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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 regulation system that could produce a future malfunction.

This objective is decomposed into another fourteen 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 fourteen micro needs (incidents) ordered by the certainty factors associated to each incident.

The incidents relative to regulation system malfunction are:

_ Oil pressure pump motor malfunction (Pelton and Francis)
_ Oil pressure pump malfunction (Pelton and Francis)
_ Bad oil aspiration in pump (Pelton and Francis)
_ Internal oil leakage (Pelton and Francis)
_ External oil leakage (Pelton and Francis)
_ Air leakage (Pelton and Francis)
_ Lack of cooling (Pelton and Francis)
_ Increase of stress in injection system (Pelton)
_ Excessive time in water closing , water leakage (Pelton)
_ Gaps in needles and deflector position (Pelton)
_ Increase of stress in guide vane system (Francis)
_ Leakage in vane closing (Francis)
_ Leakage in guide vane seal (Francis)
_ Gaps in guide vane system and in rudder (Francis)

This information will be enough for the expert to take any action about the preventive maintenance of the plant in this concrete item (regulation system).

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: increase of equip vibrations
B: motor current
C: increase of noises
D: increase of motor temperature
E: motor velocity < nominal velocity
G: unbalance between phases
H: variation of motor torque

I: pump state

i1:
XD-V0113 main oil regulation pump working (Francis)
XD-V0309 main oil regulation pump working (Pelton)

i2:
XD-V0114 support oil regulation pump working (Francis)
XD-V0310 support oil regulation pump working (Pelton)

i3:
XD-S0107 emergency oil regulation pump working (Pelton)

i4:
XD-S0113 no control defect in main and support oil regulation pumps PR1, PR2 (Francis)
XD-S0108 no control defect in main and support oil regulation pumps 1000, 1010 (Pelton)

i5:
XD-V0109 alarm of failure in main and support oil regulation pump (Francis)
XD-V0108 alarm of main and support oil regulation pump failure (Pelton)

i6:
XD-V0107 alarm of main oil regulation pump failure (Pelton)
XD-V0108 alarm of main oil regulation pump failure (Francis)

i7:
XD-V0114 oil regulation pump 1010 control defect (Pelton)
XD-V0201 oil regulation pump PR2 control defect (Francis)
XD-V0113 oil regulation pump 1000 control defect (Pelton)
XD-V0200 oil regulation pump PR1 control defect (Francis)

i8:
XD-V0115 oil regulation emergency pump 1150 control defect (Pelton)
i9:
XD-V0109 oil regulation emergency pump stopped (Pelton)

J: Oil pressure in pressure tank
j1:
XD-V0207 alarm of low oil pressure (Francis)
XD-V0123 alarm of low oil pressure (Pelton)
XD-V0124 alarm of very low oil pressure (Pelton)
j2:
XD-S0113 regulation oil pressure established (Pelton)
XD-S0202 regulation oil in normal conditions (Francis)
j3:
XD-V0122 alarm of too high oil pressure (Pelton)
XD-V0226 alarm of high oil pressure (Pelton)

K: increase of motor working time

L: XD-V1304 hydroelectric set stopped (Francis)
XD-V0711 hydroelectric set stopped (Pelton)

LL:
XD-S0206 guide vanes closed (Francis)
XD-S0115 needles closed (Pelton)
XD-S0116 deflector closed (Pelton)

LLL: XD-V0301 guide vanes open (Francis)
XD-V0216 needle 1 in service (Pelton)
XD-V0217 needle 2 in service (Pelton)
XD-V0218 needle 3 in service (Pelton)
XD-V0219 needle 4 in service (Pelton)
XD-V0220 needle 5 in service (Pelton)
XD-V0221 needle 6 in service (Pelton)

M: filter saturated
XD-V0126 oil regulation filter saturated (Pelton)
XD-V0201 regulation oil return filter saturated (Pelton)
XD-V0209 oil regulation filter saturated (Francis)

N: decrease of oil flow (there is sensor but not signal)
O: Oil analysis (impurities , degradation)
P: oil level in atmospheric tank
p1:
XD-V0212 alarm of too low oil level in atmospheric tank (Francis)
XD-V0112 alarm of too low oil level in atmospheric tank (Pelton)
p2:
XD-S0203 normal oil level in atmospheric tank (Francis)
p3:
XD-V0211 alarm of too high oil level in atmospheric tank (Francis)
p4:
XD-V0128 alarm of high oil level in atmospheric tank (Pelton)
p5:
XD-V0129 alarm of low oil level in atmospheric tank (Pelton)

Q: Level in pressure tank

q1:
XD-V0205 too low oil level in regulation pressure tank (Francis)
XD-V0121 too low oil level in regulation pressure tank (Pelton)

q2:
XD-V0206 too high oil level in pressure tank (Francis)
XD-V0119 too high oil level in pressure tank (Pelton)

q3:
XD-V0203 low oil level in pressure tank (Francis)
XD-V0120 low oil level in pressure tank (Pelton)

q4:
XD-S0112 normal oil level in pressure tank (Pelton)

q5:
XD-V0132 high oil level in pressure tank (Pelton)

R: Oil volume = volume of atmospheric tank + volume of pressure tank
(Volume in tanks = oil level indication *tank area)

r1:
oil level in atmospheric tank

r2:
oil level in pressure tank

S: increase of oil temperature

s1:
XD-V0213: high temperature of regulation oil tank (Francis)
XD-V0130: high temperature of regulation oil tank (Pelton)

s2:
XD-V0214 very high temperature of regulation oil tank (Francis)

s3:
XD-V0131: low temperature of regulation oil tank (Pelton)

s4:
XD-V0203: refrigeration pump of oil regulation system working (Pelton)
XD-V0202: refrigeration pump of oil regulation system stopped(Pelton)

s5:
XD-V0204:control defect in refrigeration pump of oil regulation system (Pelton)

s6.:
XD-V0215 low refrigeration water flow alarm in regulation system tank (Francis)

U: increase of servomotor differential pressure

W: oil regulation system working state

w1:
XD-S0112 oil regulation system in service (Francis)
XD-S0106 oil regulation system in service (Pelton)

w2:
XD-S0111 oil regulation system stopped (Francis)
XD-S0105 oil regulation system stopped (Pelton)

X: increase of number of electric-valve air manoeuvres

Y: decrease of time between pump starting

Z: water flow control system

z1:
XD-V0230 Failure of needles signals position/ Pot. Active (Pelton).
z2:
XD-V0232 Defect in needles position control (Pelton)
z3:
adequacy of relationship between vanes position, ring position, rod position (Francis)
XD-S0211 guide vanes synchronised

AA: increase of velocity drop time between the 85% and 20% with the group stopping. Increase of time between (**no aa4**) and **aa2** with group stopping or **aa2** and **aa1**

aa1:
XD-S0121 void speed + T (Pelton)
XD-S0305 void speed + T (Francis)
aa2:

XD-S0122 speed < 20% (Pelton)
XD-S0301 speed < 25% (Francis)
aa3:
XD-S0123 speed < 50% (Pelton)
aa4:
XD-S0124speed > 85% (Pelton)
XD-S0302 speed > 85% (Francis)

BB: group stopping process
YD-S0111 to close guide vanes order (Francis)
YD-S0109 to close deflector order (Pelton)

CC: variation of level of guide vane system and rudder (Francis)
DD: increase of turbine cover water level (Francis)
XD-V0504 high level in turbine cover
XD-V0503very high level in turbine cover

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 regulation system 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._ Oil pressure pump motor malfunction (0,8) HIGH
2._ Oil pressure pump malfunction (0,6) MEDIUM
3._ Bad oil aspiration in pump (0,4) LOW
4._ Internal oil leakage (0,3) LOW
5._ External oil leakage (0,2) 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:

Oil pressure pump motor malfunction (Pelton and Francis

Defect in bearings
Defect in stator coil
Defect in rotor
Defect in terminals
Unbalance between phases

Oil pressure pump malfunction (Pelton and Francis)

Defect in bearings
Internal defect in pump
Presence of metallic residues in oil
Wearing and gaps

Bad oil aspiration in pump (Pelton and Francis)

Air aspiration
Low oil level in atmospheric tank (deposit)
Obstruction in the aspiration

Internal oil leakage (Pelton and Francis)
Breaking in system caused by:
-mechanic stress in pipes
-over-pressure (obstruction in circuit, abrasion and adherence of suspended particles)
-air bubbles in circuit
-sudden thermal changes
Bad maintenance \ low quality material. Junctions have been carried out badly
Lack of seal
Leakage through peep-holes, oil level and temperature indicators and other devices

External oil leakage (Pelton and Francis)

Breaking in system caused by:
-mechanic stress in pipes
-over-pressure (obstruction in circuit, abrasion and adherence of suspended particles)
-air bubbles in circuit

-sudden thermal changes

Bad maintenance \ low quality material. Junctions have been carried out badly
Lack of seal
Leakage through peep-holes, oil level and temperature indicators and other devices

Air leakage (Pelton and Francis)

Breaking in pipes
Problems in seals
Leakage in the pressure tank air safety valve

Lack of cooling

Lack of cooling water:

-loss of flow in input water admission
-filter obstruction
-air in lines
-obstruction in coil circuit

Increase of stress in water injection system (Pelton)

Stiffness of needles
Foreign bodies inside injectors
Discrepancy between injector needles
Discrepancy between deflectors
Gaps in deflectors position mechanism
Gaps in needles position mechanism

Increase of stress in guide vane system (Francis)

Stiffness of blades
Foreign bodies between blades
Discrepancy between eccentric wheels
Guide vane system gaps
Regulating ring bad levelled

Excessive time in water closing , water leakage

Bad closing of deflectors
Bad closing of needles

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 the regulation system malfunction due to a concrete incident of the 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:

Oil pressure pump motor malfunction (Pelton and Francis)

IF ((A v B) INCREASE) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=MEDIUM)

IF ((C v D) INCREASE) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=LOW)

IF ((E v G v H) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=MEDIUM)

IF ((q3 v q1) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=HIGH)

IF ((i7 v i8) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=HIGH)

IF ((j1 v ¬ j2) ^ (i1 v i2 v i3)) THEN
OIL PRESSURE PUMP MOTOR MALFUNCTION (CERTANTY=HIGH)

Oil pressure pump malfunction

IF ((j1 v ¬ j2) ^ (i1 v i2 v i3)) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=HIGH)

IF ((N) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=HIGH)

IF ((A v B v C) INCREASE) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=MEDIUM)

IF (L ^ (K INCREASE)) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=MEDIUM)

IF ((q3 v q1) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=HIGH)

IF ((i1 v i2 v i3) ^ (r1 NO DECREASE)) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=HIGH)

IF ((i5 v i6) THEN
OIL PRESSURE PUMP MALFUNCTION (CERTANTY=HIGH)

Bad oil aspiration in pump

IF ((i1 v i2 v i3) ^ (r1 NO DECREASE)) THEN
BAD OIL ASPIRATION IN PUMP (CERTANTY=HIGH)

IF (M) THEN
BAD OIL ASPIRATION IN PUMP (CERTANTY=HIGH)

IF (A ^ K ^ N) THEN
BAD OIL ASPIRATION IN PUMP (CERTANTY=MEDIUM)

Internal oil leakage

IF ((i1 v i2 v i3) ^ (R CONSTANT) ^ (K v Y)) THEN
INTERNAL OIL LEAKAGE (CERTANTY=HIGH)

External oil leakage

IF (R DECREASE) THEN
INTERNAL OIL LEAKAGE (CERTANTY=HIGH)

Air leakage

IF (j1 v q2) THEN
AIR LEAKAGE (CERTANTY=MEDIUM)

IF (X) THEN
AIR LEAKAGE (CERTANTY=HIGH)

Lack of cooling (Pelton)

IF (s1 v s5) THEN
LACK OF COOLING (CERTANTY=HIGH)

Lack of cooling (Francis)

IF (s1 v s2 v s6) THEN
LACK OF COOLING (CERTANTY=HIGH)

Increase of stress in water injection system (Pelton)

IF (U v z1 v z2) THEN
INCREASE OF STRESS IN WATER INJECTION SYSTEM (CERTANTY=HIGH)

Excessive time in water closing , water leakage (Pelton)

IF (BB ^ AA) THEN
EXCESSIVE TIME IN WATER CLOSING , WATER LEAKAGE (CERTANTY=HIGH)

IF (z1 v z2) THEN
EXCESSIVE TIME IN WATER CLOSING , WATER LEAKAGE (CERTANTY=HIGH)

IF (L ^ C) THEN
EXCESSIVE TIME IN WATER CLOSING , WATER LEAKAGE (CERTANTY=HIGH)

IF (excessive time LL to L) THEN

EXCESSIVE TIME IN WATER CLOSING , WATER LEAKAGE (CERTANTY=HIGH)

<u>Gaps in needles and deflector position (Pelton)</u>

IF (z1 v z2) THEN
GAPS IN NEEDLES AND DEFLECTOR POSITION (CERTANTY =MEDIUM)

<u>Increase of stress in guide vane system (Francis)</u>

IF (U v CC) THEN
INCREASE OF STRESS IN GUIDE VANE SYSTEM (CERTANTY =MEDIUM)

IF (¬CC) THEN
INCREASE OF STRESS IN GUIDE VANE SYSTEM (CERTANTY =MEDIUM)

<u>Leakage in vane closing (Francis)</u>

IF (¬z3) THEN
LEAKAGE IN VANE CLOSING (CERTANTY =HIGH)

IF (BB ^ AA) THEN
LEAKAGE IN VANE CLOSING (CERTANTY =HIGH)

IF (L ^ C) THEN
LEAKAGE IN VANE CLOSING (CERTANTY =HIGH)

IF (excessive time LL to L) THEN
LEAKAGE IN VANE CLOSING (CERTANTY =HIGH)

<u>Leakage in guide vane seal (Francis)</u>

IF (DD) THEN
LEAKAGE IN GUIDE VANE SEAL (CERTANTY =HIGH)

<u>Gaps in guide vane system and in rudder (Francis)</u>

IF (¬ z3 ^ DD) THEN
GAPS IN GUIDE VANE SYSTEM AND IN RUDDER (CERTANTY =MEDIUM)

IF (¬ z3 ^ CC) THEN
GAPS IN GUIDE VANE SYSTEM AND IN RUDDER (CERTANTY =MEDIUM)

Note: The variables functions like

- INCREASING A , B, C, D, K

- r1_NO_DECREASING
- EXCESIVE TIME LL TO L
- Y
- R
- X
- AA
-

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.