be compared with the theoretical efficiencies showed by theoretical engineering calculations and efficiency curves supplied by manufacturers.

The real and theoretical efficiency discrepancy, as well as the different values calculated will be monitored and trending.

1. FUNCTION ENVIRONMENT

The function will evaluate the several efficiencies indicated. So, the information presented to the user will contain all values computed by means of the model showed in point 3.

This evaluation will be executed every time the input data described below is selected from SCADA sensors by the monitoring system, and will use the most recent data collected by the instrumentation in real time. The results obtained from the execution of the function will be stored into the real-time DB.

The sequence of requests and responses of the function is the following:

Event	Request/Response (RQ/RS)	From	To
Monitoring Request	RQ	Function	Function
Collect Data (continuous extern function with a fixed sample interval)	RQ	Function	Data Acquisition System (D.A.S.)
Data Collected (continuous function with a fixed sample interval)	RS	Data Acquisition System (D.A.S.)	Data Base
Select Data (on monitoring request)	RQ	Function	Function
Data Selected (on monitoring request)	RS	Data Base	Function
Perform Monitoring	RQ	Function	Function
Store Results (calculated values)	RS	Function	Data Base

2. INPUT DATA DEFINITION

Input data will be the following:

The following data are necessary for function development. They will proceed from the SCADA system or function S22 (energy dissipated in refrigeration coils).

$DH_{CHAMB\text{-}FRAN}$: Differential water pressure in Francis spiral chamber (Winter Kennedy)
DIFFERENTIAL_WATER_PRESS_SPIR_CHAM
(analogic, mm H_2O, range 0-50000)

$DH_{CONE\text{-}PELT}$: Differential water pressure in Pelton transition cone (Winter Kennedy)
DIFFERENTIAL_WATER_PRESS_MANIFOLD
(analogic, mm Hg, range 0-1000)

H_{CENZA} : Water level indication in Cenza reservoir
XA-V0100 (UCPS) WATER_LEVEL_CENZA
(analogic, m. over sea level, range 1300-1350)

H_{PORTAS} : Water level indication in Las Portas reservoir ,
XA-V0---- WATER_LEVEL_LASPORTAS
(analogic, m. over sea level, range 800-900)

$H_{RAW\text{-}FRAN}$: Water raw head in Francis set, between Cenza and Las Portas reservoir
XA-V0111 (UCP2) WATER_RAW_HEAD_CENZA_LASPORTAS
(analogic, m H_2O, range 0-1000)

$H_{CHIMNEY}$: Water level indication in chimney
XA-V0101 (UCPS) WATER_LEVEL_CHIMNEY
(analogic, m. over sea level, range 1300-1350)

$H_{CUSTODY\text{-}PELT}$: Water pressure in Pelton spherical custody valve
XA-V0---- INLET_WATER_PRESS_MANIFOLD
(analogic, m H_2O, range 0-1000)

$H_{CUSTODY\text{-}FRAN}$: Water pressure in Francis spherical custody valve
INLET_WATER_PRESS_SPIRAL_CHAMBER
(analogic, m H_2O, range 0-1000)

$H_{DRAFT\text{-}FRAN}$: Water pressure in Francis draft tube
WATER_PRESS_DRAFT_TUBE
(analogic, m H_2O, range 0-1000)

$P_{STATOR\ COIL\text{-}PELT}$: Power dissipated in stator by water refrigeration coils (From S22)
STAT_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{UP\text{-}BEARING\ \text{-}PELT}$: Power dissipated in upper oil carter by refrigeration coils (From S22)
UGB_COIL_DISSIPATED_ENERGY

(analogic, kW, range 0-5000)

$P_{LOW\text{-}BEARING\text{-}PELT}$: Power dissipated in lower oil carter by refrigeration coils (From S22)
LGB_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{TURB\ COIL\text{-}PELT}$: Power dissipated in turbine oil carter by refrigeration coils (FromS22)
TURB_GB_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{ACT\text{-}PELT}$: Active Power generated by set
XA-V0114 ACTIVE_POWER
(analogic, MW, range 0-180)

$P_{REACT\text{-}PELT}$: Reactive Power generated by set
XA-V0115 REACTIVE_POWER
(analogic, MVAr, range -90 : +90)

$V_{EXCIT\text{-}PELT}$: Excitation tension
XA-V0201 EXCITATION_TENSION
(analogic, V, range 0-1000)

$I_{EXCIT\text{-}PELT}$: Excitation current
XA-V0202 EXCITATION_CURRENT
(analogic, A, range 0-5000)

V_{PELT} : generator tension
XA-V0113 STATOR_TENSION
(analogic, V, range 0-20000)

I_{PELT} : generator current
XA-V0112 STATOR_CURRENT
(analogic, A, range 0-10000)

$P_{STATOR\ COIL\text{-}FRAN}$: Power dissipated in stator by water refrigeration coils (From S22)
STAT_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{UP\text{-}BEARING\text{-}FRAN}$: Power dissipated in upper oil carter by refrigeration coils (From S22)
UGB_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{LOW\text{-}BEARING\text{-}FRAN}$: Power dissipated in lower oil carter by refrigeration coils (From S22)
LGB_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{TURB\ COIL\text{-}FRAN}$: Power dissipated in turbine oil carter by refrigeration coils (From S22)
TURB_GB_COIL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

P_{SEAL} : Power dissipated in turbine by water seal (From S27)

SEAL_DISSIPATED_ENERGY
(analogic, kW, range 0-5000)

$P_{ACT-FRAN}$: Active Power generated by set
XA-V0107 ACTIVE_POWER
(analogic, MW, range 0-180)

$P_{REACT-FRAN}$: Reactive Power generated by set
XA-V0108 REACTIVE_POWER
(analogic, MVAr, range -90 : +90)

$V_{EXCIT-FRAN}$: Excitation tension
XA-V0109 EXCITATION_TENSION
(analogic, V, range 0-1000)

$I_{EXCIT-FRAN}$: Excitation current
XA-V0110 EXCITATION_CURRENT
(analogic, A, range 0-5000)

V_{FRAN} : generator tension
XA-V0106 STATOR_TENSION
(analogic, V, range 0-20000)

I_{FRAN} : generator current
XA-V0105 STATOR_CURRENT
(analogic, A, range 0-10000)

Water flow control devices(Francis):
XA-V0100 GUIDE_VANES_POSITION (analogic, %, range 0-100%)

Water flow control devices(Pelton):
XA-V0105 NEEDLE1_POSITION (analogic, %, range 0-100%)
XA-V0106 NEEDLE2_POSITION (analogic, %, range 0-100%)
XA-V0107 NEEDLE3_POSITION (analogic, %, range 0-100%)
XA-V0108 NEEDLE4_POSITION (analogic, %, range 0-100%)
XA-V0109 NEEDLE5_POSITION (analogic, %, range 0-100%)
XA-V0110 NEEDLE6_POSITION (analogic, %, range 0-100%)

Water temperature.
(ERTSH2) XA-20102 WATER_TEMPERATURE_CHIMNEY
(analogic , ºC, range -20:+90)

3. OUTPUT DATA DEFINITION

output data will show the following input data and calculated results of the hydroelectric set, pipes, turbine, and generator efficiency. This values will be monitored by the system.

WORKING CONDITIONS

GENERATOR	POWER GENERATED					ROTOR EXCITATION		
	V	I	MVA	MW	MVAr	V	I	MW
PELTON	V_{PELT}	I_{PELT}	P_{PELT}	$P_{ACT-PELT}$	$P_{REACT-PELT}$	$V_{EXCIT-PELT}$	$I_{EXCIT-PELT}$	$P_{EXCIT-PELT}$
FRANCIS	V_{FRAN}	I_{FRAN}	P_{FRAN}	$P_{ACT-FRAN}$	$P_{REACT-FRAN}$	$V_{EXCIT-FRAN}$	$I_{EXCIT-FRAN}$	$P_{EXCIT-FRAN}$

TURBINE PELTON						
INJECTORS WORKING Nº	1	2	3	4	5	6
APERTURE GRADE						

TURBINE FRANCIS	
GUIDE VANES APERTURE	

RAW HEAD AND WATER FLOW	RAW HEAD(m)	EFFECTIVE PRESSURE HEAD (m)			FLOW (m^3 /s)	DIFF.PRESSURE WINT-KENNEDY	WATER TEMPERATURE
		Theoretical	Real (valued)	Variation (%)(R-T)			
PELTON	$H_{RAW-PELT}$	$H_{T-EFFECT-PELT}$	$H_{R-EFFECT-PELT}$	$V\_H_{EFFECT-PELT}$	Q_{PELT}	$DH_{CONE-PELT}$	(ERTSH2) -
FRANCIS	$H_{RAW-FRAN}$	$H_{T-EFFECT-FRAN}$	$H_{R-EFFECT-FRAN}$	$V\_H_{EFFECT-FRAN}$	Q_{FRAN}	$DH_{CHAMB-FRAN}$	XA-20102

ESTIMATED EFFICIENCY AND LOSSES

FACILITY	HYDROELECTRIC SET EFFICIENCY (%)			GLOBAL PLANT EFFICIENCY (%)		
	Theoretical	Real (valued)	Variation (R-T)	Theoretical	Real	Variation (R-T)
PELTON	$E_{T-SET-PELT}$	$E_{R-SET-PELT}$	$V\_E_{SET-PELT}$	$E_{T-GLOB-PELT}$	$E_{R-GLOB-PELT}$	$V\_E_{GLOB-PELT}$
FRANCIS	$E_{T-SET-FRAN}$	$E_{R-\ SET-FRAN}$	$V\_E_{SET-FRAN}$	$E_{T-GLOB-FRAN}$	$E_{R-\ GLOB-FRAN}$	$V\_E_{GLOB-FRAN}$

TURBINE	EFFICIENCY (%)			COOLING LOSSES (KW)		TOTAL
	Theoretical	Real	Variation (R-T)	Carter	Seal	LOSES(KW)
PELTON	$ET_{T\text{-}PELT}$	$ET_{R\text{-}PELT}$	V_ET_{PELT}			$P_{R\text{-}TOT\text{-}TURB\text{-}PELT}$
FRANCIS	$ET_{T\text{-}FRAN}$	$ET_{R\text{-}FRAN}$	V_ET_{FRAN}	$P_{TURB\ COIL\text{-}FRAN}$	P_{SEAL}	$P_{R\text{-}TOT\text{-}TURB\text{-}FRAN}$

GENERATOR	EFFICIENCY (%)			COOLING LOSSES IN HEAT EXCHANGERS (KW)			TOTAL GEN. LOSSES (KW)
	Theoretical	Real	Variation	Upper carter	Lower carter	Stator	real
PELTON	$EG_{T\text{-}PELT}$	$EG_{R\text{-}PELT}$	V_EG_{PELT}	$P_{UP\text{-}BEARING\ \text{-}PELT}$	$P_{LOW\text{-}BEARING\ \text{-}PELT}$	$P_{STATOR\ COIL\text{-}PELT}$	$P_{R\text{-}TOT\text{-}GE\text{-}PELT}$
FRANCIS	$EG_{T\text{-}FRAN}$	$EG_{R\text{-}FRAN}$	V_EG_{FRAN}	$P_{UP\text{-}BEARING\ \text{-}FRAN}$	$P_{LOW\text{-}BEARING\text{-}FRAN}$	$P_{STATOR\ COIL\text{-}FRAN}$	$P_{R\text{-}TOT\text{-}GE\text{-}FRAN}$

INSTALLATION PIPES	EFFICIENCY (%)		
	Theoretical	Real	Variation (R-T)
PELTON	$EI_{T\text{-}PEL}$	$EI_{R\text{-}PEL}$	V_EI_{PEL}
FRANCIS	$EI_{T\text{-}FRAN}$	$EI_{R\text{-}FRAN}$	V_EI_{FRAN}

INSTALLATION PIPES	HEAD LOSSES		
	Theoretical	Real	Variation (R-T) (%)
GALLERY Cenza	$DH_{T\text{-}GALL}$	$DH_{R\text{-}GALL}$	V_DH_{GALL}
FORCED PIPE Cenza	$DH_{T\text{-}PIPE}$		
PELTON BRANCH	$DH_{T\text{-}BRANCH\text{-}PELT}$		
FRANCIS BRANCH	$DH_{T\text{-}BRANCH\text{-}FRAN}$		
FORCED PIPE+BRANCH PELTON	$DH_{T\text{-}PIPE\text{-}BRAN\text{-}PELT}$	$DH_{R\text{-}PIPE\text{-}BRAN\text{-}PELT}$	$V\_DH_{PIPE\text{-}BRAN\text{-}PELT}$
FORCED PIPE+BRANCH FRANCIS	$DH_{T\text{-}PIPE\text{-}BRAN\text{-}FRAN}$	$DH_{R\text{-}PIPE\text{-}BRAN\text{-}FRAN}$	$V\_DH_{PIPE\text{-}BRAN\text{-}FRAN}$
FORCED PIPE Las Portas	$DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$	$DH_{R\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$	$V\_DH_{PIPE\text{-}PORTAS\text{-}FRAN}$
TOTAL PELTON LINE	$DH_{T\text{-}TOT\text{-}PELT}$	$DH_{R\text{-}TOT\text{-}PELT}$	$V\_DH_{TOT\text{-}PELT}$
TOTAL FRANCIS LINE	$DH_{T\text{-}TOT\text{-}FRAN}$	$DH_{R\text{-}TOT\text{-}FRAN}$	$V\_DH_{TOT\text{-}FRAN}$

4. DYNAMIC BEHAVIOUR

As mentioned in section 1., the function will make some simple calculations to transform the initial data selected from the D.A.S. So, the function will be executed when retrieving data from SCADA by the monitoring system, and the results stored into the real-time DB.

5. DATA PROCESSING (ALGORITHMS)

In this section we will define the model used to determine the different calculations

1. Estimation of water flow turbinated

The turbinated water flow is calculated by means of Winter-Kennedy instrumentation installed in the plant. The necessary formulas are:

$$Q_{PELT} = 1{,}0364 * (DH_{CONE\text{-}PELT})^{1/2}$$
$$Q_{FRAN} = 0{,}1528 * (DH_{CHAMB\text{-}FRAN})^{1/2}$$

2. Estimation of effective water pressure head and pressure losses

In this point the effective water pressure and pressure losses in pipes will be calculated for Pelton and Francis group considering the total water flow turbinated by both.
The system will calculate the theoretical and the real effective pressure and pressure losses. Theoretical will be estimated according to theoretical engineering pressure losses coefficients. Real will be estimated according to plant instrumentation.
The discrepancy will be determinate in percentage and will be trended.

a) Theoretical.

$H_{RAW\text{-}PELT}$: Water raw head in Pelton set.
$H_{T\text{-}EFFECT\text{-}PELT}$: Theoretical effective water pressure head in Pelton set
$H_{T\text{-}EFFECT\text{-}FRAN}$: Theoretical effective water pressure head in Francis set
$DH_{T\text{-}GALL}$: Theoretical water pressure losses in pressure gallery
$DH_{T\text{-}PIPE}$: Theoretical water pressure losses in forced pipeline
$DH_{T\text{-}BRANCH\text{-}PELT}$: Theoretical water pressure losses in Pelton branch
$DH_{T\text{-}BRANCH\text{-}FRAN}$: Theoretical water pressure losses in Francis branch
$DH_{T\text{-}PIPE\text{-}BRAN\text{-}PELT}$: Theoretical water pressure losses in forced pipe and Pelton branch
$DH_{T\text{-}PIPE\text{-}BRAN\text{-}FRAN}$: Theoretical water pressure losses in forced pipe and Francis branch
$DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$: Theoretical water pressure losses in forced pipe Francis- Las Portas reservoir
$EI_{T\text{-}PEL}$: Pipe installation Theoretical efficiency in Pelton set

$EI_{T\text{-}FRAN}$: Pipe installation Theoretical efficiency in Francis set

$$H_{RAW\text{-}PELT} = H_{CENZA} - 676{,}5$$
$$DH_{T\text{-}GALL} = 0{,}007507 * (Q_{FRAN} + Q_{PELT})^2$$
$$DH_{T\text{-}PIPE} = 0{,}009935 * (Q_{FRAN} + Q_{PELT})^2$$
$$DH_{T\text{-}BRANCH\text{-}PELT} = 0{,}002861 * (Q_{PELT})^2$$
$$DH_{T\text{-}BRANCH\text{-}FRAN} = 0{,}015167 * (Q_{FRAN})^2$$
$$DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN} = 0{,}007717 * (Q_{FRAN})^2$$
$$DH_{T\text{-}TOT\text{-}PELT} = DH_{T\text{-}GALL} + DH_{T\text{-}PIPE} + DH_{T\text{-}BRANCH\text{-}PELT}$$
$$DH_{T\text{-}TOT\text{-}FRAN} = DH_{T\text{-}GALL} + DH_{T\text{-}PIPE} + DH_{T\text{-}BRANCH\text{-}FRAN} + DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$$

$$\mathbf{H_{T\text{-}EFFECT\text{-}PELT} = H_{RAW\text{-}PELT} - DH_{T\text{-}GALL} - DH_{T\text{-}PIPE} - DH_{T\text{-}BRANCH\text{-}PELT}}$$
$$\mathbf{H_{T\text{-}EFFECT\text{-}FRAN} = H_{RAW\text{-}FRAN} - DH_{T\text{-}GALL} - DH_{T\text{-}PIPE} - DH_{T\text{-}BRANCH\text{-}FRAN} - DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}}$$

$$\mathbf{EI_{T\text{-}PEL}(\%) = (1 - (H_{RAW\text{-}PELT} - H_{T\text{-}EFFECT\text{-}PELT}) / H_{RAW\text{-}PELT}) * 100}$$
$$\mathbf{EI_{T\text{-}FRAN}(\%) = (1 - (H_{RAW\text{-}FRAN} - H_{T\text{-}EFFECT\text{-}FRAN}) / H_{RAW\text{-}FRAN}) * 100}$$

b) Real

$H_{R\text{-}EFFECT\text{-}PELT}$: Real effective water pressure head in Pelton set
$H_{R\text{-}EFFECT\text{-}FRAN}$: Real effective water pressure head in Francis set
$DH_{R\text{-}GALL}$: Real water pressure losses in pressure gallery
$DH_{R\text{-}PIPE}$: Real water pressure losses in forced pipeline
$DH_{R\text{-}PIPE\text{-}BRAN\text{-}PELT}$: Real water pressure losses in forced pipe and Pelton branch
$DH_{R\text{-}PIPE\text{-}BRAN\text{-}FRAN}$: Real water pressure losses in forced pipe and Francis branch
$DH_{R\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$: Real water pressure losses in forced pipe Francis- Las Portas reservoir
$EI_{R\text{-}PEL}$: Pipe Installation real efficiency in Pelton set
$EI_{R\text{-}FRAN}$:pipe installation real efficiency in Francis set

$$DH_{R\text{-}GALL} = H_{CENZA} - H_{CHIMNEY} - [(Q_{PELT} + Q_{FRAN})^2 / (2*9{,}8 * 68{,}82)]$$

$$DH_{R\text{-}PIPE\text{-}BRAN\text{-}PELT} = DH_{R\text{-}PIPE} + DH_{R\text{-}BRANCH\text{-}PELT} = H_{CHIMNEY} - H_{CUSTODY\text{-}PELT} - [(Q_{PELT})^2 / (2*9{,}8 * 2{,}37)]$$

$$DH_{R\text{-}PIPE\text{-}BRAN\text{-}FRAN} = DH_{R\text{-}PIPE} + DH_{R\text{-}BRANCH\text{-}FRAN} = H_{CHIMNEY} - H_{CUSTODY\text{-}FRAN} - [(Q_{FRAN})^2 / (2*9{,}8 * 1{,}196)]$$

$$DH_{R\text{-}PIPE\text{-}PORTAS\text{-}FRAN} = H_{PORTAS} - [(Q_{FRAN})^2 / (2*9{,}8 * 17{,}26)] - H_{DRAFT\text{-}FRAN}$$

$$DH_{R\text{-}TOT\text{-}PELT} = DH_{R\text{-}GALL} + DH_{R\text{-}PIPE\text{-}BRAN\text{-}PELT}$$

$$DH_{R\text{-}TOT\text{-}FRAN} = DH_{R\text{-}GALL} + DH_{R\text{-}PIPE\text{-}BRAN\text{-}FRAN} + DH_{R\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$$

$$\mathbf{H_{R\text{-}EFFECT\text{-}PELT} = H_{CUSTODY\text{-}PELT} + [(Q_{PELT})^2 / (2*9{,}8 * 2{,}37)] + 679{,}123 - 676{,}5}$$

$$\mathbf{H_{R\text{-}EFFECT\text{-}FRAN} = H_{CUSTODY\text{-}FRAN} + [(Q_{FRAN})^2 / (2*9{,}8 * 0{,}97)] + 679{,}31 - 676{,}5 - H_{DRAFT\text{-}FRAN} - [(Q_{FRAN})^2 / (2*9{,}8 * 17{,}26)]}$$

$$EI_{R\text{-}PEL}\ (\%) = (1 - (H_{RAW\text{-}PELT} - H_{R\text{-}EFFECT\text{-}PELT}) / H_{RAW\text{-}PELT}) * 100$$
$$EI_{R\text{-}FRAN}\ (\%) = (1 - (H_{RAW\text{-}FRAN} - H_{R\text{-}EFFECT\text{-}FRAN}) / H_{RAW\text{-}FRAN}) * 100$$

c) Variation

$$DH_{T\text{-}PIPE\text{-}BRAN\text{-}PELT} = DH_{T\text{-}PIPE} + DH_{T\text{-}BRANCH\text{-}PELT}$$

$$DH_{T\text{-}PIPE\text{-}BRAN\text{-}FRAN} = DH_{T\text{-}PIPE} + DH_{T\text{-}BRANCH\text{-}FRAN}$$

$$V\_H_{EFFECT\text{-}PELT}\ (\%) = (H_{R\text{-}EFFECT\text{-}PELT} - H_{T\text{-}EFFECT\text{-}PELT}) * 100 / H_{T\text{-}EFFECT\text{-}PELT}$$

$$V\_H_{EFFECT\text{-}FRAN}\ (\%) = (H_{R\text{-}EFFECT\text{-}FRAN} - H_{T\text{-}EFFECT\text{-}FRAN}) * 100 / H_{T\text{-}EFFECT\text{-}FRAN}$$

$$V\_DH_{GALL}\ (\%) = (DH_{R\text{-}GALL} - DH_{T\text{-}GALL}) * 100 / DH_{T\text{-}GALL}$$

$$V\_DH_{PIPE\text{-}BRAN\text{-}FRAN}\ (\%) = (DH_{R\text{-}PIPE\text{-}BRAN\text{-}FRAN} - DH_{T\text{-}PIPE\text{-}BRAN\text{-}FRAN}) * 100 / DH_{T\text{-}PIPE\text{-}BRAN\text{-}FRAN}$$

$$V\_DH_{PIPE\text{-}BRAN\text{-}PELT}\ (\%) = (DH_{R\text{-}PIPE\text{-}BRAN\text{-}PELT} - DH_{T\text{-}PIPE\text{-}BRAN\text{-}PELT}) * 100 / DH_{T\text{-}PIPE\text{-}BRAN\text{-}PELT}$$

$$V\_DH_{PIPE\text{-}PORTAS\text{-}FRAN}(\%) = (DH_{R\text{-}PIPE\text{-}PORTAS\text{-}FRAN} - DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}) * 100 / DH_{T\text{-}PIPE\text{-}PORTAS\text{-}FRAN}$$

$$V\_DH_{TOT\text{-}PELT}\ (\%) = (DH_{R\text{-}TOT\text{-}PELT} - DH_{T\text{-}TOT\text{-}PELT}) * 100 / DH_{T\text{-}TOT\text{-}PELT}$$

$$V\_DH_{TOT\text{-}FRAN}\ (\%) = (DH_{R\text{-}TOT\text{-}FRAN} - DH_{T\text{-}TOT\text{-}FRAN}) * 100 / DH_{T\text{-}TOT\text{-}FRAN}$$

$$V\_EI_{PEL}\ (\%) = (EI_{R\text{-}PEL} - EI_{T\text{-}PEL}) * 100 / EI_{T\text{-}PEL}$$

$$V\_EI_{FRAN}\ (\%) = (EI_{R\text{-}FRAN} - EI_{T\text{-}FRAN}) * 100 / EI_{T\text{-}FRAN}$$

3.Estimation of generator efficiency.

In this point the system will calculate the theoretical and the real generator efficiency. Theoretical will be estimated according to theoretical engineering efficiency curves supplied by manufacturer. Real will be estimated according to plant instrumentation, considering the energy dissipated in refrigeration coils (stator, and guide bearing carters).
The discrepancy will be determinate in percentage and will be trended.

a) Theoretical.

P_{PELT} = Apparent power generated by Pelton generator
P_{FRAN} = Apparent power generated by Francis generator

$$P_{EXCIT\text{-}PELT} = V_{EXCIT\text{-}PELT} * I_{EXCIT\text{-}PELT}$$
$$P_{EXCIT\text{-}FRAN} = V_{EXCIT\text{-}FRAN} * I_{EXCIT\text{-}FRAN}$$

$P_{PELT} = [(P_{ACT-PELT})^2 + (P_{REACT-PELT})^2]^{1/2}$
$P_{FRAN} = [(P_{ACT-FRAN})^2 + (P_{REACT-FRAN})^2]^{1/2}$
$\cos Y_{PELT} = P_{ACT-PELT} / P_{PELT}$
$\cos Y_{FRAN} = P_{ACT-FRAN} / P_{FRAN}$

EG_{T-PELT} =Pelton generator theoretical efficiency
EG_{T-FRAN} = Francis generator theoretical efficiency

EG_{T-PELT} (%) = CURVE (P_{PELT} , cos Y_{PELT}) ***SEE CURVE (C)***
EG_{T-FRAN} (%) = CURVE (P_{FRAN} , cos Y_{FRAN}) ***SEE CURVE (D)***

CURVE (C)and (D) are manufacturer efficiency curve for Pelton and Francis groups showing generator efficiency according to cosY and apparent power generated values (see appendix)

$P_{T-TOT-GE-PELT} = P_{PELT} * (100 - EG_{T-PELT} (\%) / 100)$
$P_{T-TOT-GE-FRAN} = P_{FRAN} * (100 - EG_{T-FRAN} (\%) / 100)$

b) Real.

EG_{R-PELT} =Pelton generator real efficiency
EG_{R-FRAN} = Francis generator real efficiency
$P_{R-GEN-INDEF-PELT}$ = Real no defined energy waste in Pelton generator (estimated)
$P_{R-GEN-INDEF-FRAN}$ = Real no defined energy waste in Francis generator (estimated)
$P_{FAN-PELT}$ = Pelton generator fan power consumed

$P_{FAN-PELT}$ =250 kW
$P_{R-GEN-INDEF-PELT}$ = 50 kW
$P_{R-GEN-INDEF-FRAN}$ = 30 kW
$P_{GEN-COIL-PELT} = P_{STATOR\ COIL-PELT} + P_{BEARING\ COIL-PELT}$
$P_{GEN-COIL-FRAN} = P_{STATOR\ COIL-FRAN} + P_{BEARING\ COIL-FRAN}$

$EG_{R-PELT} (\%) = P_{PELT} * 100 / (P_{PELT} + P_{GEN-COIL-PELT} + P_{T-GEN-INDEF-PELT} + P_{FAN-PELT})$
$EG_{R-FRAN} (\%) = P_{FRAN} * 100 / (P_{FRAN} + P_{GEN-COIL-FRAN} + P_{T-GEN-INDEF-FRAN})$

$P_{R-TOT-GEN-PELT} = P_{PELT} * (100 - EG_{R-PELT} / 100)$
$P_{R-TOT-GEN-FRAN} = P_{FRAN} * (100 - EG_{R-FRAN} / 100)$

c) Variation.

$V\_EG_{PELT} (\%) = (EG_{R-PELT} - EG_{T-PELT}) * 100 / EG_{T-PELT}$
$V\_EG_{FRAN} (\%) = (EG_{R-FRAN} - EG_{T-FRAN}) * 100 / EG_{T-FRAN}$

4.Estimation of turbine efficiency.

In this point the system will calculate the theoretical and the real turbine efficiency. Theoretical will be estimated according to theoretical engineering efficiency curves supplied by manufacturer (attached in appendix). Real will be estimated according to plant instrumentation, considering the set efficiency and subtracting generator losses and energy dissipated in turbine refrigeration coils (guide bearing), and seals. So all uncontrolled losses will be attributed to the turbine.

The discrepancy will be determinate in percentage and will be trended.

a) Theoretical.

$ET_{T\text{-}PELT}$ =Pelton turbine theoretical efficiency
$ET_{T\text{-}FRAN}$ = Francis turbine theoretical efficiency

$ET_{T\text{-}PELT} = CURVE\ (Q_{PELT} - H_{T\text{-}EFFECT\text{-}PELT})$ ***SEE CURVE (A)***
$ET_{T\text{-}FRAN} = CURVE\ (Q_{FRAN} - H_{T\text{-}EFFECT\text{-}FRAN})$ ***SEE CURVE (B)***

CURVE (A)and (B) are manufacturer efficiency curve for Pelton and Francis sets showing turbine efficiency according to water flow Q and effective water pressure values (see appendix)

b) Real.

$ET_{R\text{-}PELT}$ =Pelton turbine real efficiency
$ET_{R\text{-}FRAN}$ = Francis turbine real efficiency

$$ET_{R\text{-}PELT}\ (\%) = (P_{PELT} / EG_{R\text{-}PELT} /100) * 100 / (1000 * 9{,}8 * H_{R\text{-}EFFECT\text{-}PELT} * Q_{PELT})$$
$$ET_{R\text{-}FRAN}\ (\%) = (P_{FRAN} / EG_{R\text{-}FRAN} /100) * 100 / (1000 * 9{,}8 * H_{R\text{-}EFFECT\text{-}FRAN} * Q_{FRAN})$$

$$P_{R\text{-}TOT\text{-}TURB\text{-}PELT} = (P_{PELT} / EG_{R\text{-}PELT} /100) * (100 - ET_{R\text{-}PELT}/100)$$
$$P_{R\text{-}TOT\text{-}TURB\text{-}FRAN} = (P_{FRAN} / EG_{R\text{-}FRAN} /100) * (100 - ET_{R\text{-}FRAN}/100)$$

c) Variation.

$$V\_ET_{PELT}\ (\%) = (ET_{R\text{-}PELT} - ET_{T\text{-}PELT}) * 100 / ET_{T\text{-}PELT}$$
$$V\_ET_{FRAN}\ (\%) = (ET_{R\text{-}FRAN} - ET_{T\text{-}FRAN}) * 100 / ET_{T\text{-}FRAN}$$

5. Estimation of global plant and set efficiency in the facility.

In this point the system will calculate the theoretical and the real global plant efficiency (considering all pipe lines, turbine and generator) and set efficiency. Theoretical will be estimated according to theoretical calculations and real will be estimated according to plant instrumentation.

The discrepancy will be determinate in percentage and will be trended.

a) Theoretical.

$E_{T\text{-}GLOB\text{-}PELT}$ = Pelton global plant theoretical efficiency
$E_{T\text{-}GLOB\text{-}FRAN}$ = Francis global plant theoretical efficiency

$E_{T\text{-}GLOB\text{-}PELT} = EG_{T\text{-}PELT} * ET_{T\text{-}PELT} * EI_{T\text{-}PELT}$
$E_{T\text{-}GLOB\text{-}FRAN} = EG_{T\text{-}FRAN} * ET_{T\text{-}FRAN} * EI_{T\text{-}FRAN}$

$E_{T\text{-}SET\text{-}PELT}$ = Pelton set theoretical efficiency
$E_{T\text{-}SET\text{-}FRAN}$ = Francis set theoretical efficiency

$E_{T\text{-}SET\text{-}PELT} = EG_{T\text{-}PELT} * ET_{T\text{-}PELT}$
$E_{T\text{-}SET\text{-}FRAN} = EG_{T\text{-}FRAN} * ET_{T\text{-}FRAN}$

b) Real.

$E_{R\text{-}GLOB\text{-}PELT}$ = Pelton global plant real efficiency
$E_{R\text{-}GLOB\text{-}FRAN}$ = Francis global plant real efficiency

(1) $E_{R\text{-}GLOB\text{-}PELT} = P_{PELT} / (1000 * 9{,}8 * H_{RAW\text{-}PELT} * Q_{PELT})$
$E_{R\text{-}GLOB\text{-}FRAN} = P_{FRAN} / (1000 * 9{,}8 * H_{RAW\text{-}FRAN} * Q_{FRAN})$
(2) $E_{R\text{-}GLOB\text{-}PELT} = EG_{R\text{-}PELT} * ET_{R\text{-}PELT} * EI_{R\text{-}PELT}$
$E_{R\text{-}GLOB\text{-}FRAN} = EG_{R\text{-}FRAN} * ET_{R\text{-}FRAN} * EI_{R\text{-}FRAN}$

$E_{R\text{-}SET\text{-}PELT}$ = Pelton set real efficiency
$E_{R\text{-}SET\text{-}FRAN}$ = Francis set real efficiency

(1) $E_{R\text{-}SET\text{-}PELT} = P_{PELT} / (1000 * 9{,}8 * H_{R\text{-}EFFECT\text{-}PELT} * Q_{PELT})$
$E_{RSET\text{-}FRAN} = P_{FRAN} / (1000 * 9{,}8 * H_{R\text{-}EFFECT\text{-}FRAN} * Q_{FRAN})$
(2) $E_{R\text{-}SET\text{-}PELT} = EG_{R\text{-}PELT} * ET_{R\text{-}PELT}$
$E_{R\text{-}SET\text{-}FRAN} = EG_{R\text{-}FRAN} * ET_{R\text{-}FRAN}$

c) Variation.

$V\_E_{GLOB\text{-}PELT} (\%) = (E_{R\text{-}GLOB\text{-}PELT} - E_{T\text{-}GLOB\text{-}PELT}) * 100 / E_{T\text{-}GLOB\text{-}PELT}$
$V\_E_{GLOB\text{-}FRAN} (\%) = (E_{R\text{-}GLOB\text{-}FRAN} - E_{T\text{-}GLOB\text{-}FRAN}) * 100 / E_{T\text{-}GLOB\text{-}FRAN}$

$V\_E_{SET\text{-}PELT} (\%) = (E_{R\text{-}SET\text{-}PELT} - E_{T\text{-}SET\text{-}PELT}) * 100 / E_{T\text{-}SET\text{-}PELT}$

$$V\_E_{SET-FRAN}\ (\%) = (E_{R-SET-FRAN} - E_{T-SET-FRAN}) * 100 / E_{T-SET-FRAN}$$

6. INTERFACES

6.1 OPERATOR INTERFACES

The operator interfaces will be the same of those relative to monitoring tasks, since the result of this function will be used in monitoring tasks.

The implementation of this function can be done in C or C++.

The simulation of the system for testing purposes can be done easily by including in the D.B. some historical incident data.

6.2 SYSTEM INTERFACES

The system interfaces are the input and output data specified above.

7. ERROR MANAGEMENT

- Input data into normal limits .
- Control software errors (overflow, division by zero).
- To discard abnormal input values (deviation from the mean)
- Control null values or not existent (for a given period) in B.D.
- Control result values .
- Errors must be included in separate files/tables, identified by a key and containing error type.
- All kind of error signals from the computer must be captured in the function.

8. CONSTRAINTS

The only real-time constraint is the availability of data in the D.B. for the chosen period of time. This means that the process for the data gathering from the sensors must insert data into the D.B. almost continuously (with a sample rate to determine).

9. HARDWARE AND SOFTWARE REQUIREMENTS

C,C++ (Borland), Oracle, PC architecture, Windows-NT.

10. TEST PLAN

The testing of this function will be specified in the WP6 IBERDROLA documents for the Adaptation and Experimentation Specifications of the System.

Among other features the following will be tested:

- Control of incorrect input data/input data format.
- Values by default.
- To prove that the resulting values keep into normal limits ($Ed >= Ed_{MIN}$).
- Control of limit values.

VARIABLE DEFINITIONS

VARIABLE DEFINITIONS

$DH_{CHAMB-FRAN}$:Differential water pressure in Francis spiral chamber (Winter Kennedy)
$DH_{CONE-PELT}$: Differential water pressure in Pelton transition cone (Winter Kennedy)
DH_{T-GALL} : Theoretical water pressure losses in pressure gallery
DH_{T-PIPE} : Theoretical water pressure losses in forced pipeline
$DH_{T-BRANCH-PELT}$: Theoretical water pressure losses in Pelton branch and Pelton pipe
$DH_{T-BRANCH-FRAN}$: Theoretical water pressure losses in Francis branch and Francis pipe
DH_{R-GALL} : Real water pressure losses in pressure gallery
DH_{R-PIPE} : Real water pressure losses in forced pipeline
$DH_{T-PIPE-BRAN-PELT}$: Theoretical water pressure losses in forced pipe and Pelton branch
$DH_{T-PIPE-BRAN-FRAN}$: Theoretical water pressure losses in forced pipe and Francis branch
$DH_{T-PIPE-PORTAS-FRAN}$: Theoretical water pressure losses in forced pipe Francis- Las Portas reservoir
$DH_{R-PIPE-PORTAS-FRAN}$: Real water pressure losses in forced pipe Francis- Las Portas reservoir
$DH_{R-PIPE-BRAN-PELT}$: Real water pressure losses in forced pipe and Pelton branch
$DH_{R-PIPE-BRAN-FRAN}$: Real water pressure losses in forced pipe and Francis branch
$DH_{T-TOT-PELT}$ = Total theoretical water pressure losses in Pelton line pipes
$DH_{T-TOT-FRAN}$ = Total theoretical water pressure losses in Francis line pipes
$DH_{R-TOT-PELT}$ = Total real water pressure losses in Pelton line pipes
$DH_{R-TOT-FRAN}$ = Total real water pressure losses in Francis line pipes
$E_{R-GLO-PELT}$ =Pelton set real efficiency
$E_{R-GLO-FRAN}$ = Francis set real efficiency
$E_{T-GLO-PELT}$ =Pelton set theoretical efficiency
$E_{T-GLO-FRAN}$ = Francis set theoretical efficiency
EG_{R-PELT} =Pelton generator real efficiency
EG_{R-FRAN} = Francis generator real efficiency
EG_{T-PELT} =Pelton generator theoretical efficiency
EG_{T-FRAN} = Francis generator theoretical efficiency
EI_{R-PEL} :Pipe installation real efficiency in Pelton set
EI_{R-FRAN} : Pipe installation real efficiency in Francis set
EI_{T-PEL} : Pipe installation Theoretical efficiency in Pelton set
EI_{T-FRAN} : Pipe installation Theoretical efficiency in Francis set
ET_{R-PELT} =Pelton turbine real efficiency
ET_{R-FRAN} = Francis turbine real efficiency
ET_{T-PELT} =Pelton turbine theoretical efficiency
ET_{T-FRAN} = Francis turbine theoretical efficiency
H_{CENZA} : Water level indication in Cenza reservoir
$H_{RAW-FRAN}$: Water raw head in Francis set, between Cenza and Las Portas reservoir,
$H_{RAW-PELT}$: Water raw head in Pelton set.
$H_{CHIMNEY}$: Water level indication in chimney
$H_{CUSTODY-PELT}$: Water pressure in Pelton spherical custody valve
$H_{CUSTODY-FRAN}$: Water pressure in Francis spherical custody valve
$H_{DRAFT-FRAN}$: Water pressure in Francis draft tube
$H_{R-EFFECT-PELT}$: Real effective water pressure head in Pelton set
$H_{R-EFFECT-FRAN}$: Real effective water pressure head in Francis set
$H_{T-EFFECT-PELT}$: Theoretical effective water pressure head in Pelton set
$H_{T-EFFECT-FRAN}$: Theoretical effective water pressure head in Francis set
I_{FRAN} : generator current
I_{PELT} : generator current

$I_{EXCIT\text{-}PELT}$: Excitation current
$I_{EXCIT\text{-}FRAN}$: Excitation current
$P_{STATOR\ COIL\text{-}PELT}$: Power dissipated in stator by water refrigeration coils
$P_{TURB\ COIL\text{-}PELT}$: Power dissipated in turbine oil carter by water refrigeration coils
$P_{ACT\text{-}PELT}$: Active Power generated by set
$P_{REACT\text{-}PELT}$: Reactive Power generated by set
$P_{STATOR\ COIL\text{-}FRAN}$: Power dissipated in stator by water refrigeration coils
$P_{TURB\ COIL\text{-}FRAN}$: Power dissipated in turbine oil carter by water refrigeration coils
P_{SEAL} : Power dissipated in turbine by water seal
$P_{ACT\text{-}FRAN}$: Active Power generated by set
$P_{REACT\text{-}FRAN}$: Reactive Power generated by set
$P_{TUR\text{-}VARIO\text{-}PELT}$ = Several power waste by Pelton turbine (estimated)
$P_{TUR\text{-}VARIO\text{-}FRAN}$ = Several power waste by Francis turbine (estimated)
$P_{R\text{-}TUR\text{-}INDEF\text{-}PELT}$ = Real no defined energy waste in Pelton turbine (estimated)
$P_{R\text{-}TUR\text{-}INDEF\text{-}FRAN}$ = Real no defined energy waste in Francis turbine (estimated)
$P_{R\text{-}GEN\text{-}INDEF\text{-}PELT}$ = Real no defined energy waste in Pelton generator (estimated)
$P_{R\text{-}GEN\text{-}INDEF\text{-}FRAN}$ = Real no defined energy waste in Francis generator (estimated)
$P_{FAN\text{-}PELT}$ = Pelton generator fan power consumed
$P_{FAN\text{-}FRAN}$ = Francis generator fans power
P_{PELT} = Apparent power generated by Pelton generator
P_{FRAN} = Apparent power generated by Francis generator
$P_{GEN\text{-}VARIO\text{-}PELT}$ = Several power waste by Pelton generator (estimated)
$P_{GEN\text{-}VARIO\text{-}FRAN}$ = Several power waste by Francis generator (estimated)
$P_{T\text{-}GEN\text{-}INDEF\text{-}PELT}$ = Theoretical indefinite power waste in Pelton generator (estimated)
$P_{T\text{-}GEN\text{-}INDEF\text{-}FRAN}$ = Theoretical indefinite power waste in Francis generator (estimated)
$P_{EXCIT\text{-}PELT}$ = Pelton generator excitation power
$P_{EXCIT\text{-}FRAN}$ = Francis generator excitation power
$P_{UP\text{-}BEARING\ \text{-}FRAN}$: Power dissipated in upper oil carter by water refrigeration coils
$P_{LOW\text{-}BEARING\text{-}FRAN}$: Power dissipated in lower oil carter by water refrigeration coils
$P_{UP\text{-}BEARING\ \text{-}PELT}$: Power dissipated in upper oil carter by water refrigeration coils
$P_{LOW\text{-}BEARING\ \text{-}PELT}$: Power dissipated in lower oil carter by water refrigeration coils
$P_{R\text{-}TOT\text{-}GEN\text{-}PELT}$ = Total real losses in Pelton generator
$P_{R\text{-}TOT\text{-}GEN\text{-}FRAN}$ = Total real losses in Francis generator
$P_{T\text{-}TOT\text{-}GE\text{-}PELT}$ = Total theoretical losses in Pelton generator
$P_{T\text{-}TOT\text{-}GE\text{-}FRAN}$ = Total theoretical losses in Francis generator
$P_{R\text{-}TOT\text{-}TURB\text{-}PELT}$ = Total real losses in Pelton turbine
$P_{R\text{-}TOT\text{-}TURB\text{-}FRAN}$ = Total real losses in Francis turbine
Q_{FRAN} : Water flow turbinated by Francis set
Q_{PELT} : Water flow turbinated by Pelton set
$V_{EXCIT\text{-}PELT}$: Excitation tension , XA-V0201
$V_{EXCIT\text{-}FRAN}$: Excitation tension , XA-V0109
V_{FRAN} : generator tension , XA-V0106
V_{PELT} : generator tension , XA-V0113
$V\_H_{EFFECT\text{-}PELT}$ (%) = real and theoretical Pelton effective head variation
$V\_H_{EFFECT\text{-}FRAN}$ (%) = real and theoretical Francis effective head variation
V_DH_{GALL} (%) =real and theoretical head losses variation in gallery
$V\_DH_{PIPE\text{-}BRAN\text{-}FRAN}$ (%) =real and theoretical head losses variation in forced pipe and Francis branch

$V\_DH_{PIPE-BRAN-PELT}$ (%) =real and theoretical head losses variation in forced pipe and Pelton branch
$V\_DH_{PIPE-PORTAS-FRAN}$ (%) =real and theoretical head losses variation in Francis to Portas pipe
$V\_DH_{TOT-PELT}$ (%) = Real and theoretical total water pressure losses variation in Pelton line pipes
$V\_DH_{TOT-FRAN}$ (%) = Real and theoretical total water pressure losses variation in Francis line pipes
V_EG_{PELT} (%) = real and theoretical efficiency variation in Pelton generator
V_EG_{FRAN} (%) = real and theoretical efficiency variation in Francis generator
V_ET_{PELT} (%) = real and theoretical efficiency variation in Pelton turbine
V_ET_{FRAN} (%) = real and theoretical efficiency variation in Francis turbine
$V\_E_{GLO-PELT}$ (%) = real and theoretical global efficiency variation in Pelton set
$V\_E_{GLO-FRAN}$ (%) = real and theoretical global efficiency variation in Francis set
V_EI_{PEL} (%) = real and theoretical installation pipes efficiency variation in Pelton set
V_EI_{FRAN} (%) = real and theoretical installation pipes efficiency variation in Francis set