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CONTENTS

0. OBJECTIVE OF THE FUNCTION

The objective of the function is to detect and report any anomalous event concerning the Francis turbine runner and seals that could produce a future malfunction.

This objective is decomposed into another several functions corresponding to the micro needs associated to the macro need described by this function. The final objective of this function will be to detect any malfunction from the results returned by the micro needs functions. Thus, the output of this function will be the micro needs (incidents) ordered by the certainty factors associated to each incident.

The incidents relative to Francis turbine runner and seals malfunction are:

_ Hydraulic phenomena in runner (cavitation, oxidation, profile looses, erosion , cracks)
_ Water leakage in runner seal
_ Runner seal heating
_ Friction in runner (interstice rings)
_ Water leakage in aeration system
_ Bad ventilation
_ Damage in stay vanes
_ Damage in draft tube

This information will be enough for the expert to take any action about the preventive maintenance of the plant in this concrete item (Francis turbine runner and seals).

Also, the system will be able to make cause determination for each one of the possible incidents and to give a justification of the results.

1. FUNCTION ENVIRONMENT

The function will evaluate for each incident its own certainty factor showing the expert degree of confidence for that event to occur under the conditions given by the measures.

The information presented to the user will contain the list of incidents associated to the braking system, ordered by degree of certainty. Also, the degree of certainty will be showed for the user to evaluate the importance of each possible event.

This evaluation will be developed as a user request or cyclically, and will use data collected by the SCADA instrumentation in real time and data collected in periodical tests if they are available (or included by the user).

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

Event	Request/Response (RQ/RS)	From	To
Forecasting Request (user request)	RQ	Maintenance Operator (M.O.)	Function
Forecasting Request (cyclic execution)	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 forecasting request)	RQ	Function	Function
Data Selected (on forecasting request)	RS	Data Base	Function
Perform Forecasting	RQ	Function	Function
Manual Data Request	RQ	Function	M.O.
Manual Data (Manual Tests)	RS	M.O.	Function/ Data Base
Report Results (ordered list of incidents with their associated certainty degree)	RS	Function	M.O.
Store Results (certainty degree incidents)	RS	Function	Data Base

There are two processes involved in the data handling. There is a process that collects data from the D.A.S. and includes it into the real time data base (D.B). The other process selects the data needed by the function in a range of time. The first function will operate independently from the second and in a continuous way. The second will respond to the maintenance operator requests and when expiring the hibernating period .

2. INPUT DATA DEFINITION

Input data to the function are divided into three types:

1. Digital signals from SCADA system: We will need the last updated value from the SCADA system contained in the real time DB.
2. Analogic signal from SCADA system: We will also need the last updated value from the SCADA system contained in the real time DB.
3. Digital and analogic data, inserted by the user into the real time DB: We will need the last value updated by the maintenance operator as well as the date when it was updated.

All these data must be presented to the user before executing the function and the user must be able to modify any value to adjust the results obtained in the execution. These modifications must not be updated in the DB.

The input data will be the following SCADA signals and maintenance actions that could indicate possible malfunction incidents:

A : Water refrigeration

- **a1:** XD-S0307 Normal water flow in turbine guide bearing and runner seal
- **a2:** XD-V0506 alarm of low water flow in runner seal
- **a3:** XD-V0508 alarm of high temperature in water seal
- **a4:** XD-V0507 alarm of anomaly in seal water filter
- **a5:** XD-S308 Water pressure in seal established
- **a6:** XD-S309 Water flow in seal rings established

B: Vibrations

- **b1:** XD-V0406 high vibrations alarm in turbine guide bearing
- **b2:** XD-V0409 very high vibrations alarm in turbine guide bearing

C: Turbine cover water level

- **c1:** XD-V0504 high water level alarm in turbine cover
- **c2:** XD-V0503 very high water level alarm in turbine cover

D: XD-V0511 runner seal wearing alarm

E: turbine bearing metal temperature

- **e1:** XA-V0200 metal temperature indicator of turbine guide bearing
- **e2:** XD-V0412 high metal temperature alarm of turbine guide bearing
- **e3:** XD-V0413 very high metal temperature alarm of turbine guide bearing

F: turbine bearing oil temperature

- **f1:** XA-V0201 oil temperature indicator of turbine guide bearing carter
- **f2:** XD-V0414 high oil temperature alarm of turbine guide bearing carter

G: loss of efficiency
H: cover oscillations increase

I: increase of turbine cover axial displacements
J: increase of water pressure oscillations in cover
K: abnormal noises in runner
L: abnormal measures of interstices
M: abnormal variations of pressure in spiral case and draft tube.
N: increase of intermittent vibrations
O: increase of intermittent abnormal noises
Q: ventilation nozzles closed
R: water losses.(From function S28)
S: visual inspection, profile check

3. OUTPUT DATA DEFINITION

The output of this function will be used to report directly to the user the evaluation results of the different incidents relative to the Francis turbine runner and seals malfunction. These results are the ordered list of the related incidents with the certainty factor associated to each one. The output will be then for example :

1. *Hydraulic phenomena in runner (cavitation, oxidation, profile looses, erosion , cracks) (0.7) HIGH*
2. *Water leakage in runner seal (0.7) HIGH*
3. *Runner seal heating (0.2) LOW*
4. *Friction in runner (interstice rings) (0.2) LOW*
5. *Water leakage in aeration system (0.1) VERY LOW*
6. *Bad ventilation (0.1) VERY LOW*
7. *Damage in stay vanes (0.1) VERY LOW*
8. *Damage in draft tube (0.1) VERY LOW*

As in the input, the output interface for the function will be a file, that must be created by the function when finishing execution and will contain the name of the incident, the certainty factor and the label associated to the certainty factor.

As mentioned earlier, the list of the possible causes for each incident must be displayed if the user requests it. This information will be also given by the function in the output file.

The list of possible causes is the following:

Hydraulic phenomena in runner (cavitation, oxidation, profile looses, erosion , cracks

Ferrobacterium -> corrosion
Incorrect runner profiles-> cavitation
Excessive working time under critical loads -> cavitation
Low submersion-> cavitation
Galvanic couples-> electrical-chemical, shadows and erosion
Erosions by impact of abrasive materials(sand) -> shadows and erosion
Foreign bodies between vanes-> shadows
Material stress under normal or transitory working-> fissures
Bad ventilation-> cavitation

Water leakage in runner and ring seals

Loss of press tightening
Breaking of press
Erosions in fixed ring
Rotating seal ring: surface corrosion of wearing ring
Rotating seal ring: there are wearing channels
Rotating seal ring: micro-gaps caused by temperature
Rotating seal ring: loosening of moving wearing tip
Increase of water level

Runner seal heating

Excessive tightening
Low water circulation
Roughness in rotating ring

Friction in runner (interstice rings)

Foreign bodies (between vanes and interstices)
Mechanical unbalance of runner (breaking of vanes and cracks)
Bad adjustment of turbine guide bearing
Hydraulic unbalance (mechanical fusible broken, etc.)
Decrease of interstice gaps by displacements of upper and lower wearing rings (loosening)
Deformation or breaking of shaft-runner coupling screws
Problems concerning to ventilation
Abrasion caused by sand
Detaching of runner cone

Bad ventilation

Breaking of valve operation transmission

Malfunctioning of valve
Obstruction in aspiration

Damage in stay vanes

Vibrations in foundation
Abrasion by impact (sand)
Fissures
Corrosion
Ferrobacterium
Galvanic couples
Improper vane profiles
Foreign bodies between vanes

Damage in draft tube

Cavitation
Breaking of sealing door:
-fissures
-cavitation
-breaking of frame

The output file will also contain a justification text of the deductions made by the fuzzy module to obtain the conclusions.

4. DYNAMIC BEHAVIOUR

As mentioned in section 1. , there are two processes involved in the forecasting functions. The first of them is the responsible of gathering data at sample intervals (given by the availability of SCADA signals) and inserting them into the D.B. in real time. This function allows us to dispose of all the data needed to carry out the forecasting and cause determination needs.

As mentioned above, we will have 2 types of executions:

1. As a user request.
2. Cyclically.

For the configuration of the cyclic execution, the system must provide the way to define:

- The event/s (a group of SCADA signals that satisfy some conditions) that starts the execution of the functions under a certain type of cycle.
- The period of activation for each type of cycle.

Thus, when the event defined by the user for a type of cycle is true, the functions will be executed cyclically within a period of activation. This period could be null, in the case of the group stop event, for example.

5. DATA PROCESSING (ALGORITHMS)

For the data processing, we have to consider the deduction mechanism used to determine the possibility of any braking system malfunction due to a concrete incident of the seven listed previously in section 0.

This mechanism uses the certainty associated to each event of the system to make deductions for each incident. That is, we will have a deduction tree for each incident going from lower to upper nodes, evaluating the rules and spreading the certainty to upper levels. In those cases where we have independent variables for a common conclusion, we will accumulate the certainty for the conclusion. Where we have dependent variables (for example: A defined as A1 AND A2) we must not.

The implementation of the function is based on the deduction rules and their probabilities. The deduction must be made with forward chaining going from the signals to the incidents certainty. All the rules for an incident will be applied accumulating the resulting certainty because they represent independent events.

The rules to apply are listed below grouped by incidents:

Hydraulic phenomena in runner (cavitation, oxidation, profile looses, erosion , cracks)

IF (G ^ H ^ I ^ J ^ K) THEN
HYDRAULIC PHENOMENA IN RUNNER (CAVITATION, OXIDATION, PROFILE LOOSES, EROSION , CRACKS) (CERTANTY =HIGH)

IF (G ^ K) THEN
HYDRAULIC PHENOMENA IN RUNNER (CAVITATION, OXIDATION, PROFILE LOOSES, EROSION , CRACKS) (CERTANTY =MEDIUM)

IF (H) THEN
HYDRAULIC PHENOMENA IN RUNNER (CAVITATION, OXIDATION, PROFILE LOOSES, EROSION , CRACKS) (CERTANTY =MEDIUM)

IF (S) THEN
HYDRAULIC PHENOMENA IN RUNNER (CAVITATION, OXIDATION, PROFILE LOOSES, EROSION , CRACKS) (CERTANTY =HIGH)

Water leakage in runner seal

IF (c1) THEN
WATER LEAKAGE IN RUNNER SEAL (CERTANTY =HIGH)

IF (c2) THEN
WATER LEAKAGE IN RUNNER SEAL (CERTANTY =VERY HIGH)

Runner seal heating

IF (a3) THEN
RUNNER SEAL HEATING (CERTANTY =VERY HIGH)

IF (a2 v a4) THEN
RUNNER SEAL HEATING (CERTANTY = HIGH)

IF (D) THEN
RUNNER SEAL HEATING (CERTANTY = HIGH)

Friction in runner (interstice rings)

IF (K ^H ^ (B INCREASE)) THEN
FRICTION IN RUNNER (INTERSTICE RINGS) (CERTANTY = HIGH)

IF (K ^ (e1 ^f1)HIGH)) THEN
FRICTION IN RUNNER (INTERSTICE RINGS) (CERTANTY = MEDIUM)

IF (L) THEN
FRICTION IN RUNNER (INTERSTICE RINGS) (CERTANTY = HIGH)

IF (J ^H ^ B) THEN
FRICTION IN RUNNER (INTERSTICE RINGS) (CERTANTY = HIGH)

Bad ventilation

IF (N ^ O) THEN
BAD VENTILATION (CERTANTY = HIGH)

IF (Q) THEN
BAD VENTILATION (CERTANTY = HIGH)

Damage in stay vanes

IF (H ^ J ^ B) THEN
DAMAGE IN STAY VANES (CERTANTY = MEDIUM)

IF (K) THEN
DAMAGE IN STAY VANES (CERTANTY = LOW)

Damage in draft tube

IF (K v B v R) THEN
DAMAGE IN DRAFT TUBE (CERTANTY = LOW)

Note: The variables functions like

- H
- I
- J
- M
- N

must be defined.

6. INTERFACES

6.1 OPERATOR INTERFACES

The operator interface is defined by the input and output data listed in the previous sections:

- Input:

♦ The user must be able to view and modify all input data.

♦ Also, the user must be able to define and modify the different types of cycles for the cyclic execution.

♦ The user must be able to define and modify the thresholds for the resulting certainty factors that will produce the triggering of an alarm in the monitoring system. So, the result of every incident must be defined and used in the DB as SCADA inputs.

- Output: The user must be able to view the list of possible incidents, related certainty factors and certainty labels. Also the list of possible causes for each incident, and justification of the deductions must be listed is the user requests it. This information must be displayed :

♦ When the user executes the function.

♦ When the user retrieves an alarm report or a certainty factor evolution graph.

- When the highest certainty incident is greater than its associated threshold (alarm detected).

The implementation of this function can be done in C or C++. This would allow us to incorporate to the program some libraries already implemented by IBERDROLA. We can also use an inference engine for the resolution of the rule handling and any tools to build the knowledge base and to fuzzyficate variables.

The simulation of the system for testing purposes can be done easily by including in the D.B. some historical incident data. So, the mechanisms to update the DB with simulation values must be provided by the system.

6.2 SYSTEM INTERFACES

The system interface will be the mentioned input and output files and the parameters given in the function call.

• The parameters will indicate the number of the function to be executed and the type of turbine (Pelton/Francis).

• The input file will contain the data listed in the input data section.
• The output file always contains the incidents, certainty factors of the incidents, labels associated with the certainty factors, lists of possible causes and justification of the deductions.
• The certainty factors must always be inserted into the DB by the system.
• The rest of the information must only be inserted when an alarm is detected.

So, the system must provide the way to access to the forecasting data stored in the DB to study the tendencies of the incidents.

7. ERROR MANAGEMENT

• Input data into normal limits (for analogic data it's specified in the fuzzy sets, for alarms 0/1).
• The resulting certainty accumulated or inferred from the application of any rule must be into normal values [0,1] during the inference process.
• To control null values or not existent (for a given period) in D.B.
• Errors must be included in separate files/tables and identified by a key.
• The tuning of the fuzzy sets and the adjusting of the certainty factors associated to each rule will be done according to the special conditions of the equipment in the plant.
• The grouping , partition or including of any rule could be done while testing if the results are not the most accurate to the working conditions of the plant, so the system must be flexible in this aspect.
• All kind of error signals from the computer must be captured in the function.

8. CONSTRAINTS

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

9. HARDWARE AND SOFTWARE REQUIREMENTS

The mentioned above for the building of the Knowledge Base and the inference engine, 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.
Some of the features we will try to test are the following:

- Control of incorrect input data.
- To prove that for a set of symptoms related to an incident the probability of the incident is high enough.
- To prove that for a set of symptoms related to an incident the probability of the incident is higher than the rest (conclusion is clear).
- To prove that for a set of symptoms related to several incidents the probability is higher for the all the incidents implicated.
- To prove that for a set of symptoms indicating normal working there are not high probability values for any incident.
- To prove that exist any symptoms set that returns a high probability for a given incident.
- To prove that the fuzzyficated symptoms describe precisely the existence of a fault. In that item.